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Codes and Standards Enhancement (CASE) Initiative 2022 California Energy Code

Multifamily Domestic Hot Water Distribution

2022-MF-DHW-F **|** Multifamily Water Heating **|** September 2020 FINAL CASE REPORT

Prepared by TRC.

Please submit comments to info@title24stakeholders.com.

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Table of Contents

List of Tables

List of Figures

Executive Summary

This document presents recommended code changes that the California Energy Commission will be considering for adoption in 2021. If you have comments or suggestions prior to the adoption, please email info@title24stakeholders.com. Comments will not be released for public review or will be anonymized if shared.

Introduction

The Codes and Standards Enhancement (CASE) Initiative presents recommendations to support the California Energy Commission's (Energy Commission) efforts to update the California Energy Code (Title 24, Part 6) to include new requirements or to upgrade existing requirements for various technologies. Three California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company, San Diego Gas and Electric, and Southern California Edison – and two Publicly Owned Utilities – Los Angeles Department of Water and Power and Sacramento Municipal Utility District (herein referred to as the Statewide CASE Team when including the CASE Author) – sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to improve energy efficiency and energy performance in California buildings. This report and the code change proposals presented herein are a part of the effort to develop technical and cost effectiveness information for proposed requirements on building energy-efficient design practices and technologies.

The Statewide CASE Team submits code change proposals to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The Energy Commission may revise or reject proposals. See the Energy Commission's 2022 Title 24 website for information about the rulemaking schedule and how to participate in the process: https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2022-building-energy-efficiency.

Measure Description

Background Information

There are three separate domestic hot water (DHW) distribution submeasures: pipe insulation verification, increased pipe insulation, and California Plumbing Code (CPC) Appendix M sizing.

The pipe insulation verification submeasure stems from the poor quality of existing insulation exhibited by the 2013 PIER Report "Multifamily Central Domestic Hot Water Distribution Systems" (PIER 2013) and the Statewide CASE data collection and Stakeholder feedback during the CASE Process. This submeasure is similar in scope and mechanism to the existing multifamily quality insulation installation (QII) energy credit through Home Energy Rating System (HERS) or Acceptance Test Technician (ATT) verification and would apply to multifamily buildings with DHW recirculation systems.

The increased pipe insulation submeasure builds on the 2013 Water and Space Heating ACM Improvement CASE Report (Statewide CASE Team 2011), that analyzed and showed increasing DHW pipe insulation to be cost effective. The 2013 CASE effort did not result in an increase in pipe insulation level in the code because the increased insulation level for heating ventilation and air conditioning (HVAC) was not cost effective, and insulation level requirements for both DHW and HVAC pipes are codified in the same code Table, 120.3-A.

The CPC Appendix M sizing submeasure would introduce a performance-based pipe sizing calculation procedure from Uniform Plumbing Code (UPC) and CPC into Title 24, Part 6. Appendix M was added to the UPC in 2018 and includes an alternative pipe sizing procedure. Appendix M contains a performance-based pipe sizing calculation procedure that typically results in smaller pipe sizes than standard practice sizing, which results in lower first costs and distribution system heat loss.

Additionally, current prescriptive requirement for two-loop recirculation systems faces compliance and enforcement challenges including inconsistent interpretations of the requirement and challenges establishing appropriate baseline and proposed systems in the compliance software.

Proposed Code Change

The pipe insulation verification measure adds a prescriptive requirement for field verification of pipe insulation quality for multifamily DHW recirculation systems. Field verification would confirm installation of code required pipe insulation, including insulation on all fittings and valves, pumps, and thermal isolation at pipe hangers. This measure builds on the current low-rise residential pipe insulation inspection credit and extends it to become a prescriptive baseline for all multifamily buildings.

The increased pipe insulation level measure increases mandatory pipe insulation requirements for multifamily DHW pipes two inches in diameter and larger. This measure aligns pipe insulation requirements for all multifamily buildings.

The CPC Appendix M Sizing measure adds a compliance option for pipe sizing based on CPC Appendix M (IAPMO 2019). Appendix M is an optional appendix to CPC with an alternative pipe sizing procedure.

In addition, the existing prescriptive requirement for two recirculation loops in central DHW systems would be changed to a compliance option.

Scope of Code Change Proposal

Table 1 summarizes the scope of the proposed changes and the sections of Standards, Reference Appendices, Alternative Calculation Method (ACM) Reference Manual, and compliance documents that would be modified as a result of the proposed change(s).

Table 1: Scope of Code Change Proposal

Measure Name	Type of Requirement	Modified Section(s) of Title 24, Part 6	Modified Title 24, Part 6 Appendices	Would Compliance Software Be Modified	Modified Compliance Document(s)
Pipe Insulation Verification	Prescriptive	150.1(b)3 B and (c)8	New RA 3.6.x	Yes; ACM Ref Manual App B5.1	CF1R-NCB-01-E; CF1R-PRF-E; CF2R-PLB-01 and -21a; CF3R-PLB-21a; NRCC-PLB-E; NRCC-PRF-01-E; NRCI-PLB-02 and -21; NRCV-PLB-21
Increased Pipe Insulation	Mandatory	120.3; 150.0(j)	None	None	CF1R-NCB-01-E; CF1R-PRF-E; CF2R-PLB-01 and -21a; CF3R-PLB-21a; NRCC-PLB-E; NRCC-PRF-01-E; NRCI-PLB-02 and -21; NRCV-PLB-21
CPC Appendix M Sizing	Compliance option	None	None	Yes; ACM Ref Manual App B5.1	CF1R-PRF-E; NRCC-PRF-01-E
Change Existing Reqm’t for Two-Loop Recirc Systems to a Compliance Option	Compliance option	150.1(c)8B ii	RA 3.6.8	Yes; ACM Ref Manual App B5.3	CF1R-PRF-E; CF2R-PLB-21a; CF3R-PLB-21a; NRCC-PRF-01-E; NRCI-PLB-21; NRCV-PLB-21

Market Analysis and Regulatory Assessment

The Statewide CASE Team performed a market analysis with the goals of identifying market structure, product availability, technical feasibility, and impacts of the proposed code change on the market.

In support of the insulation quality verification submeasure, the Statewide CASE Team found that DHW pipe insulation that covers all pipes, fittings, valves, pumps, etc., is already required in Residential and Nonresidential Energy Code, and the CPC. Therefore, the pipe insulation verification requirement would not change installation techniques or significantly impact the market.

For the increased insulation submeasure, the Statewide CASE Team found that pipe insulation has well established supply chains and does not anticipate that the proposed code change would impact them significantly. DHW pipe insulation is a well-established technology and the proposed code change does not require changing existing installation techniques.

For the CPC Appendix M Pipe Sizing submeasure, the Statewide CASE Team found that plumbing designers, engineers, and contractors perform sizing calculations and pipe layout for DHW piping systems. However, they do not typically use the Appendix M sizing method and would require design professionals to use new procedures including the Water Demand Calculator (WDC) tool from IAPMO.

Cost Effectiveness

The proposed code changes were found to be cost effective for all climate zones where they are proposed to be required. The benefit-to-cost (B/C) ratio compares the benefits or cost savings to the incremental costs over the 30-year period of analysis. Proposed code changes that have a B/C ratio of 1.0 or greater are cost effective. The larger the B/C ratio, the faster the measure pays for itself from energy cost savings. The B/C ratio is not applicable to measures with first cost savings. Table 2 summarizes the B/C ratio range and climate zone that each measure is cost effective in. See Section 5 for the methodology, assumptions, and results of the cost-effectiveness analysis.

Table 2: Cost Benefit by Measure

Measure	Sub-Measure	B/C Ratio Range	Cost Effective in Climate Zones
Domestic Hot Water Distribution	Pipe Insulation Verification	5.1-11.1	All
Domestic Hot Water Distribution	Increased Insulation	1.8-2.9	All

Domestic Hot Water Distribution	CPC Appendix M Sizing[a]	NA	NA

a. CPC Appendix M Pipe Sizing is a cost saving submeasure so B/C ratio is not applicable.

Statewide Energy Impacts: Energy, Water, and Greenhouse Gas (GHG) Emissions Impacts

Table 3 presents the estimated energy and demand impacts of the proposed code change that would be realized statewide during the first year that the 2022 Title 24, Part 6 requirements are in effect. First-year statewide energy impacts are represented by the following metrics: electricity savings in gigawatt-hours per year (GWh/yr), peak electrical demand reduction in megawatts (MW), natural gas savings in million therms per year (MMTherms/yr), and time dependent valuation (TDV) energy savings in kilo British thermal units per year (TDV kBtu/yr). See Section 6 for more details on the first-year statewide impacts calculated by the Statewide CASE Team. Section 4 contains details on the per-unit energy savings calculated by the Statewide CASE Team.

Table 3: First-Year Statewide Energy and Impacts – New Construction

Measure	Submeasure	Electricity Savings (GWh/yr)	Peak Electrical Demand Reduction (MW)	Natural Gas Savings (MMTherms/yr)	TDV Energy Savings (TDV kBtu/yr)
Domestic Hot Water Distribution	Pipe Insulation Verification	0	0	0.28	73.6
	Increased Insulation	0	0	0.03	7.6
	CPC Appendix M Pipe Sizing	0	0	0.09	24.0
	Subtotal	0	0	0.40	105.2

Source: Statewide CASE Team

The pipe insulation verification submeasure has large savings due to the poor quality of existing pipe insulation the Statewide CASE Team discovered through interviews and surveys with subject matter experts, designers, and installation contractors. The Statewide CASE Team discusses this interview and survey process in detail in Appendix G. However, the Statewide CASE Team made conservative assumptions about the quality of existing pipe insulation compared to the interview and survey results.

The increased insulation submeasure marginally increases insulation thickness. This measure has greater savings for larger buildings, as the larger buildings have more pipe of larger diameter, particularly supply headers near the hot water system.

CPC Appendix M sizing submeasure addresses the issue of oversizing pipe based on outdated flow rate assumptions. This is a cost and energy saving measure but requires designers to learn a new sizing method.

Table 4 presents the estimated avoided greenhouse gas (GHG) emissions associated with the proposed code change for the first year the standards are in effect. Avoided GHG emissions are measured in metric tons of carbon dioxide equivalent (Metric Tons CO2e). Assumptions used in developing the GHG savings are provided in Section 6.2 and Appendix C of this report. The monetary value of avoided GHG emissions is included in TDV cost factors and is thus included in the cost-effectiveness analysis.

Table 4: First-Year Statewide GHG Emissions Impacts

Measure	Avoided GHG Emissions (Metric Tons CO2e/yr)	Monetary Value of Avoided GHG Emissions ($2023)
Domestic Hot Water Distribution	2,217	$66,491

Source: Statewide CASE Team

Water and Water Quality Impacts

None of the proposed submeasures impact water consumption. Water savings that the proposed code changes would have during the first year they are in effect are presented in Table 5 along with the associated embedded electricity savings. See Section 6.3 of this report to see water quality impacts and the methodology used to derive water savings and water quality impacts. The methodology used to calculate embedded electricity in water is presented in Appendix B.

Table 5: First-Year Water and Embedded Electricity Impacts

	On-Site Indoor Water Savings (gallons/yr)	On-Site Outdoor Water Savings (gallons/yr)	Embedded Electricity Savings (kWh/yr)
Domestic Hot Water Distribution			
Per Dwelling Unit Impacts	0	0	0
First-Year Statewide Impacts	0	0	0

Source: Statewide CASE Team

Compliance and Enforcement

Overview of Compliance Process

The Statewide CASE Team worked with stakeholders to develop a recommended compliance and enforcement process and to identify the impacts this process would have on various market actors. The compliance process is described in Section 2.5. Impacts that the proposed measure would have on market actors is described in Section 3.3 and Appendix E. The key issues related to compliance and enforcement are summarized below:

- Issue 1: Pipe insulation verification would require additional coordination between trades on site to enable visual verification of insulation by a HERS Rater or ATT. The scale and required coverage in verifying multifamily DHW pipe insulation adds time and complexity to the construction and installation process. Multiple verification visits may be needed as plumbing insulation is often phased with other trades on site, particularly for larger buildings.
- Issue 2: For increased insulation, designers who issue specifications that include a table of insulation thicknesses would need to update their specifications to reflect new insulation thickness requirements. Designers and enforcement personnel would reference one code location for all multifamily pipe insulation requirements.
- Issue 3: For increased insulation, plumbers may need to change practices to allow clearance around the piping for two-inch thick insulation. This scenario is uncommon because most horizontal piping with two-inch or larger diameters occurs in horizontal configuration with little to no space limitation.
- Issues 4: Plumbing designers would need to provide additional design documentation if they choose to exercise the CPC Appendix M Sizing compliance option.

Field Verification and Diagnostic Testing/Acceptance Testing

Updates to the existing compliance forms are needed to incorporate installer documentation and field verifications for the pipe insulation verification, pipe insulation submeasures and for changing the two-loop recirculation requirement to a compliance option. The CPC Appendix M Sizing submeasure would add to an existing Certificate of Compliance form.

Refer to Section 7.6 for additional information.

1. Introduction

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The Codes and Standards Enhancement (CASE) initiative presents recommendations to support the California Energy Commission's (Energy Commission) efforts to update California Energy Code (Title 24, Part 6) to include new requirements or to upgrade existing requirements for various technologies. Three California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company, San Diego Gas and Electric, and Southern California Edison– and two Publicly Owned Utilities – Los Angeles Department of Water and Power and Sacramento Municipal Utility District (herein referred to as the Statewide CASE Team when including the CASE Author) – sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to improve energy efficiency and energy performance in California buildings. This report and the code change proposal presented herein are a part of the effort to develop technical and cost effectiveness information for proposed requirements on building energy-efficient design practices and technologies.

The Statewide CASE Team submits code change proposals to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The Energy Commission may revise or reject proposals. See the Energy Commission's 2022 Title 24 website for information about the rulemaking schedule and how to participate in the process: https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2022-building-energy-efficiency.

The overall goal of this CASE Report is to present the code change proposals for multifamily domestic hot water (DHW) distribution systems. The report contains pertinent information supporting the code change.

When developing the code change proposal and associated technical information presented in this report, the Statewide CASE Team worked with a number of industry stakeholders including officials, manufacturers, architects, and designers, engineers, builders, installers, utility incentive program managers, Title 24 energy analysts, and others involved in the code compliance process. The proposal incorporates feedback received during two public stakeholder workshops that the Statewide CASE Team held on October 3, 2019, and March 17, 2020 (Statewide CASE Team 2019).

The following is a brief summary of the contents of this report:

- Section 2 – Measure Description of this CASE Report provides a description of the measure and its background. This section also presents a detailed description of how this code change is accomplished in the various sections and documents that make up the Title 24, Part 6 Standards.
- Section 3 – In addition to the Market Analysis section, this section includes a review of the current market structure. Section 3.2 describes the feasibility issues associated with the code change, including whether the proposed measure overlaps or conflicts with other portions of the building standards, such as fire, seismic, and other safety standards, and whether technical, compliance, or enforceability challenges exist.
- Section 4 – Energy Savings presents the per-unit energy, demand reduction, and energy cost savings associated with the proposed code change. This section also describes the methodology that the Statewide CASE Team used to estimate per-unit energy, demand reduction, and energy cost savings.
- Section 5 – This section presents analysis of the materials and labor required to implement the measure and a quantification of the incremental cost. It also includes estimates of incremental maintenance costs, i.e., equipment lifetime and various periodic costs associated with replacement and maintenance during the period of analysis.
- Section 6 – First-Year Statewide Impacts presents the statewide energy savings and environmental impacts of the proposed code change for the first year after the 2022 code takes effect. This includes the amount of energy that would be saved by California building owners and tenants and impacts (increases or reductions) on material with emphasis placed on any materials that are considered toxic by the state of California. Statewide water consumption impacts are also reported in this section.
- Section 7 – Proposed Revisions to Code Language concludes the report with specific recommendations with ~~strikeout~~ (deletions) and underlined (additions) language for the Standards, Reference Appendices, ACM Reference Manual, compliance manuals, and compliance documents.
- Section 8– Bibliography presents the resources that the Statewide CASE Team used when developing this report.

Appendices A through F house content applicable to the submeasures, followed by appendices G and H that provide supplemental information in support of proposal development.

- Appendix A: Statewide Savings Methodology presents the methodology and assumptions used to calculate statewide energy impacts.

- Appendix B: Embedded Electricity in Water Methodology presents the methodology and assumptions used to calculate the electricity embedded in water use (e.g., electricity used to draw, move, or treat water) and the energy savings resulting from reduced water use.
- Appendix C: Environmental Impacts Methodology presents the methodologies and assumptions used to calculate impacts on GHG emissions and water use and quality.
- Appendix D: California Building Energy Code Compliance (CBECC) Software Specification presents relevant proposed changes to the compliance software (if any).
- Appendix E: Impacts of Compliance Process on Market Actors presents how the recommended compliance process could impact identified market actors.
- Appendix F: Summary of Stakeholder Engagement documents the efforts made to engage and collaborate with market actors and experts.
- Appendix G: Insulation Quality Data Collection Results
- Appendix H: Prototype Building Domestic Hot Water Distribution Designs

2. Measure Description

2.1 Measure Overview

The 2022 multifamily DHW distribution CASE measure would add a prescriptive requirement, change a mandatory requirement, and add a new compliance option. A summary of proposed changes includes:

- Submeasure A: Pipe Insulation Verification: Add a prescriptive requirement for field verification of pipe insulation quality
- Submeasures B: Increased Insulation: Increase stringency of existing mandatory pipe insulation thickness for pipes larger than two inches
- Submeasures C: CPC Appendix M Pipe Sizing: Add a compliance option for pipe sizing according to CPC Appendix M (IAPMO 2019)
- Change the existing prescriptive requirement for two recirculation loops in central DHW systems to a compliance option

All three proposed submeasures apply to new construction multifamily buildings with central water heating. None of the three proposed submeasures apply to additions or alterations. The Statewide CASE Team is still considering how best to reconcile the nonresidential and residential requirements that apply to hotel/motels and so did not analyze the impact of this measure on the hotel building prototype.

The proposed multifamily hot water distribution submeasures would reduce the energy budget of multifamily DHW recirculation systems by adding a new prescriptive requirement, increasing the stringency of an existing mandatory requirement, while reducing compliance barriers by changing an existing prescriptive requirement to a compliance option, and adding a new compliance option.

2.1.1 Submeasure A: Pipe Insulation Verification

This submeasure adds a prescriptive requirement for field verification of pipe insulation installation quality for DHW recirculation systems. Field verification would confirm installation of code required pipe insulation, including insulation on all fittings and valves, pumps, thermal isolation at pipe hangers, and overall insulation installation quality. This submeasure builds on the current single-family and low-rise multifamily residential pipe insulation inspection credit (PIC-H) and extends it to become a prescriptive baseline for all multifamily buildings with DWH recirculation systems. This submeasure includes minor updates to default values for derating insulation quality in the compliance software.

2.1.2 Submeasure B: Increased Insulation

This submeasure increases mandatory pipe insulation requirements for multifamily DHW pipes two inches and larger. This submeasure also aligns pipe insulation requirements for all multifamily buildings. This submeasure includes minor updates to default insulation thickness values in the compliance software.

2.1.3 Submeasure C: CPC Appendix M Sizing

This submeasure adds a compliance option for pipe sizing based on CPC Appendix M. Appendix M (IAPMO 2019) is an optional CPC appendix with an alternative pipe sizing procedure. Appendix M contains a performance-based pipe sizing calculation procedure that typically results in smaller pipe sizes than standard practice sizing, which results in lower first costs and distribution system heat loss. The current primary prescriptive baseline model assumes standard practice pipe sizing based on CPC Appendix A (fixture units, Hunter's curve, etc.). This measure requires updates to the compliance software to include two pipe sizing approaches.

2.1.4 Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

The 2022 multifamily DHW distribution CASE measure would change the existing requirement for two recirculation loops in central DHW systems to a compliance option, while reducing the performance budget for multifamily DHW recirculation systems with new requirements in Submeasure A and B described above. This measure requires minor updates to the compliance software.

2.2 Measure History

The 2013 multifamily central DHW and solar thermal CASE Report estimated that 33 percent of hot water generated at the water heater is lost in the recirculation loop to ambient space (Statewide CASE Team 2011). In multifamily buildings, DHW is often generated via a central gas-fired water heater and delivered via a pump and recirculation loop to all dwelling units. Central DHW systems lead to much higher distribution piping heat losses than individual water heaters at each dwelling unit, particularly in larger buildings because the recirculation loop must be sized and designed to adequately serve the hot water demand of all dwelling units. This increases piping heat losses as compared to smaller distribution networks.

To address central distribution heat losses, Title 24, Part 6 currently prescriptively requires demand control recirculation, as well as a minimum of two recirculation loops in multifamily buildings that have nine or more dwelling units. The proposed multifamily DHW distribution submeasures further reduce distribution system heat losses with three proposed submeasures and addresses compliance and enforcement challenges of the current two loop requirement.

2.2.1 Submeasure A: Pipe Insulation Verification

The Statewide CASE Team investigated a pipe insulation verification measure similar to the existing multifamily QII energy credit through HERS verification. This measure is needed because of the poor quality of existing insulation exhibited by the 2013 PIER Report “Multifamily Central Domestic Hot Water Distribution Systems” (PIER 2013) and based on the Statewide CASE Team’s interviews with design firms and stakeholder feedback during the CASE Process.

The 2013 PIER Study monitored several key parameters of central hot water systems including hot water supply temperature, hot water return temperature, cold-water supply temperature, recirculation flow, hot water draw flow, and natural gas consumption. The study monitored 28 buildings in five different climate zones in California. The PIER Study Team then developed an energy flow analysis model to separate DHW natural gas consumption into four energy flow components: water heating equipment efficiency and standby heat loss, recirculation system heat loss, branch pipe heat loss, and delivered hot water energy. Recirculation system heat loss ranged from three to 67 percent of total hot water usage with an average of 33 percent (see Figure 1). The study found that measured heat loss from DHW distribution piping was approximately twice the anticipated heat loss that would occur with perfect insulation.

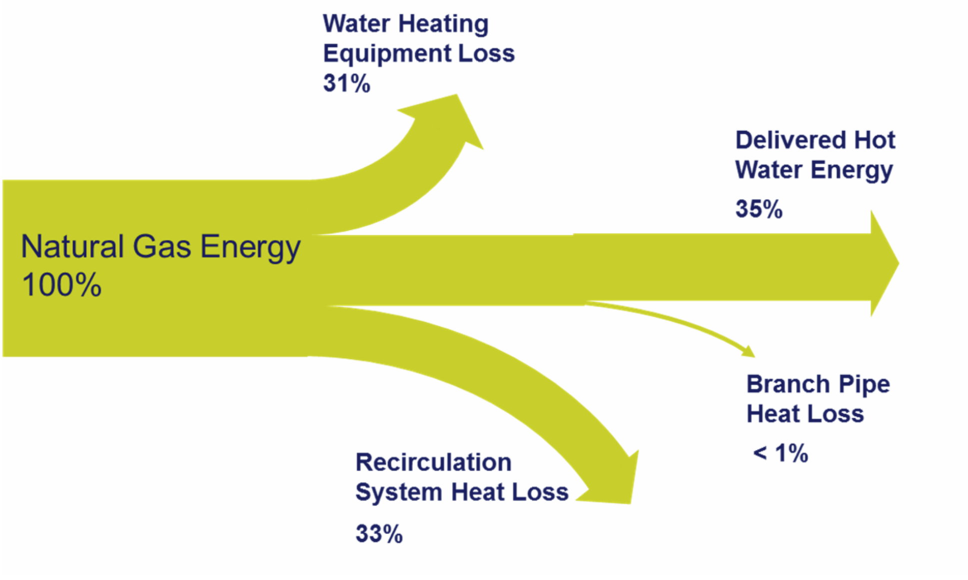

Figure 1: DHW distribution heat losses.

Source: (PIER 2013).

Based on the PIER Study energy flow analysis model, the 2013 Statewide CASE Team developed two CASE Reports, one of which was the 2013 CASE Water and Space Heating ACM Improvement (Statewide CASE Team 2011). The 2013 Statewide CASE

Team developed and proposed the performance calculation algorithms for recirculation systems in multifamily and hotel/motel buildings. The 2013 CASE Report suggested an ACM Reference Manual “correction factor to reflect imperfect insulation” that was adopted by the Energy Commission and is part of the current Title 24, Part 6 performance approach. The current ACM Reference Manual includes this correction factor described as, “Correction factor to reflect imperfect insulation, insulation material degradation over time, and additional heat transfer through connected branch pipes that is not reflected in the branch heat loss calculation. It is assumed to be 2.0.”

In addition to the precedent for insulation modifications informed by the PIER study, the Verified Pipe Insulation Credit (PIC-H) Residential Verification described in Section RA3.6.2 of the residential appendices offers a compliance credit for HERS verification of pipe insulation quality. This credit is only available for trunk and branch distribution systems in single family and low-rise residential buildings. If this credit is achieved and the HERS Rater verifies the hot water distribution system is insulated according to CPC609.11, the project receives a 15 percent energy credit in the Assigned Distribution System Multiplier (ADSM). ADSM is an adjustment for alternative water heating distribution systems within the dwelling unit.

The Statewide CASE Team also collected data on insulation quality through designer interviews, CASE Stakeholder meeting surveys, construction managers and designers survey, and field observation punch lists[1] and photos. A detailed summary of insulation quality data collection is contained in Appendix G, and the methods and results are summarized below.

- **Designer interviews:** The Statewide CASE Team conducted interviews with six multifamily plumbing designers to garner feedback on recirculation design strategies, compliance, enforcement, and insulation quality. Insulation quality questions were open ended. Based on these interviews, the Statewide CASE Team learned that hot water distribution systems are frequently missing insulation or have poorly installed insulation (missing insulation on fittings including improperly mitered joints, insulation not covering 100 percent of a straight pipe run, and overall poor insulation quality).
- **Utility-sponsored stakeholder meeting survey:** A survey was administered through the live Adobe interface during the first DHW Stakeholder meeting on October 4, 2019. Two questions were asked 1) “How often have you seen deficiencies in pipe insulation quality, such as missing insulation on fittings or poor quality installation?” and 2) “What are the most common deficiencies in pipe

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[1] A punch list is a document detailing items in a construction project that do not meet the specifications which must be addressed by the contractor.

insulation quality?" Ten out of the twelve respondents said that greater than 50 percent of projects have insulation deficiencies and that the typical deficiencies are "fittings are not insulated," "pipe insulation is poorly installed (there are gaps)," and "valves are not insulated."

- **Construction managers and designers survey:** The Statewide CASE Team asked several questions about interviewee's observations of insulation quality in buildings where interviewees have participated in construction administration activities. The Statewide CASE Team found that insulation quality is lacking in 60-70 percent of multifamily buildings on average and the most common issues are uninsulated piping specialties[2] including valves, tees, improperly mitered joints, and uninsulated pumps.
- **Field observation punch lists and photos:** The Statewide CASE Team collected field observation documentation from designers and construction managers. This data provides visual confirmation of the insulation quality issues found through interviews and surveys listed above. For example, Figure 2 shows missing insulation on elbow and tee fittings.

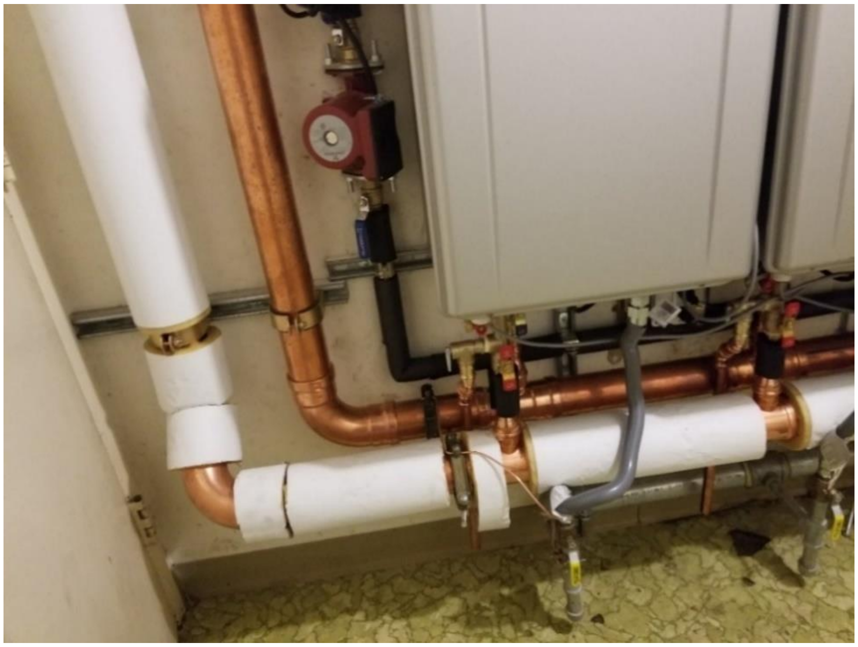

Figure 2: Field observation punch list photo showing missing pipe insulation.

Source: (AEA n.d.).

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[2] Piping specialties refers to all components of a piping system other than the pipe itself.

In addition, the United States Department of Energy (U.S. DOE) identified the issue of missing elbow insulation in a 2012 Building Technologies Program Code Notes regarding insulation requirements in commercial buildings for mechanical and service hot water piping (U.S. DOE 2012). The publication includes the graphic illustration shown in Figure 3.

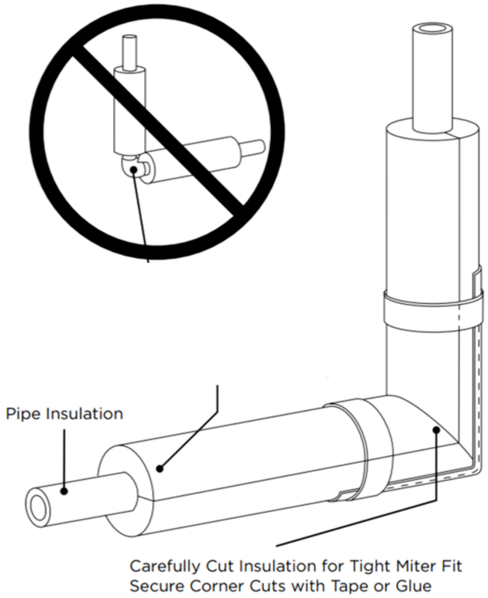

Figure 3: Illustration of improper and proper elbow insulation.

Source: (U.S. DOE 2012).

2.2.2 Submeasure B: Increased Insulation

The Statewide CASE Team proposes a measure to increase insulation thickness requirements specifically for multifamily DHW systems by adding a new row to Table 120.3-A that refers only to DHW systems.

The 2013 CASE Water and Space Heating ACM Improvement (Statewide CASE Team 2011) analyzed increased pipe insulation requirements in Table 120.3-A, which would have impacted DHW systems, HVAC systems, and other process hot water distribution. The analysis found that increasing DHW pipe insulation was cost effective, but that increasing HVAC pipe insulation was not cost effective in most cases. As a result, the CASE study did not propose increased insulation thickness in Table 120.3-A because the table applied to both system types. The 2013 CASE effort did not analyze market availability and other market barriers such as wall thickness limitations on total pipe plus insulation diameter. This issue is addressed in this CASE Report.

Existing pipe insulation requirements are not consistent for multifamily buildings as summarized in Table 6. In addition to increasing insulation thickness for DHW piping, this measure would align pipe insulation requirements for all multifamily buildings.

Table 6: Current Code Hot Water Pipe Insulation Thickness Requirements

Pipe Size	Title 24, Part 6 Residential (150(j)) Insulation Thickness	Title 24, Part 6 Nonresidential (120.3-A) Insulation Thickness
3/8"	1"	1"
1/2"	1"	1"
3/4"	1"	1"
1"	1"	1.5"
1.5"	1.5"	1.5"
2"	2"	1.5"
2.5"	2"	1.5"
3"	2"	1.5"
3.5"	2"	1.5"
4"	2"	1.5"
4.5"	2"	1.5"
5"	2"	1.5"
6"	2"	1.5"

Source: (CEC, Building Energy Efficiency Standards for Residential and Nonresidential Buildings 2019)

2.2.3 Submeasure C: CPC Appendix M Sizing

The Statewide CASE Team is proposing a new compliance credit for CPC Appendix M pipe sizing, as a way for early adopters to get credit for a measure that reduces both energy use and first costs. CPC 2109 Appendix M was adopted verbatim from the 2018 UPC.

Appendix M was added to the UPC in 2018 and includes an alternative pipe sizing procedure. Appendix M contains a performance-based pipe sizing calculation procedure that typically results in smaller pipe sizes than standard practice sizing, which results in lower first costs and distribution system heat loss.

The International Association of Plumbing and Mechanical Officials (IAPMO) Water Demand Calculator (WDC) is a tool developed by Buchberger, et. al., used to size pipes according to the CPC/UPC Appendix M (Buchberger, et al. 2017). The authors of this tool developed this sizing methodology in response to the increased prevalence of low-flow fixtures. The previous Hunter’s curve/fixture units sizing method assumed outdated gallons per minute (GPM) rating for each fixture type (sink, water closet, shower, etc.), and used outdated data on diversity of flow in pipes upstream of multiple fixtures. CPC

Appendix M and the IAPMO water demand calculator account for modern low-flow fixtures required in California code and use a large new dataset of flow diversity in real buildings to create a more accurate prediction of peak flow for pipe sizing.

The Statewide CASE Team found that there is interest in using Appendix M for design calculations, but stakeholder conversations, designer interviews, and a review of the American Society of Plumbing Engineers (ASPE) Connect forum show there is limited market adoption (ASPE n.d.).

There is currently not an option for a design team to get compliance credit for using Appendix M sizing because the ACM Reference Manual mandates pipe sizing in the prescriptive baseline model that is based on CPC Appendix A.

2.2.4 Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

The current code requirement for two-loop recirculation systems, which was first adopted in 2013, has faced compliance and enforcement challenges including inconsistent interpretations of the requirement and challenges establishing appropriate baseline and proposed systems in the California Compliance Simulation Engine (CSE). In addition, the two-loop requirement was developed based on research on the low-rise multifamily building type and is not directly applicable across all multifamily building types (low-, mid-, and high-rise). Feedback from Statewide CASE Team’s interviews with plumbing designers show general confusion over the definition and practicality of implementing multiple-loop DHW recirculation systems.

The Statewide CASE Team had discussions with the CSE Team that implemented the two-loop requirement in 2013 and were informed that the CSE results were conflicting with the 2013 CASE results in some cases. Modeled energy use in CSE was showing larger energy use for two-loop designs compared to one-loop designs. In subsequent discussions with the Energy Commission, the Statewide CASE Team was informed that the Energy Commission requested a change in CSE to use one-loop as the baseline, rather than two-loops. The CSE modeling results and subsequent changes to CSE are not documented in official publications, but the Statewide CASE Team confirmed that the current CSE baseline assumption is one-loop by running simulations in the California Building Energy Code Compliance (CBECC)-Residential (CBECC-Res) and Commercial (CBECC-Com) software. Simulations showed that models with two-loops used more energy than models with one-loop, confirming the verbal description from the CSE Team. The fact that CSE uses a baseline of one-loop was not documented in Title 24, Part 6 for the last three code cycles, 2013, 2016, and 2019. Title 24, Part 6 along with appendices, ACM Reference Manual, and other related documentation, all describe a two-loop baseline in 2013, 2016, and 2019 versions.

The Statewide CASE Team conducted interviews with six multifamily plumbing designers to garner feedback on recirculation design strategies, compliance, enforcement, and insulation quality. Interviews included specific questions regarding how often designers used two-loops and their knowledge of current code requirement for two-loops. Predominantly (four out of six) interviewees were not aware of the current two-loop requirement and said that they had never implemented two-loops with separate loop pumps which is the intention of the current Title 24, Part 6 requirements (Statewide CASE Team 2011). Many interviewees asked for an explanation of the requirement, and after an explanation was provided most designers explained that their typical designs already have multiple piping loops (in the form of multiple riser pipes) but did not have two pump loops. They went on to explain that they saw no benefit or reason to install multiple pumps on their designs. The Statewide CASE Team compared this recent designer feedback to the 2013 CASE Report and concluded that the 2013 CASE Report focus on low-rise multifamily building type is not directly applicable across all multifamily building types (low-, mid-, and high-rise). Most mid-and high-rise designs use multiple risers with a single supply header and single return header, that effectively have multiple loops and division into two pumping zones has limited energy benefit. See Appendix H for a summary of the plumbing designs for the four prototype buildings used for this CASE analysis.

The Statewide CASE Team recommends changing the existing requirement for two-loop recirculation systems to a compliance option, to reduce prescriptive compliance barriers while allowing for improvements in CSE to support multi loop designs.

2.2.5 Other Hot Water Distribution Measures Considered but Not Pursued

The Statewide CASE Team considered three other measures in the scope of reducing distribution heat losses but chose not to pursue them for various reasons. These measures include installing heat trace on multifamily distribution systems, requiring installation of radiant barriers on pipe insulation, and installing temperature dependent valves on supply risers.

2.2.5.1 *Trace Heating*

Trace heating involves placing electrical resistance heating elements directly in contact with distribution piping, covered with insulation, to keep the pipe and water warm. Aside from reducing demand at the water heater, heat trace also eliminates the need for a recirculation loop and the associated pumping power and distribution heat losses from the return pipe. However, Ecotope and Purdue University performed studies that showed minimal energy savings with trace heating compared to a central recirculation approach (Heller, et al. 2017).

The Statewide CASE Team chose not to pursue this measure due to maintenance and replacement concerns and lack of energy savings. During interviews with manufacturers, the Statewide CASE Team discovered that maintenance is difficult since it is not possible to pinpoint the location of issues with the product if it is not working correctly. Additionally, at the end of life of the product, insulation must be removed to replace the heat tape. The expected life of the product is 20 years, less than the life of the DHW distribution piping. Since pipes are often sealed behind sheetrock and within wall insulation, replacement would be cost and time intensive making this measure not cost effective over the life of the building.

2.2.5.2 *Radiant Barrier Equipped Insulation*

Radiant barrier equipped insulation is frequently used to reduce radiative heat loss in attics of residential buildings. The Statewide CASE Team chose not to pursue requiring radiant barrier equipped pipe insulation due to the lack of product availability. Pipe insulation with radiant barriers pre-installed is not commonly available. The Statewide CASE Team found products available for site-installed radiant barriers but did not find insulation with pre-installed radiant barriers. Subsequently, the amount of labor necessary to install the product on pipe insulation would cause the measure to not be cost effective. The Statewide CASE Team was also concerned that dust settling on radiant barriers would degrade performance over time.

2.2.5.3 *Temperature Dependent Valves*

Temperature dependent valves replace the hot water return circuit setters on supply risers and branch loops in distribution systems. Typically, circuit setter valves must be manually balanced to ensure consistent flow in each of the risers. Temperature dependent valves automatically adjust flow to the risers based on the temperature at the valve which eliminates the need for manual balancing and provides better temperature controls.

The Statewide CASE Team chose not to pursue this measure further due to the lack of savings opportunity. In new construction, most of the savings potential is already captured by the current code requirements for recirculation pump control. The prescriptive baseline since 2013 has a requirement for central systems to be controlled based on hot water supply and return temperatures which is similar to what occurs with temperature dependent valves.

2.3 Summary of Proposed Changes to Code Documents

The Energy Commission is planning consolidation of low-and high-rise multifamily requirements under a new multifamily section(s) in 2022 Title 24, Part 6. Restructuring the standards for multifamily building may also result in revisions to the ACM Reference Manual, Reference Appendices, compliance manuals, and compliance documents. Location and section numbering of the 2022 Standards and supporting documents for multifamily buildings depend on the Energy Commission’s approach to and acceptance of a unified multifamily section(s). For clarity, the changes proposed in this CASE Report are demonstrated in terms of the 2019 structure and language.

The sections below summarize how the standards, Reference Appendices, ACM Reference Manuals, compliance manuals, and compliance documents would be modified by the proposed change. See Section 7 of this report for detailed proposed revisions to code language.

2.3.1 Submeasure A: Pipe Insulation Verification

2.3.1.1 *Summary of Changes to the Standards*

This proposal would modify the following section of Title 24, Part 6. See Section 7.2 of this report for marked-up code language.

SUBCHAPTER 8 LOW-RISE RESIDENTIAL BUILDINGS - PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES

SECTION 150.1 – PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES FOR LOW-RISE RESIDENTIAL BUILDINGS

- **[Item (c)8]:** The proposed code change would add language that requires field verification of pipe insulation and make direct reference to the corresponding new Reference Appendix Section.

2.3.1.2 *Summary of Changes to the Reference Appendices*

This proposal would modify the sections of the Reference Appendices identified below. See Section 7.3 of this report for the detailed proposed revisions to the text of the Reference Appendices.

Reference Appendices

RA2.2 Measures that Require Field Verification and Diagnostic Testing

- **Table RA2-1 Summary of Measures Requiring Field Verification and Diagnostic Testing:** The proposed new pipe insulation verification requirement would be added to the summary table under the Multifamily Domestic Hot Water Heating Measures heading.

RA 3.6 Field Verification of Water Heating Systems

- The proposed change would add a new section RA3.6.x requiring inspection to verify that all DHW pipes are insulated according to the pipe insulation requirements in Title 24, Part 6 and CPC. The new section would describe the verification coverage within the mechanical room and horizontal supply header piping and sampling approach for vertical supply risers.

2.3.1.3 *Summary of Changes to the Residential ACM Reference Manual*

This proposal would modify the following section of the Residential ACM Reference Manual. See Section 7.4 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

Residential ACM Appendix B – Water Heating Calculation Method

- **B5.1 Hourly Recirculation Loop Pipe Heat Loss Calculation:** The proposed changes would update default values and text descriptions for Correction Factor, f_{UA}, referenced in Equation 20 to reflect the energy impact without and with pipe insulation verification. Relocation of the text descriptions for $U_{bare,n}$ and $U_{insul,n}$ and Equation 21 improves readability and clarity.

2.3.1.4 *Summary of Changes to the Residential Compliance Manual*

The proposed code change would modify the following sections of the Residential Compliance Manual.

CHAPTER 5 Water Heating Requirements

SECTION 5.3 Mandatory Requirements for Water Heating

- 5.3.5 Mandatory Requirements for Hot Water Distribution Systems
- 5.3.5.3 Distribution Systems Serving Multiple Dwelling Units – with Recirculation Loops

The proposed code change would add descriptions of benefits, procedures, and tips for carrying out pipe insulation verification.

SECTION 5.4 Prescriptive Requirements for Water Heating

- 5.4.2 Multiple Dwelling Units: Multifamily, Motel/Hotels, and High-Rise Residential
- 5.5.3 Systems Serving Multiple Dwelling Units

See Section 7.5 of this report for the detailed proposed revisions to the text of the compliance manuals.

2.3.1.5 *Summary of Changes to Compliance Documents*

The proposed changes would require updates to the following compliance forms:

- CF2R-PLB-01a-NonHERS-MultifamilyCentralHotWaterSystemDistribution
- CF2R-PLB-21a-HERS-MultifamilyCentralHotWaterSystemDistribution
- CF3R-PLB-21a-HERS-MultifamilyCentralHotWaterSystemDistribution
- NRCI-PLB-02-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution
- NRCI-PLB-21-HERS-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution

- NRCV-PLB-21-HERS-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution

The proposed change would add a new table in the forms for quality pipe insulation installation and field verification documentation.

2.3.2 Submeasure B: Increased Insulation

2.3.2.1 *Summary of Changes to the Standards*

This proposal would modify the following section of Title 24, Part 6. See Section 7.2 of this report for marked-up code language.

SUBCHAPTER 3 NONRESIDENTIAL, HIGH-RISE RESIDENTIAL, HOTEL/MOTEL OCCUPANCIES, AND COVERED PROCESSES—MANDATORY REQUIREMENTS

SECTION 120.3 – REQUIREMENTS FOR PIPE INSULATION

- **[Table 120.3-A]:** The proposed code change would add a row to Table 120.3-A that applies specifically to multifamily DHW systems. The requirements would specify both insulation thickness and R-value by pipe diameter for the 105-140°F fluid operating temperature range. The new row would have identical insulation requirements as the current table 120.3-A for pipes under two inches diameter. Pipes equal to two inches diameter and larger would have higher insulation requirements than the current table 120.3-A.

SUBCHAPTER 7 LOW-RISE RESIDENTIAL BUILDINGS – MANDATORY FEATURES AND DEVICES

SECTION 150.0 – MANDATORY FEATURES AND DEVICES

- **Subsection (j) Insulation for Piping and Tanks:** The proposed code change would add clarifying language that references the mandatory pipe insulation levels for multifamily DHW systems.

2.3.2.2 *Summary of Changes to the Reference Appendices*

The proposed code change would not modify the Reference Appendices documents.

2.3.2.3 *Summary of Changes to the Residential ACM Reference Manual*

The proposed code change would not modify the ACM Reference Manual.

2.3.2.4 *Summary of Changes to the Residential Compliance Manual*

The proposed code change would modify the following section of the Residential Compliance Manual.

CHAPTER 5 Water Heating Requirements

SECTION 5.3 Mandatory Requirements for Water Heating

- 5.3.5 Mandatory Requirements for Hot Water Distribution Systems
- 5.3.5.1 Pipe Insulation for All Buildings

The proposed changes would add clarifying language and reference to applicable code sections.

2.3.2.5 *Summary of Changes to Compliance Documents*

The proposed code change would require minor updates to reference locations for the multifamily pipe insulation requirements in the following forms:

- CF2R-PLB-01a-NonHERS-MultifamilyCentralHotWaterSystemDistribution
- CF2R-PLB-21a-HERS-MultifamilyCentralHotWaterSystemDistribution
- CF3R-PLB-21a-HERS-MultifamilyCentralHotWaterSystemDistribution
- NRCI-PLB-02-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution
- NRCI-PLB-21-HERS-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution
- NRCV-PLB-21-HERS-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution

2.3.3 Submeasure C: CPC Appendix M Sizing

2.3.3.1 *Summary of Changes to the Standards*

The proposed code change would not modify the standards.

2.3.3.2 *Summary of Changes to the Reference Appendices*

The proposed code change would not modify the Reference Appendices documents.

2.3.3.3 *Summary of Changes to the Residential ACM Reference Manual*

This proposal would modify the following section of the Residential ACM Reference Manual. See Section 7.4 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

Residential ACM Appendix B – Water Heating Calculation Method

B5.1 Hourly Recirculation Loop Pipe Heat Loss Calculation

The proposed changes would add a new correction factor, $f_{A,n}$, to the formula for pipe heat loss rate (Equation 21) to reflect the benefit of Appendix M pipe sizing. The new factor would vary based on the number of dwelling units served by the DHW system.

2.3.3.4 *Summary of Changes to the Residential Compliance Manual*

The proposed code change would modify the following section of the Residential Compliance Manual.

CHAPTER 5 Water Heating Requirements

SECTION 5.4 Prescriptive Requirements for Water Heating

- 5.4.2 Multiple Dwelling Units: Multifamily, Motel/Hotels, and High-Rise Residential

The proposed compliance option would add a new Section 5.4.2.x to describe benefits, procedures, and useful resources for Appendix M sizing methodology.

2.3.3.5 *Summary of Changes to Compliance Documents*

The proposed code change would add a table to an existing Certificate of Compliance or create a new Certificate of Compliance.

2.3.4 Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

2.3.4.1 *Summary of Changes to the Standards*

The proposed code change would strike language that requires recirculation systems to include two or more loops serving separate dwelling units and the related exception allowing buildings with eight or fewer dwelling units to use a single recirculation loop. See Section 7.2 of this report for marked-up code language.

SUBCHAPTER 8 LOW-RISE RESIDENTIAL BUILDINGS - PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES

SECTION 150.1 – PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES FOR LOW-RISE RESIDENTIAL BUILDINGS

- **[Item (c)8Bii]**

2.3.4.2 *Summary of Changes to the Reference Appendices*

This proposal would modify the following section of the Reference Appendices. See Section 7.3 of this report for the detailed proposed revisions to the text of the Reference Appendices.

Reference Appendices

RA 3.6 Field Verification of Water Heating Systems

- **RA3.6.8 HERS-Multiple Recirculation Loop Design for DHW Systems Serving Multiple Dwelling Units:** The proposed code change would modify the descriptions in HERS or Acceptance Test Technician (ATT) verification procedure RA3.6.8 to reflect two-loop recirculation being a compliance option.

2.3.4.3 *Summary of Changes to the Residential ACM Reference Manual*

This proposal would modify the following section of the Residential ACM Reference Manual. See Section 7.4 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

Residential ACM Appendix B – Water Heating Calculation Method

- **APPENDIX B2. WATER HEATING SYSTEMS**
- **B5. Hourly Distribution Loss for Central Water Heating System**
- **B5.3 Recirculation System Plumbing Design**

The proposed change would clarify that Standard Design is a DHW system with one recirculation loop.

2.3.4.4 *Summary of Changes to the Residential Compliance Manual*

The proposed code change would modify the following section of the Residential Compliance Manual.

CHAPTER 5 Water Heating Requirements

SECTION 5.4 Prescriptive Requirements for Water Heating

- 5.4.2 Multiple Dwelling Units: Multifamily, Motel/Hotels, and High-Rise Residential
- 5.4.2.1 Dual-Loop Recirculation System Design

The proposed changes would delete the dual-loop prescriptive requirement in Section 5.4.2.1 and add clarifying language that dual-loop systems is a performance option that requires HERS verification.

2.3.4.5 *Summary of Changes to Compliance Documents*

The proposed changes would require minor updates to the following compliance forms:

- CF2R-PLB-21a-HERS-MultifamilyCentralHotWaterSystemDistribution
- CF3R-PLB-21a-HERS-MultifamilyCentralHotWaterSystemDistribution
- NRCI-PLB-21-HERS-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution
- NRCV-PLB-21-HERS-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution

The proposed code change would update compliance forms so that multiple loop is a compliance option.

2.4 Regulatory Context

2.4.1 Submeasure A: Pipe Insulation Verification

2.4.1.1 Existing Requirements in the Energy Code

Title 24, Part 6 Section 150.0 requires insulation on all pipes and piping accessories by implication because only specific exceptions are cited. Exceptions include factory installed piping, piping penetrating framing members (although a thermal isolation material is required when pipes penetrate metal framing), piping in exterior walls that have QII, and piping surrounded by minimum thicknesses of wall, crawlspace, or attic insulation.

Title 24, Part 6 Section 120.0 specifically requires insulation on all pipes and piping accessories stating as “all elements that are in series with the fluid flow” and specifically mentions pipes, pumps, valves, strainers, coil u-bends, and air separators. There are exceptions for factory installed piping and piping penetrating framing members similar to Title 24, Part 6 Section 150.0.

The ACM Reference Manual has a compliance credit for field verification of pipe insulation quality called PIC-H where distribution heat losses are reduced by 15 percent according to Table B-1 of the ACM Reference Manual. In the residential appendices, RA3.6.2 contains HERS verification of pipe insulation for hot water distribution systems that is required when taking the PIC-H credit. This credit is only available for trunk and branch distribution systems in single family and low-rise residential buildings. RA3.6.2 requires verification that pipe insulation installation meets the requirements of Title 24, Part 6 Section 150.0(j).

There are similar insulation verification procedures for QII of wall insulation in RA3.5.

Lastly, RA2.6 describes the verification, testing, and sampling protocols for HERS verifications. This section outlines the definition of open groups, closed groups, the protocol for sampling rates, and the procedures for additional testing if a unit or units fail which would be referenced in the requirements for pipe insulation verification.

A separate multifamily high performance thermal envelope CASE topic for the 2022 code cycle is proposing to extend the QII HERS verification to high-rise multifamily buildings which is peripherally related to pipe insulation verification[3]. The Statewide

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[3] For more information, visit https://title24stakeholders.com/measures/cycle-2022/multifamily-chapter-restructuring/

CASE Team does not anticipate the thermal envelope QII verification and pipe insulation verification requirements to be in conflict because they require inspections of different building components.

2.4.1.2 Relationship to Requirements in Other Parts of the California Building Code

CPC 2019 Section 609.11 requires insulation on all pipes and piping accessories by implication because only specific exceptions are cited. Exceptions include piping penetrating framing member and piping between the fixture control valve and appliances.

2.4.1.3 Relationship to Local, State, or Federal Laws

There are no relevant local, state, or federal laws.

2.4.1.4 Relationship to Industry Standards

There are no relevant industry standards.

2.4.2 Submeasure B: Increased Insulation

Table 7: Current Regulations for Service Hot Water Pipe Insulation Thickness in Title 24, Part 6 summarizes the insulation requirements in Title 24, Part 6 Residential, Nonresidential, and CPC hot water pipe insulation requirements. This table is discussed further in the sections below.

Table 7: Current Regulations for Service Hot Water Pipe Insulation Thickness in Title 24, Part 6

Pipe Size	Title 24, Part 6 Residential	Title 24, Part 6 Nonresidential	CPC
3/8"	1"	1"	3/8"
1/2"	1"	1"	1/2"
3/4"	1"	1"	3/4"
1"	1"	1.5"	1"
1.5"	1.5"	1.5"	1.5"
2"	2"	1.5"	2"
2.5"	2"	1.5"	2"
3"	2"	1.5"	2"
3.5"	2"	1.5"	2"
4"	2"	1.5"	2"
4.5"	2"	1.5"	2"
5"	2"	1.5"	2"

6"	2"	1.5"	2"

2.4.2.1 *Existing Requirements in the Energy Code*

2019 Title 24, Part 6 Section 150.0(j) contains requirements for residential and low-rise multifamily pipe insulation thickness that refers to section 609.11 of the 2019 CPC (described in 2.4.2.2). Section 150.0(j) further requires pipe insulation for certain sections of the distribution system such as the first five feet of cold-water pipe from the storage tank and hot water piping serving a DHW Recirculation system. In addition, this section allows for a few exceptions including when piping penetrates a wood framing member.

2019 Title 24, Part 6 Section 120.3 contains requirements for nonresidential and high-rise residential pipe insulation. This section refers to Table 120.3-A which contains the specific thickness/R-value of insulation required for pipes based on the fluid operating range. Section 120.3 requires insulation on all elements of a pipe distribution system that are in series with the fluid flow (pumps, valves, strainers, and coils u-bends), and includes requirements for insulation on cold-water piping to storage tanks and heat traps.

2.4.2.2 *Relationship to Requirements in Other Parts of the California Building Code*

2019 CPC Section 609.11 requires pipe insulation thickness equal to pipe diameter up to two inches, and a minimum of two inches for larger pipes.

2.4.2.3 *Relationship to Local, State, or Federal Laws*

There are no relevant local, state, or federal laws.

2.4.2.4 *Relationship to Industry Standards*

ASHRAE Standard 90.1 requirements exactly match Title 24, Part 6 Table 120.3-A. The proposed increase in insulation thickness for multifamily DHW pipes two inches and larger would exceed current ASHRAE 90.1 requirements.

2.4.3 Submeasure C: CPC Appendix M Pipe Sizing

2.4.3.1 *Existing Requirements in the Energy Code*

While Title 24, Part 6 does not have requirements for how pipes should be sized, Appendix B of the Residential ACM has pipe sizing assumptions that are based on current CPC Appendix A pipe sizing requirements (fixture units, Hunter’s curve) that apply to both the reference and proposed pipe sizes.

2.4.3.2 *Relationship to Requirements in Other Parts of the California Building Code*

The CPC, which is largely the same as the UPC, contains requirements for pipe sizing in Appendix A which has been adopted by most state agencies. CPC Appendix A uses the water supply fixture units (WSFU) approach along with estimated demand curves (commonly referred to as Hunter's curves) to account for diversity of flow in upstream pipes that service multiple fixtures.

An alternative pipe sizing approach in Appendix M was a new addition to the UPC in the 2018 version and subsequently adopted into CPC 2019 (Buchberger, et al. 2017). CPC Appendix M sizing results in smaller pipe sizes compared CPC Appendix A. CPC Appendix M was not specifically adopted by any state agencies so remains an optional approach. It is too early to know how local jurisdictions would respond to projects that propose using Appendix M rather than Appendix A for pipe sizing.

2.4.3.3 *Relationship to Local, State, or Federal Laws*

There are no relevant local, state, or federal laws.

2.4.3.4 *Relationship to Industry Standards*

The IAPMO Water Demand Calculator is a tool developed by Buchberger et. al. used to size pipes according to the CPC/UPC Appendix M (Buchberger, et al. 2017). The authors of this tool developed this sizing methodology in response to the increased prevalence of low-flow fixtures. The previous Hunter's curve/fixture units sizing method assumed outdated GPM rating for each fixture type (sink, water closet, shower, etc.), and used outdated data on diversity of flow in pipes upstream of multiple fixtures. CPC Appendix M and the IAPMO water demand calculator account for modern low-flow fixtures required in California code and use a large new dataset of flow diversity in real buildings to create a more accurate prediction of peak flow for pipe sizing.

2.5 Compliance and Enforcement

When developing this proposal, the Statewide CASE Team considered methods to streamline the compliance and enforcement process and how negative impacts on market actors who are involved in the process could be mitigated or reduced. This section describes how to comply with the proposed code change. It also describes the compliance verification process. Appendix E presents how the proposed changes could impact various market actors.

2.5.1 Submeasure A: Pipe Insulation Verification

The activities that need to occur during each phase of the project are described below:

- **Design Phase:** Designers provide and note pipe insulation levels on design drawings if taking the prescriptive approach. This provides a queue for the general contractor to anticipate the coordination needed for timing and scheduling HERS Rater or ATT verification during later phases.
- **Permit Application Phase:** Energy consultants make the desired pipe insulation verification selection (Y/N) in the compliance software for the project if taking the performance approach, and the information is submitted as part of the application package.
- **Construction Phase:** Pipe insulation verification would require additional coordination between trades on site to enable visual verification of insulation by a HERS Rater or ATT. Installers would populate and sign the CF2R-PLB form.
- **Inspection Phase:** HERS Rater or ATT would need to coordinate and schedule verification visits with installers or general contractors (more likely for larger buildings) to ensure proper construction stages and adequate access while on site. Installers would likely need to accompany HERS Rater or ATT personnel during verification visits. HERS Rater/ ATT would populate the CF3R-PLB form, and after the verification visits, both the HERS Rater or ATT and installers would provide signatures for the compliance form.

Pipe insulation verification builds on an existing pipe insulation compliance credit available only to single family and low-rise multifamily buildings, and the proposed measure requires field verification of insulation quality on recirculation pipes. The scale and required coverage in verifying multifamily DHW pipe insulation adds time and complexity to the construction and installation process. Multiple verification visits may be needed as plumbing insulation is often phased with other trades on site, particularly for larger buildings.

Combined verification efforts where multiple verification activities are performed at the same time is possible. QII is the prime example for potential combined verification visits since there are similarities between construction phasing of wall cavity installation, sampling requirements, and verifications activities between QII and pipe insulation verification.

2.5.2 Submeasure B: Increased Insulation

The activities that need to occur during each phase of the project are described below:

- **Design Phase:** Designers who issue specifications that refer to current code for pipe insulation thickness would not need to change their specifications. Designers who issue specifications that include a table of insulation thicknesses would need to update their specifications to reflect new insulation thickness requirements. Designers who issue specifications that include a table of insulation thicknesses would use the same table for all multifamily building types, in contrast to current code where two different tables are required for low- and high-rise buildings.

No enforcement changes are anticipated because all existing pipe insulation enforcement would remain the same.

- **Permit Application Phase:** No compliance or enforcement changes are anticipated.
- **Construction Phase:** Insulation installers would not experience substantial shift in present practice except for the increased insulation thickness associated with larger pipes where installed. Plumbers may need to change practices to allow clearance around the piping for the 2-inch thick insulation. This scenario is rare because most horizontal piping with two-inch or larger diameters occurs in horizontal configuration with little to no space limitation.
- **Inspection Phase:** Building officials would need to learn the new insulation thickness requirements, although they would only have to learn one set of requirements for all multifamily buildings in contrast to current code where two different sets of requirements are required for low- and high-rise buildings.

Overall increasing insulation for pipe diameters two inches and larger entails similar compliance and enforcement activities as currently required. The proposed insulation increase applies to larger pipe diameters used primarily for recirculation, run-outs, and riser portions, and not in-unit portions of DHW piping. Alignment of multifamily pipe insulation levels regardless of building height provides consistency for enforcement use.

2.5.3 Submeasure C: CPC Appendix M Sizing

The activities that need to occur during each phase of the project are described below:

- **Design Phase:** Plumbing designers have the option to perform pipe sizing calculations and design tasks based on CPC Appendix M method.
- **Permit Application Phase:** Plumbing designers would provide additional design documentation if they choose to exercise this compliance option. Designers would populate detailed piping schedule per the Appendix M sizing methodology on the CF1R-PLB form. Building department plan inspector would need to understand and review Appendix M sizing reported in the CF1R compliance form.
- **Construction Phase:** No compliance or enforcement changes are anticipated as the installers would follow pipe sizing specified design documents as usual.
- **Inspection Phase:** There would be no impact on inspection activities.

Charting a compliance pathway for designers choosing to use Appendix M Sizing methodology raises the awareness of this relatively new option and encourages designer adoption as well as local building official acceptance.

2.5.4 Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

The activities that need to occur during each phase of the project are described below:

- **Design Phase:** Minimal compliance or enforcement changes are anticipated, and plumbing designers continue to exercise design options in terms of recirculation system layout. Changing the prescriptive baseline is a single DHW recirculation loop without a requirement for HERS verification would simplify design and compliance documentation for projects that follow the prescriptive requirements.
- **Permit Application Phase:** No compliance or enforcement changes are anticipated.
- **Construction Phase:** Minimal compliance or enforcement changes are anticipated. Changing the prescriptive baseline is a single DHW recirculation loop without a requirement for HERS verification would simplify coordination of HERS field verification for projects that follow the prescriptive requirements.
- **Inspection Phase:** No compliance or enforcement changes are anticipated except for changing the recirculation loop from a prescriptive requirement to a performance option on CF2R-PLB and CF3R-PLB forms.

The current requirement for two-loop recirculation systems (first adopted in 2013 for Title 24, Part 6) has faced compliance and enforcement challenges including inconsistent interpretations of the requirement and challenges establishing appropriate baseline and proposed systems in the CSE. Changing the existing prescriptive requirement to a compliance option would simplify the compliance process for projects that follow the prescriptive path, where only one loop is required without a requirement for HERS verification.

3. Market Analysis

3.1 Market Structure

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, product availability, and market trends. The Statewide CASE Team then considered how the proposed standard may impact the market in general as well as individual market actors. The Statewide CASE Team gathered information about the incremental cost of complying with the proposed measure. The Statewide CASE Team identified estimates of market size and measure applicability through research and outreach with stakeholders including utility program staff, Energy Commission staff, and a wide range of industry actors. In addition to conducting personalized outreach, the Statewide CASE Team discussed the current market structure and potential market barriers during public stakeholder meetings that the Statewide CASE Team held on October 3, 2019, and March 17, 2020 (Statewide CASE Team 2019).

3.1.1 Submeasure A: Pipe Insulation Verification

DHW pipe insulation is typically installed by the plumbing subcontractor or an independent insulation subcontractor. Plumbing subcontractors usually provide both plumbing and insulation on smaller buildings, while larger buildings often have separate contractors for plumbing and insulation installation. This submeasure would impact insulation contractors and installers in larger multifamily buildings with central DHW systems that require pipes two inches and larger (approximately, buildings with more than 30 units).

Pipe insulation that covers all pipes, fittings, valves, pumps, etc., is already required in the residential and nonresidential language of Title 24, Part 6, and the CPC. Therefore, the pipe insulation verification requirement would not significantly change installation requirements. This submeasure would require increased attention to detail by pipe insulation installers to ensure that insulation is complete and well installed.

HERS Raters currently inspect wall insulation quality when QII is required and a limited number also inspect pipe insulation quality for the existing PIC-H credit. This measure would add a new inspection similar to the existing PIC-H inspection that the HERS Rater providers would include in their services. ATT personnel perform compliance verifications for lighting and mechanical systems in high-rise multifamily buildings but not for central DHW system. This measure, if performed by an ATT, would present a new type of ATT verification services for multifamily new construction buildings.

3.1.2 Submeasure B: Increased Insulation

Pipe insulation has existing supply chains that would not change for this measure. Insulation installation discussed in the section above would not change for this measure.

The Statewide Case Team gathered data on the insulation supply chain through communication with a manager of a Northern California insulation contractor with 30 years of pipe insulation experience. There are three primary manufacturers of DHW pipe insulation: Owens Corning, Knauf, and Johns Manville. All three manufacturers make the same sizes and in general meet the same specifications. Insulation contractors stock insulation for half- inch up to 16- inch pipe, up to two inches thick. When greater than two inches of insulation is required, contractors would nest two layers of insulation to achieve the required thicknesses. Insulation supply delivery typically occurs every week and special orders are delivered within two weeks. The Statewide CASE Team also reviewed online retailer offerings and found similar availability of insulation from at least three manufacturers. The Statewide CASE Team confirmed the top three pipe insulation manufacturers mentioned above in a Marketwatch market report (MarketWatch 2019).

3.1.3 Submeasure C: CPC Appendix M Pipe Sizing

Plumbing designers, engineers, and contractors perform sizing calculations and pipe layout for DHW piping systems. This submeasure would require existing design professionals to use new procedures, likely utilizing the WDC tool from IAPMO.

Plumbing materials supply and installation markets would not change for this submeasure because the only change would be use of smaller pipe sizing in a portion of the DHW system layout. Pipes used for DHW distribution are the same pipes used in HVAC systems and commercial and industrial facilities, so they are widely available through retail, online, and distributor distribution channels. Multifamily pipe sizes and quantities are a small portion of the overall market, so changes in pipe size demands would not impact the supply chain.

3.2 Technical Feasibility, Market Availability, and Current Practices

3.2.1 Submeasure A: Pipe Insulation Verification

Current construction phasing practices may be a barrier to pipe insulation verification, where drywall is often installed soon after pipe insulation is installed. This submeasure requires a window of time where pipe insulation is exposed before drywall installation. If phasing is an issue, general contractors would need to coordinate subcontractor schedules to allow for pipe insulation verification. The Statewide CASE Team conducted interviews with designers and a HERS Rater to discuss this issue and concluded that close coordination between the general contractor/construction supervisor and HERS Rater is necessary to time the visits and limit the impact on the construction schedule while maintaining an adequate sampling rate. Interviewees thought that coordination was achievable if a sampling method was used (one in seven DHW recirculation pipe risers for example) and would be an issue if complete (100 percent) inspection was required. Interviewees noted that similar coordination is required for other HERS activities, such as QII.

There is a precedent for verification of pipe insulation with the current PIC-H credit (see Section 2.2.1) and 15 percent of single family projects permitted on CalCERTS HERS Registry have applied for this credit in 2019, so HERS Raters have somewhat limited experience[4].

During the stakeholder outreach process, stakeholders said that insulation installers might not know how to properly install insulation that meets current code requirements. Pipe insulation installers may need to be trained, potentially by manufacturers or other code supporting entities on how to correctly install pipe insulation as required in the current energy and plumbing codes.

Insulation quality is a passive measure that would persist for the life of the materials. There is no maintenance required.

See Appendix G for more background on current practices for pipe insulation installation and verification.

3.2.2 Submeasure B: Increased Insulation

The Statewide CASE Team focused the code proposal efforts on considering pipe insulation levels where the recirculation system experiences the greatest heat loss – piping upstream of unit-level runouts where pipe diameters are larger, water temperatures are higher, and flows are more frequent. Stakeholders provided information on the state and challenges of current insulation practices that as follows:

- Some stakeholders were concerned about availability of thicker insulation. The Statewide CASE Team reviewed insulation products online from common retailers and found insulation up to two inches thick from multiple manufacturers. Through outreach to insulation contractors, the Statewide CASE Team found that contractors typically stock insulation up to two inches thick for half inch pipe up to 16-inch pipe. Contractors stated that when greater than two inches of insulation

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[4] A HERS Rater is a person who has been trained, tested, and certified by a HERS Provider to perform the field verification and diagnostic testing required for demonstrating compliance with Part 6, Title 24 code. CEC oversees the HERS Providers who train and certify HERS Raters. CalCERTS and California Energy Registry are the two HERS Providers, and CalCERTS (CalCERTS n.d.) reported have more than 600 active Raters providing 5,600 home ratings in 2018.

is required, they would nest two layers of insulation to achieve the required thicknesses. Installing two layers of insulation approximately doubles costs compared to one layer because installation is a large portion of the cost, so this submeasure limits insulation thickness to two inches.

- Increasing insulation thickness on certain pipes may result in an assembly that is too large to fit in a standard wall size. For example, a two-inch pipe with two-inch insulation thickness (six inch assembly diameter) would not fit in a standard two inch by six inch wall that is typically provided for plumbing services. The Statewide CASE Team reviewed plumbing distribution systems for the four prototype multifamily buildings used in this CASE analysis (summarized in Appendix G) and found that all vertical pipes would fit in a standard plumbing wall. Most instances of large diameter pipe plus insulation assemblies occur for horizontal pipes that have less space limitations or are pipes at the hot water plant which do not have space limitations. The proposed increase in insulation thickness does not impact vertical pipe risers because the riser pipe sizes are always less than two inches in diameter.
- Stakeholders expressed that there are diminishing energy savings returns when increasing insulation thickness, particularly for smaller pipe diameters. The Statewide CASE Team is proposing increasing insulation requirements for pipes two inches and larger pipes, such as those used in recirculation loops and at the hot water plant to maximize energy savings.
- Stakeholders have expressed concern about conflicting insulation thickness requirements in Title 24, Part 6 and other parts of California Building Code. The Statewide CASE Team acknowledges that the requirements vary between the CPC, Residential Energy Code, and Nonresidential Energy Code (see Table 7). The Statewide CASE Team is proposing unification of requirements for all multifamily buildings which would remove conflicting requirements within Title 24, Part 6. Title 24, Part 6 will continue to have more stringent insulation thickness requirements than the CPC.

Increased insulation is a passive measure that would persist for the life of the materials. There is no maintenance required.

3.2.3 Submeasure C: CPC Appendix M Pipe Sizing

CPC Appendix M is a new optional appendix with a pipe sizing method that differs from the method in the required CPC Appendix A (see Section 2.4). CPC Appendix M was not specifically adopted by any state agencies, and so remains an optional approach. This measure is being proposed as a compliance option because Appendix M is not the basis of the current code and may require jurisdictional approval.

Several stakeholders suggested that Appendix M should be a mandatory or prescriptive requirement because it reduces energy use and cost, but the Statewide CASE Team determined this is not feasible without updates to the CPC that require local jurisdiction adoption of Appendix M as an optional (or primary) sizing method.

Stakeholders asked if there is a risk of smaller pipe sizes not being able to meet peak hot water demand. The Statewide CASE Team believes the risk of under sizing is small based on the data and history behind Appendix M. A large portion of the field data used in the Water Demand Calculator (WDC) for Appendix M was from field data in multifamily buildings (Buchberger, et al. 2017).

Designers would need to learn a new calculation procedure for Appendix M, although the learning curve should be quick because the WDC spreadsheet is already available from IAPMO.

Appendix M sizing is a passive measure that would persist for the life of the materials. There is no maintenance required.

3.2.4 Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

The Statewide CASE Team discussed the technical feasibility of having two recirculation loops in multifamily buildings during interviews with multifamily plumbing designers. The designers expressed concern that a two-loop design does not have a physical meaning for the mid- and high-rise prototypes. Designers said that a typical plumbing design for a multifamily building is a supply loop at the top level of the building with supply risers (vertical pipes) distributed throughout the building, and a loop at the bottom of the building which gathers the supply risers and returns water to the hot water plant. In this case, there are several loops created by each of the supply risers. Designers also said that they were not sure what the term “two-loops” means in the context of multifamily plumbing layouts they typically design. The Statewide CASE Team recommends changing the existing requirement for two-loop recirculation systems to a compliance option, to reduce prescriptive compliance barriers while allowing for improvements in CSE to support multi loop designs.

3.3 Market Impacts and Economic Assessments

3.3.1 Impact on Builders

Builders of residential and commercial structures are directly impacted by many of the measures proposed by the Statewide CASE Team for the 2022 code cycle. It is within the normal practices of these businesses to adjust their building practices to changes in building codes. When necessary, builders engage in continuing education and training in order to remain compliant with changes to design practices and building codes.

The proposed requirements for the increased insulation would have a limited impact on builders, including purchase of thicker insulation products and the marginally longer installation labor required to install thicker insulation.

3.3.2 Impact on Building Designers and Energy Consultants

Adjusting design practices to comply with changing building codes practices is within the normal practices of building designers. Building codes (including Title 24, Part 6) are typically updated on a three-year revision cycle and building designers and energy consultants engage in continuing education and training in order to remain compliant with changes to design practices and building codes.

Businesses that focus on residential, commercial, institutional, and industrial building design are contained within the Architectural Services sector (North American Industry Classification System 541310). Table 8 shows the number of establishments, employment, and total annual payroll for Building Architectural Services. The proposed code changes for the 2022 code cycle would potentially impact all firms within the Architectural Services sector. The Statewide CASE Team anticipates the impacts for DHW Distribution to affect firms that focus on multifamily construction.

There is not a North American Industry Classification System (NAICS)[5] code specific for energy consultants. Instead, businesses that focus on consulting related to building energy efficiency are contained in the Building Inspection Services sector (NAICS 541350), which is comprised of firms primarily engaged in the physical inspection of residential and nonresidential buildings.[6] It is not possible to determine which business establishments within the Building Inspection Services sector are focused on energy efficiency consulting. The information shown in Table 8 provides an upper bound indication of the size of this sector in California.

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[5] NAICS is the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy. NAICS was development jointly by the U.S. Economic Classification Policy Committee (ECPC), Statistics Canada, and Mexico's Instituto Nacional de Estadistica y Geografia, to allow for a high level of comparability in business statistics among the North American countries. NAICS replaced the Standard Industrial Classification (SIC) system in 1997.

[6] Establishments in this sector include businesses primarily engaged in evaluating a building’s structure and component systems and includes energy efficiency inspection services and home inspection services. This sector does not include establishments primarily engaged in providing inspections for pests, hazardous wastes or other environmental contaminates, nor does it include state and local government entities that focus on building or energy code compliance/enforcement of building codes and regulations.

Table 8: California Building Designer and Energy Consultant Sectors

Sector	Establishments	Employment	Annual Payroll (billions $)
Building Inspection Services [a]	824	3,145	$0.22

Source: (State of California, Employment Development Department n.d.)

a. Building Inspection Services (NAICS 541350) comprises private-sector establishments primarily engaged in providing building (residential & nonresidential) inspection services encompassing all aspects of the building structure and component systems, including energy efficiency inspection services.

Building inspection services, including HERS Raters and ATT Technicians would experience an increase in labor due to the proposed requirements for the pipe insulation verification measure.

Building designers may need to be trained to size pipes according to Appendix M if they are not already familiar with the methodology.

3.3.3 Impact on Occupational Safety and Health

The proposed code change does not alter any existing federal, state, or local regulations pertaining to safety and health, including rules enforced by the California Division of Occupational Safety and Health (Cal/OSHA). All existing health and safety rules would remain in place. Complying with the proposed code change is not anticipated to have adverse impacts on the safety or health of occupants or those involved with the construction, commissioning, and maintenance of the building.

3.3.4 Impact on Building Owners and Occupants (Including Homeowners and Potential First-Time Homeowners)

The Statewide CASE Team anticipates the proposed change would have no material impact on California building owners and occupants.

3.3.5 Impact on Building Component Retailers (Including Manufacturers and Distributors)

The Statewide CASE Team anticipates that California component retailers and wholesalers would sell thicker insulation to residential builders and contractors in response to the increased insulation requirements in Submeasure B.

3.3.6 Impact on Building Inspectors

The Statewide CASE Team anticipates the proposed change would have no impact on employment of building inspectors including those employed by the Administration of

Housing Programs and the Urban and Rural Development Administration or the scope of their role conducting energy efficiency inspections.

3.3.7 Impact on Statewide Employment

As described in Sections 3.3.1 through 3.3.6, the Statewide CASE Team anticipates modest employment and financial impacts to a few sectors of the California economy. In Section 3.3 the Statewide CASE Team estimated how the proposed change in DHW distribution would affect statewide employment and economic output directly and indirectly through its impact on builders, designers and energy consultants.

3.4 Economic Impacts

For the 2022 code cycle, the Statewide CASE Team used the IMPLAN model software, along with economic information from published sources, and professional judgement to developed estimates of the economic impacts associated with each proposed code changes.[7] While this is the first code cycle in which the Statewide CASE Team develops estimates of economic impacts using IMPLAN, it is important to note that the economic impacts developed for this report are only estimates and are based on limited and to some extent speculative information. In addition, the IMPLAN model provides a relatively simple representation of the California economy and, though the Statewide CASE Team is confident that direction and approximate magnitude of the estimated economic impacts are reasonable, it is important to understand that the IMPLAN model is a simplification of extremely complex actions and interactions of individual, businesses, and other organizations as they respond to changes in energy efficiency codes. In all aspect of this economic analysis, the CASE Authors rely on conservative assumptions regarding the likely economic benefits associated with the proposed code change. By following this approach, the Statewide CASE Team believes the economic impacts presented below represent lower bound estimates of the actual impacts associated with this proposed code change.

Adoption of this code change proposal would result in relatively modest economic impacts through the additional direct spending by those in the residential building and remodeling industry, as well as indirectly as residents spend all or some of the money saved through lower utility bills on other economic activities. There may also be some nonresidential customers that are impacted by this proposed code change, however the Statewide CASE Team does not anticipate such impacts to be materially important to the building owner and would have measurable economic impacts.

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[7] IMPLAN (Impact Analysis for Planning) software is an input-output model used to estimate the economic effects of proposed policies and projects. IMPLAN is the most commonly used economic impact model due to its ease of use and extensive detailed information on output, employment, and wage information.

3.4.1 Creation or Elimination of Jobs

The Statewide CASE Team does not anticipate that the measures proposed for the 2022 code cycle regulation would lead to the creation of new *types* of jobs or the elimination of *existing* types of jobs. In other words, the Statewide CASE Team's proposed change would not result in economic disruption to any sector of the California economy. Rather, the estimates of economic impacts discussed in Section 3.3 would lead to modest changes in employment of existing jobs.

The proposed measures would create additional HERS or ATT labor hours due to the increased inspections required from the pipe insulation verification measure. Table 9 below summarizes these impacts.

Table 9: Building Designers & Energy Consultants Economic Impacts

Type of Economic Impact	Employment (jobs)[a]	Labor Income (millions $)	Total Value Added (millions $)	Output[b] (millions $)
Direct Effects (Additional spending by Residential Builders)	1.9	$0.19	$0.19	$0.34
Indirect Effect (Additional spending by firms supporting Residential Builders)	1.2	$0.08	$0.11	$0.17
Induced Effect (Spending by employees of firms experiencing "direct" or "indirect" effects)	1.5	$0.08	$0.15	$0.24
Total Economic Impacts	**4.5**	**$0.36**	**$0.45**	**$0.75**

Source: Analysis by Evergreen Economics of data from the IMPLAN V3.1 modeling software.

a. Employment is in units of "annual average of monthly jobs for the respective industry" per IMPLAN V3.1's definition from the Bureau of Labor Statistics. This is *not* equivalent to a full time equivalent (FTE) but rather represents the industry average mis of full-time and part-time jobs.
b. Output is in terms of the economic value of production.

Additionally, the increased pipe insulation would lead to an increase in labor and materials for pipe insulation installation. Table 10 summarizes these impacts.

Table 10: Residential Construction & Remodel Economic Impacts

Type of Economic Impact	Employment (jobs)	Labor Income (millions $)	Total Value Added (millions $)	Output[b] (millions $)
Direct Effects (Additional spending by Residential Builders)	1.5	$0.09	$0.16	$0.26
Indirect Effect (Additional spending by firms supporting Residential Builders)	0.6	$0.04	$0.06	$0.10
Induced Effect (Spending by employees of firms experiencing "direct" or "indirect" effects)	0.7	$0.04	$0.07	$0.11
Total Economic Impacts	**2.7**	**$0.17**	**$0.28**	**$0.47**

Source: Analysis by Evergreen Economics of data from the IMPLAN V3.1 modeling software.

3.4.2 Creation or Elimination of Businesses in California

As stated in Section 3.4.1, the Statewide CASE Team's proposed change would not result in economic disruption to any sector of the California economy. The proposed change represents a modest change to insulation of DHW distribution systems, which would not excessively burden or competitively disadvantage California businesses – nor would it necessarily lead to a competitive advantage for California businesses. Therefore, the Statewide CASE Team does not foresee any new businesses being created, nor does the Statewide CASE Team think any existing businesses would be eliminated due to the proposed code changes to Title 24, Part 6.

3.4.3 Competitive Advantages of Disadvantages for Businesses in California

The proposed code changes for the 2022 code cycle would apply to all businesses operating in California, regardless of whether the business is incorporated inside or outside of the state.[8] Therefore, the Statewide CASE Team does not anticipate that these measures proposed for the 2022 code cycle regulation would have an adverse effect on the competitiveness of California businesses. Likewise, the Statewide CASE Team does not anticipate businesses located outside of California would be advantaged or disadvantaged.

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[8] Gov. Code, §§ 11346.3(c)(1)(C), 11346.3(a)(2); 1 CCR § 2003(a)(3) Competitive advantages or disadvantages for California businesses currently doing business in the state.

3.4.4 Increase or Decrease of Investments in the State of California

The Statewide CASE Team does not anticipate that the economic impacts associated with the proposed measure would lead to significant change (increase or decrease) in investment in any directly or indirectly affected sectors of California's economy.

3.4.5 Effects on the State General Fund, State Special Funds, and Local Governments

The Statewide CASE Team does not expect the proposed code changes to have a measurable impact on the California's General Fund, any state special funds, or local government funds.

3.4.6 Impacts on Specific Persons

While the objective of any of the Statewide CASE Team's proposal is to promote energy efficiency, the Statewide CASE Team recognizes that there is the potential that a proposed update to the 2022 code cycle may result in unintended consequences. To this end, the Statewide CASE Team considers the potential impacts that the proposed updates to the 2022 code cycle regulation described in this report would have on specific groups, and anticipates the proposed change would have no economic impact on the following groups:

- Low-income households and communities
- First-time home buyers
- Renters
- Seniors
- Families
- Rural communities

4. Energy Savings

The energy and cost analysis presented in this report used the TDV factors that were released in the 2022 CBECC- Res research version that was released in December 2019. These TDV factors were consistent with the TDV factors that the Energy Commission presented during their public workshop on compliance metrics held October 17, 2019 (California Energy Commission 2020). The electricity TDV factors did not include the 15 percent retail adder and the natural gas TDV factors did not include the impact of methane leakage on the building site, updates that the Energy Commission presented during their workshop on March 27 , 2020 (California Energy Commission 2020). Presentations from Bruce Wilcox and NORESCO during the March 27, 2020 workshop indicated that the 15 percent retail adder and methane leakage would result in most energy efficiency measures having slightly higher TDV energy and energy cost savings than using the TDV factors without these refinements. As a result, the TDV energy savings presented in this report are lower than the values that would have been obtained using TDV with the 15 percent retail adder and methane leakage, and the proposed code changes would be more cost effective using the revised TDV. The Energy Commission notified the Statewide CASE Team on April 21, 2020 that they were investigating further refinements to TDV factors using 20-year global warming potential (GWP) values instead of the 100-year GWP values that were used to derive the current TDV factors. It is anticipated that the 20-year GWP values may increase the TDV factors slightly making proposed changes that improve energy efficiency more cost effective. Energy savings presented in kWh and therms are not affected by TDV or demand factors.

4.1 Key Assumptions for Energy Savings Analysis

Plumbing layouts and pipe sizes used for energy savings analysis are based on four prototype building plumbing designs. Table 11 has a summary of pipe sizes and lengths used for analysis. Table 18 includes a summary of the prototype building features and Appendix H includes detailed plumbing designs for each of the four prototypes.

Table 11: Summary of Pipe Sizes and Lengths in Prototype Plumbing Designs

	Pipe Lengths (feet) Using CPC Appendix A Sizing (Hunter's Curve)				Pipe Lengths (feet) Using CPC Appendix M Sizing (IAPMO WDC)			
Pipe Diameter (inches)	Low-Rise Garden	Low-Rise Loaded Corridor	Mid-Rise Mixed-Use	High-Rise Mixed Use	Low-Rise Garden	Low-Rise Loaded Corridor	Mid-Rise Mixed Use	High-Rise Mixed Use
4	0	0	53	9	0	0	0	0
3	0	25	91	130	0	0	0	5
2.5	0	90	73	165	0	0	121	129
2	20	24	85	58	0	80	66	80
1.5	58	153	829	782	52	107	244	148
1	29	182	338	313	55	287	1,058	1,095
0.75	150	404	744	953	150	404	724	953

Source: Statewide CASE Team

The Statewide CASE Team calculated the indoor space temperature for each climate zone based on the representative city‘s weather file provided with CBECC-Res and CBECC-Com. The rules for this calculation are presented in Table 22 and Section 2.5.4.3 of the 2019 Title 24, Part 6 Residential ACM, and summarized as follows. Heating and cooling mode are determined by calculating the rolling average outdoor temperature for the previous eight days. The building is in cooling mode if the rolling average is greater than 60°F and the building is in heating mode if the average is equal to or less than 60°F. Hourly thermostat setpoints vary between 78°F and 83°F (nighttime/daytime) in cooling mode and 65°F and 68°F (nighttime/daytime) in heating mode (single-zone gas-heating setpoints are used in this analysis). Table 12 presents the yearly hours in heating and cooling mode, and average indoor temperature by climate zone. The purpose of this exercise is to determine the hourly indoor temperature schedule to calculate heat loss from the distribution system. All DHW distribution pipes are assumed to be within the conditioned envelope.

Table 12: Heating and Cooling Mode and Average Indoor Temperature by Climate Zone

Climate Zone	Hours in Heating Mode	Hours in Cooling Mode	Average Indoor Temp [F]
1	8,760	0	67.0
2	5,182	3,578	72.2
3	5,525	3,235	71.7
4	4,785	3,975	72.7
5	7,205	1,555	69.2
6	4,305	4,455	73.4
7	3,562	5,198	74.5
8	3,380	5,380	74.8
9	3,595	5,165	74.5
10	3,867	4,893	74.1
11	4,556	4,204	73.1
12	4,566	4,194	73.1
13	4,230	4,530	73.5
14	4,423	4,337	73.3
15	1,706	7,054	77.2
16	5,610	3,150	71.6

Source: Statewide CASE Team

The Statewide CASE Team calculated energy savings for each prototype building because central DHW systems serve the entire building. The Statewide CASE Team then divided the building level savings by the number of units in each building to present per-unit results.

4.1.1 Submeasure A – Pipe Insulation Verification

The Statewide CASE Team collected data from multiple sources to determine current practice for pipe insulation installation, including a poll during the October 3, 2019 utility-sponsored stakeholder meeting, interviews with designers, designer punch lists from site visits, and an online survey distributed to designers and DHW subject matter experts. The Statewide CASE Team also reviewed the PIER Multifamily Central Domestic Hot Water (DHW) Distribution Systems Project (PIER 2013) that used field data to recommend de-rating of insulation U-factor in the current ACM Reference Manual. See Section 2.2.1 for a summary of data collection and Appendix G for detailed data collection results and analysis. The purpose of the analysis was to determine the proportion of uninsulated pipe in each prototype.

Insulation quality issues accounted for in the analysis include:

- Missing insulation on fittings, valves, pumps, and straight pipe

- Damaged and poorly installed insulation
- Metal hangers that are not thermally isolated from metal pipe

Table 13 shows the proportion of distribution system surface area and system length without insulation. The proportion of distribution system surface area is expressed in terms of the percentage of the entire distribution system (pipes, valves, fittings, pumps) surface area without insulation. The inputs in the model are based on surface area, however, Table 13 also shows the proportion of the length of the distribution system that is uninsulated as these values are more easily compared with real distribution systems.

Table 13. Proportion of Distribution System Surface Area and System Length without Insulation

	Low-Rise Garden	Low-Rise Loaded Corridor	Mid-Rise Mixed Use	High-Rise Mixed Use
Proportion of Distribution System Surface Area Without Insulation	15%	15%	13%	13%
Proportion of Distribution System Length Without Insulation	19%	19%	15%	15%

Source: Statewide CASE Team

Appendix G shows how the Statewide CASE Team developed the estimates shown in Table 13.

The Statewide CASE Team assumed that in the proposed case after verification has been completed, all pipe and piping specialties are insulated.

4.1.2 Submeasure B – Increased Insulation

Proposed pipe insulation requirements in Table 14, Table 15, Table 16, and Table 17 are applied to the appropriate pipe sections in the prototype buildings (see Appendix H). A summary of the pipe lengths and length of pipes impacted by increased insulation is shown in Table 14 through Table 17.

Table 14: Insulation Inputs for Low-Rise Garden Prototype Building

Pipe Size (inches)	Total Length in Prototype Design (feet)	Baseline Design Insulation Thickness (inches)	Proposed Design Insulation Thickness (inches)
2”	20	1.5	2
1.5”	58	1.5	1.5
1”	29	1.5	1.5

0.75”	150	1	1

Table 15: Insulation Inputs for Low-Rise Loaded Corridor Prototype Building

Pipe Size (inches)	Total Length in Prototype Design (feet)	Baseline Design Insulation Thickness (inches)	Proposed Design Insulation Thickness (inches)
3”	25	1.5	2
2.5”	90	1.5	2
2”	24	1.5	2
1.5”	153	1.5	1.5
1”	182	1.5	1.5
0.75”	404	1	1

Table 16: Insulation Inputs for Mid-Rise Mixed Use Prototype Building

Pipe Size (inches)	Total Length in Prototype Design (feet)	Baseline Design Insulation Thickness (inches)	Proposed Design Insulation Thickness (inches)
4”	53	1.5	2
3”	91	1.5	2
2.5”	73	1.5	2
2”	85	1.5	2
1.5”	829	1.5	1.5
1”	338	1.5	1.5
0.75”	744	1	1

Table 17: Insulation Inputs for High-Rise Mixed Use Prototype Building

Pipe Size (inches)	Total Length in Prototype Design (feet)	Baseline Design Insulation Thickness (inches)	Proposed Design Insulation Thickness (inches)
4”	9	1.5	2
3”	130	1.5	2
2.5”	165	1.5	2
2”	58	1.5	2
1.5”	782	1.5	1.5
1”	313	1.5	1.5
0.75”	953	1	1

4.1.3 Submeasure C – CPC Appendix M Pipe Sizing

Pipe sizes from prototype building plumbing designs summarized in Appendix H are used for energy savings analysis. A summary of pipes sizes comparing the baseline design pipe sizing (following CPC Appendix A) and proposed design pipe sizing (following CPC Appendix M) is in Table 11. Pipe insulation for both baseline and proposed analysis is based on the current ACM that references Title 24, Part 6 Table 120.3-A.

4.2 Energy Savings Methodology

4.2.1 Energy Savings Methodology per Prototypical Building

The Energy Commission directed the Statewide CASE Team to model the energy impacts using specific prototypical building models that represent typical building geometries for different types of buildings. The prototype buildings and DHW system designs that the Statewide CASE Team used in the analysis are presented in Table 18. Appendix H has a detailed description of the prototype building designs.

Table 18: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype Name	Number of Stories	Floor Area (square feet)	Description of DHW Recirculation System
Low-Rise Garden	2	7,680	8-unit residential building with a gas fired central domestic hot water heater serving a central recirculation loop. Water heater is located on one end the of building at the ground level. Distribution piping runs horizontally in ceiling of ground floor, vertically up four risers, and returns in the ceiling of the second floor.[9]
Low-Rise Loaded Corridor	3	40,000	36-unit residential building with a gas fired central DHW heater serving a central recirculation loop. Water heater is located in a mechanical room at the ground level. Distribution piping runs horizontally in ceiling of ground floor, vertically up 13 risers, and returns in the ceiling of the third floor.
Mid-Rise Mixed Use	5	113,100	88-unit building with 4-story residential + 1-story commercial. Gas fired central DHW heater serving dwelling units from a central recirculation loop. Water heater is located in a mechanical room at the ground level (retail level). Distribution piping runs horizontally in ceiling of second floor (first residential level), vertically up 22 risers, and returns in the ceiling of the fifth floor.
High-Rise Mixed Use	10	125,400	117-unit building with 9-story residential + 1-story commercial. Gas fired central DHW heater serving dwelling units from a central recirculation loop. Water heater is located on the roof. Distribution piping runs horizontally in ceiling of top floor, vertically down 26 risers. There are two pressure zones divided vertically, each with horizontal supply and return piping.

The Statewide CASE Team developed a custom spreadsheet calculator to analyze the energy impacts of the three DHW distribution submeasures. The spreadsheet calculator used pipe heat loss calculation methods defined in the existing 2019 ACM Reference Manual. Compared to CBECC-Res software, the spreadsheet calculator includes

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[9] This DHW Distribution CASE topic and the Central HPWH CASE topic are analyzing a central system in the Low-Rise Garden prototype. The Low-Rise Garden prototype for other CASE topics assumes individual water heaters for each dwelling unit.

features to handle detailed recirculation designs and operation. The overall modeling approach and specific features of the spreadsheet calculator are described in Section 4.2.1.1.

Following the same methods as CBECC-Com and CBECC-Res, the custom engineering spreadsheet calculation tool calculates DHW energy consumption for every hour of the year measured in kilowatt-hours per year (kWh/yr) and therms per year (therms/yr). It then applies the 2022 time-dependent-valuation (TDV) factors to calculate annual energy use in kilo British thermal units per year (TDV kBtu/yr) and annual peak electricity demand reductions measured in kilowatts (kW). The Statewide CASE Team followed the same method as CBECC-Com and CBECC-Res to generate TDV energy cost savings values measured in 2023 present value dollars (2023 PV$).

The energy impacts of the proposed code change vary by climate zone. The Statewide CASE Team analyzed the energy impacts in every climate zone and applied the climate-zone specific TDV factors when calculating energy and energy cost impacts.

Per-unit energy impacts for multifamily buildings are presented in savings per dwelling unit. Annual energy and peak demand impacts for each prototype building were translated into impacts per dwelling unit by dividing by the number of dwelling units in the prototype building. This step enables a calculation of statewide savings using the construction forecast discussed in Appendix A.

4.2.1.1 *Detailed Recirculation Heat Loss Spreadsheet Calculator*

The Statewide CASE Team developed a custom spreadsheet calculator to analyze the energy impacts of the three DHW distribution submeasures. The spreadsheet calculator used pipe heat loss calculation methods defined in the existing 2019 ACM Reference Manual. Compared to CBECC-Res software, the spreadsheet calculator includes features to handle detailed recirculation designs and operation. The overall modeling approach and specific features of the spreadsheet calculator are described in following sections.

Recirculation Network Configurations

The existing 2019 ACM Reference Manual and CBECC-Res software use six pipe sections connected in series to model recirculation systems. The six pipe section recirculation model was designed to simplify the compliance process by not requiring builders to specify detailed plumbing configurations in the compliance model.

As shown by prototype buildings plumbing designs in Appendix H, actual recirculation designs are much more complicated. CBECC-Res software provides a practical recirculation performance model for compliance but is not adequate to model complicated recirculation designs. Having realistic recirculation designs enables accurate assessment of energy impacts of proposed measures. For this reason, the

Statewide CASE Team created the spreadsheet calculator which uses detailed and full recirculation piping configurations to perform energy impact analysis.

Full recirculation piping models use the same overall approach as the six pipe section compliance models to specify recirculation configurations. In this approach, a recirculation pipe network is represented by a collection of pipe sections connected to each other. Full recirculation piping models do not limit the number of pipe sections and allow parallel flow paths (e.g., those through vertical risers). Full recirculation piping models used for CASE analyses reflect actual recirculation piping layout without modifications. As shown by recirculation system designs presented in Appendix H, starting from the central water heater plant and following the recirculation flow paths, the recirculation system splits into pipe sections – via major pipe connectors – into parallel paths, and leads to pipe branches into individual dwelling units. The individual unit return pipes then merge back into parallel recirculation flows and ultimately funnel back into recirculation return pipes. In the spreadsheet model, pipe sections and major pipe connectors are identified by unique indices. The number of unique pipe sections for the four prototype buildings are as follows:

Low-Rise Garden: 12 pipe sections

Low-Rise Loaded Corridor: 57 pipe sections

Mid-Rise Mixed Use: 112 pipe sections

High-Rise Mixed Use: 138 pipe sections

Specifications of each pipe section include pipe size (diameter), length, insulation thickness, index of the beginning pipe connector, and index of the ending pipe connector. The spreadsheet calculator uses specifications of the beginning and ending pipe connectors of all pipe sections to determine the recirculation network topology. Some pipe connectors are connected to a branch pipe leading to hot water fixtures in a dwelling unit. These pipe connectors have a hot water draw schedule. The calculator determines flow rate for each pipe section based on the recirculation network topology, recirculation pump operation status, and hot water schedules of pipe connectors.

Calculation Steps

For each time step, the calculator starts pipe section analysis from the first pipe section, the supply pipe connected to the central water heater, to obtain pipe heat loss, output water temperature, and average pipe temperature at the end of the time step. The output water temperature is then used as the input water temperature for the downstream pipe section(s). A pipe section analysis is performed for each pipe section following recirculation flow paths.

According to the 2019 ACM Reference Manual, recirculation pipes can have two modes of heat loss: pipe heat loss *with* hot water flow in the pipe and heat loss *without* flow in the pipe. The latter is also called cooldown mode, and it takes place when the recirculation pump is turned off by a control and there is no hot water draw by users. When there is flow in the pipe section, due to recirculation operation and/or hot water draws, pipe heat loss is calculated according to the ACM Reference Manual for pipe heat loss with flows. If there is no flow in the pipe section, pipe heat loss is calculated according to the ACM Reference Manual for pipe cooldown process. Average pipe temperature at the end of time step is used as the initial pipe temperature for the next time step of pipe section analysis.

The 2019 ACM Reference Manual dictates that the refence recirculation system design include a demand recirculation control, which keeps the recirculation pump off for 80 percent of the time for each hour. Following this ACM Reference Manual specification, the spreadsheet calculator performs two steps of calculation for each hour: first step of 12 minutes with recirculation flows and second step of 48 minutes without the recirculation flow.

Hot Water Draw Schedules

CBECC-Res software provides ten sets of annual fixture water use schedules for six types of multifamily dwelling units: studio and one-bedroom to five-bedroom units. These draw schedules were used to develop hot water draw schedules for the four prototype buildings in the following steps.

First, CBECC-Res annual fixture water use schedules are converted to annual hot water draw schedules. CBECC-Res annual fixture water use schedules specify the combined hot and cold water mixture flow rate for each draw event. The Statewide CASE Team generated hot water draw schedules by calculating hot water flow rate according to the following assumptions used by the CBECC-Res software regarding cold and hot water mixing for different fixture types:

- All faucet draws include 50 percent hot water
- All draws from clothes washing machines include 22 percent hot water
- All draws from showers and bathtubs have a mixed water temperature of 105°F. Corresponding hot water flow is calculated based on the hot water supply temperature (125°F) and cold-water or mains temperature (obtained from CBECC-Res weather files)

As cold-water temperature changes, showers and bathtubs require different hot water flow rates to maintain the fixture output temperature to be at 105°F. Because the 16 climate zones have different cold-water temperatures, they have slightly different hot water flow rates for shower and bathtub use events, even though fixture flow rates are the same for these events among all climate zones. The difference can be up to 20 percent. However, because shower and bathtub hot water draw volumes represent approximately one third of the total hot water use, the differences in hourly hot water flows among the 16 climate zones are much smaller. Also, the impact of hot water flow rate on pipe heat loss is a secondary factor compared to the primary factors of hot water temperature and ambient temperature. Also, when there is a recirculation flow, the influence of hot water draw flow rate is negligible. Therefore, differences in shower and bathtub flow rates among the 16 climate zones have little impact on recirculation system heat loss.

Second, for each dwelling unit, one hot water draw schedule is randomly designated from the ten hot water draw schedules for the corresponding dwelling unit type. This is done for every dwelling unit in the prototype buildings.

Third, the selected hot water draw schedule is converted to be aligned with the time steps used by the spreadsheet calculator. Each hour includes two time steps of 12 minutes with the pump on and 48 minutes with the pump off. Annual hot water draw schedules developed in the prior step provide sequences of individual hot water draw events. As explained in the prior section, the calculator performs two steps of calculation for each hour; therefore, it needs average hot water draw flow rates for each time step, not hot water flow rate of individual draw events. The calculation procedure to generate average hot water draw flow rates uses the following steps:

1. For each hour, total hot water volume was calculated by summing up hot water draw volumes of all draw events within the hour.
2. Determine if all hot water draws occur during the 12-minute time step when the recirculation pump is turned on. Since hot water draws are relatively random and it is much more likely hot water draws occur during both pump-on and pump-off periods, the Statewide CASE Team assumed that there was a 20 percent chance that all draws occur during the pump-on time step and 80 percent chance that hot water draws occurs during both time steps of the hour. A random number generator was used to determine which of these two scenarios would occur for each hour. The energy savings impact of this assumption is small because the same assumption is applied in the baseline and proposed cases.
3. If all hot water draws occur during the 12-minute pump-on time step, the total hot water volume was allocated this time step and the average flow rate was calculated as total hot water volume divided by 12 minutes. For the 48-minute pump-off time step, the draw flow rate was zero.
4. If hot water draws occurred during both time steps, they would have the same average flow rate, which was calculated as total hot water volume divided by 60 minutes.

The calculation results showed that that recirculation flows are usually much larger than average hot water flow rates[10]. Therefore, pipe section performance during the pump-on time step is not sensitive to hot water draw schedules. For all prototype buildings, the baseline recirculation design and proposed recirculation designs have the same hot water draw schedule for each time step of calculation. Therefore, assumptions on alignment between hot water draws and recirculation pump operation have a secondary effect on energy savings estimation.

Recirculation System Impact on Natural Gas Use

For each time step, total recirculation system pipe heat loss is the sum of pipe heat loss from all pipe sections. Hourly recirculation system pipe heat loss was obtained by summing up results of the pump-on and pump-off time steps. Based on the ACM Reference Manual, recirculation system impact on system natural gas consumption is calculated by dividing hourly recirculation system pipe heat loss by the thermal efficiency of the central water heater or boiler, which was assumed to be 80 percent per minimum efficiency required by the California Appliance Efficiency Standards (Title 20).

Treatment of Climate Zones

Weather conditions affect recirculation system performance in two ways. First, as discussed in 4.2.1.1 Hot Water Draw Schedules, differences in cold-water temperature lead to different hot water flow rates for shower and bathtub draws because a different amount of hot water is needed for mixing with the cold-water to achieve the same fixture output temperature of 105°F. As discussed in that section, the resulting hot water flow rate differences have negligible impact on overall recirculation distribution heat loss. Second, weather conditions indirectly affect the ambient indoor temperature surrounding recirculation pipes due to differences in indoor temperature during heating mode and cooling mode. Indoor temperature calculations are discussed in Section 4.1.

For each prototype multifamily building, the Statewide CASE Team calculated recirculation system performance for the baseline design, three pipe insulation improvement scenarios, two pipe insulation verification scenarios, and improved design using CPC Appendix M Pipe Sizing method, totaling 24 design scenarios among all four prototype multifamily buildings. If modeling analyses were performed for all 24 design scenarios in all 16 climate zones, 384 model runs would be needed. The recirculation model for the low-rise prototype is relatively simple and takes approximately four hours

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[10] The recirculation flow is 0.5 gpm per riser and hot water draws vary though a wide range. The annual building hot water use patterns used for this analysis are based on CSE draw schedules. The percentage of hours with average draw flow rate less than 20% of the recirculation flow rate is approximately: 87% for low-rise garden, 79% for low-rise loaded corridor, 72% for mid-rise mixed use, and 84% for high-rise mixed use.

to complete, while the recirculation model for the high-rise prototype is much more complicated and takes approximately 12 hours to complete. With an average runtime of six hours per performance scenario, it would require 2304 hours or 96 days of computing time to complete all simulation runs.

The Statewide CASE Team found that this process could be greatly simplified. The Statewide CASE Team calculated performance for all scenarios of all submeasures and prototypes in Climate Zones 3, 9, and 12, which represents mild, heating-dominated, and balanced heating and cooling climate zones, and found that the ratios of recirculation performance, in both Btu and TDV Btu, between a design scenario and the corresponding baseline are nearly identical among the three climate zones. For example, the ratio energy use for Submeasure B – Increased Insulation to the baseline energy use in the low-rise garden prototype is 0.985447 in Climate Zone 3, 0.985466 in Climate Zone 9, and 0.985449 in Climate Zone 12. The differences between these ratios are negligible because recirculation ambient temperature has the same level of impact on all design scenarios. In other words, climate zone and indoor ambient temperatures have very small impact on percentage energy reduction of a design improvement. Therefore, for other climate zones, the Statewide CASE Team modeled the performance of the baseline design and used the ratios calculated from Climate Zone 3, models to determine performance for other design scenarios. For example, building on the example above, for the low-rise garden prototype Increased Insulation submeasure, 0.985447 was multiplied by the simulated baseline energy use for that climate zone to obtain the proposed energy use.

4.2.1.2 *Submeasure A: Pipe Insulation Verification*

The proposed design was identical to the standard design in all ways except for the revisions that represent the proposed changes to the code. Table 19 presents the parameters that were modified, and the values used in the standard design and proposed design. Specifically, the proposed conditions assume perfect insulation.

Comparing the energy impacts of the standard design to the proposed design reveals the impacts of the proposed code change relative to a building that has typical pipe insulation quality.

Table 19: Modifications Made to Standard Design in Each Prototype to Simulate Proposed Code Change

Prototype ID	Climate Zone	Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value - Pipe Insulation Verification
Low-Rise Garden	All	Insulation level	19% pipe surface area with imperfect insulation	0% pipe surface area with imperfect insulation

Mid-Rise Low-Rise Loaded Corridor	All	Insulation level	19% pipe surface area with imperfect insulation	0% pipe surface area with imperfect insulation
Mid-Rise Mixed Use	All	Insulation level	15% pipe surface area with imperfect insulation	0% pipe surface area with imperfect insulation
High-Rise Mixed Use	All	Insulation level	15% pipe surface area with imperfect insulation	0% pipe surface area with imperfect insulation

4.2.1.3 *Submeasure B: Increased Insulation*

The proposed design was identical to the standard design in all ways except for the revisions that represent the proposed changes to the code. Table 20 presents the parameters that were modified, and the values used in the standard design and proposed design. Specifically, the proposed conditions increase pipe insulation on pipes two inches in diameter and greater from one and a half to two inches of insulation, as shown in Table 21. The Statewide CASE Team also investigated the possibility of even thicker insulation requirements on pipes two and a half inches in diameter and larger. However, the Statewide CASE Team found the thicker insulation to not be cost effective, largely because pipe insulation thicker than two inches is not commonly available and is achieved by layering two pieces of insulation on top of each other, which significantly increases the cost.

Comparing the energy impacts of the standard design to the proposed design reveals the impacts of the proposed code change relative to a building that is minimally compliant with the 2019 Title 24, Part 6 requirements.

Table 20: Modifications Made to Standard Design in Each Prototype to Simulate Proposed Code Change

Prototype ID	Climate Zone	Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value - Increased Insulation
Low-Rise Garden	All	Pipe Insulation level	Per 2019 Title 24 requirements, Table 120.3-A	See Table 21
Mid-Rise Low-Rise Loaded Corridor	All	Pipe Insulation level	Per 2019 Title 24 requirements, Table 120.3-A	See Table 21

Mid-Rise Mixed Use	All	Pipe Insulation level	Per 2019 Title 24 requirements, Table 120.3-A	See Table 21
High-Rise Mixed Use	All	Pipe Insulation level	Per 2019 Title 24 requirements, Table 120.3-A	See Table 21

Table 21: Required Insulation Thickness by Pipe Diameter

Pipe Size	Baseline (Title 24, Part 6 Table 120.3-A)	Proposed
3/8"	1"	1"
1/2"	1"	1"
3/4"	1"	1"
1"	1.5"	1.5"
1.5"	1.5"	1.5"
2"	1.5"	2"
2.5"	1.5"	2"
3"	1.5"	2"
≥ 4"	1.5"	2"

4.2.1.4 *Submeasure C: CPC Appendix M Pipe Sizing*

The proposed design was identical to the standard design in all ways except for the revisions that represent the proposed changes to the code. Table 22 presents which parameters were modified and what values were used in the standard design and proposed design. Specifically, the proposed conditions assume pipes sized according to CPC Appendix M. Pumping energy is assumed to be identical in the standard design and proposed design because appendix M sizing does not impact return pipe sizing or recirculation flow, the two parameters that determine pump energy use (e.g. the return pipes and recirculation flow are identical for the standard and proposed design). Insulation thickness is based on current code, Title 24 Part 6 Table 120.3-A.

Comparing the energy impacts of the standard design to the proposed design reveals the impacts of the proposed code change relative to a building that follows industry typical practices.

Table 22: Modifications Made to Standard Design in Each Prototype to Simulate Proposed Code Change

Prototype ID	Climate Zone	Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value – Appendix M Sizing
Low-Rise Garden	All	Pipe Diameter	Per CPC Appendix A	Smaller pipe size shown in prototype layouts in Appendix H (summarized in Table 11)
Low-Rise Loaded Corridor	All	Pipe Diameter	Per CPC Appendix A	Smaller pipe size shown in prototype layouts in Appendix H (summarized in Table 11)
Mid-Rise Mixed Use	All	Pipe Diameter	Per CPC Appendix A	Smaller pipe size shown in prototype layouts in Appendix H (summarized in Table 11)
High-Rise Mixed Use	All	Pipe Diameter	Per CPC Appendix A	Smaller pipe size shown in prototype layouts in Appendix H (summarized in Table 11)

4.2.2 Statewide Energy Savings Methodology

The per-unit energy impacts were extrapolated to statewide impacts using the Statewide Construction Forecasts provided by the Energy Commission (California Energy Commission n.d.). The Statewide Construction Forecasts estimate new construction that will occur in 2023, the first year that the 2022 Title 24, Part 6 requirements are in effect. It also estimates the size of the total existing building stock in 2023 that the Statewide CASE Team used to approximate savings from building alterations. The construction forecast provides construction (new construction and existing building stock) by building type and climate zone. The building types used in the construction forecast, Building Type ID, are not identical to the prototypical building types available in CBECC-Res, so the Energy Commission provided guidance on which prototypical buildings to use for each Building Type ID when calculating statewide energy impacts. Table 23 presents the prototypical buildings and weighting factors that the Energy Commission requested the Statewide CASE Team use for each Building Type ID in the Statewide Construction Forecast.

Appendix A presents additional information about the methodology and assumptions used to calculate statewide energy impacts.

Table 23: Residential Building Types and Associated Prototype Weighting

Building Type ID from Statewide Construction Forecast	Building Prototype for Energy Modeling	Weighting Factors for Statewide Impacts Analysis
Multifamily	Low-Rise Garden	4%
	Low-Rise Loaded Corridor	33%
	Mid-Rise Mixed Use	58%
	High-Rise Mixed Use	5%

4.3 Per-Unit Energy Impacts Results

Energy savings per dwelling unit are presented in

Table 26 through Table 38 shown in Section 4.3.1 through 4.3.3 for each prototype building and each submeasure. Each measure has an impact on natural gas usage but no impact on electricity usage or peak electricity demand. The savings results are all from new construction, with no savings assumed from alterations. The per-unit energy savings figures do not account for naturally occurring market adoption or compliance rates.

In general, climate zones with more hours in heating mode have on-average lower indoor air temperatures, and therefore have higher DHW distribution system heat loss. Among the climate zones, Climate Zone 1 has the most hours in heating mode and the lowest average indoor temperature, and Climate Zone 15 has the least hours in heating mode and the highest average indoor temperature, as shown in Table 12. Accordingly, as shown in

Table 26 through Table 38, Climate Zone 1 has the highest energy savings for each submeasure in each prototype, with Climate Zone 15 having the lowest energy savings.

Additionally, energy savings per dwelling unit tend to decrease as the size of the prototype increases, i.e., high-rise has the lowest savings per dwelling unit and low-rise garden has the highest energy savings per dwelling unit. This effect is due to the ratio of distribution system surface area to the number of dwelling units. Table 24 shows that the low-rise garden has the highest distribution system surface area per dwelling unit and that high-rise mixed use has the lowest. Since the energy savings from this measure are closely tied to distribution system length and surface area, the relative energy savings when compared between prototypes follows the same order as distribution system surface area per dwelling unit. Building level energy savings results are as expected with high-rise having the most savings, followed by mid-rise, low-rise loaded corridor, and low-rise garden.

None of the submeasures have electricity or peak demand savings.

Table 24: Distribution System Surface Area per Dwelling Unit

	Distribution System Surface Area (square inches)	Dwelling Units	Surface Area per Dwelling Unit
Low-Rise Garden	21,094	8	2,637
Low-Rise Loaded Corridor	77,130	36	2,143
Mid-Rise Mixed Use	196,510	88	2,233
High-Rise Mixed Use	214,540	117	1,834

4.3.1 Submeasure A: Pipe Insulation Verification

Energy savings per dwelling unit for Submeasure A: Pipe Insulation Verification are presented in

Table 26 through for each prototype building. Per-dwelling unit savings for the first year are expected to range from 5.6 to 10.0 therms per year depending upon climate zone and multifamily building type.

In addition to the trends by building prototype noted in section 4.3, the Statewide CASE Team also correlated energy savings per dwelling unit to the ratio of the fittings and valves to the length of straight pipe, shown in Table 25. Table 25 along with the energy savings results in

Table 26 through show that energy savings increase with increasing percentage of distribution system surface area comprised by piping specialties.

Table 25: Percentage of Distribution System Surface Area Comprised of Piping Specialties by Prototype

	Piping Specialty Surface Area (square inches)	Total Distribution System Surface Area (square inches)	Percent of Distribution System Surface Area Comprised by Piping specialties
Low-Rise Garden	2,028	21,094	9.6%
Low-Rise Loaded Corridor	6,763	77,130	8.8%
Mid-Rise Mixed Use	11,605	196,510	5.9%
High-Rise Mixed Use	15,618	214,540	7.3%

Table 26: First-Year Energy Impacts Per Dwelling Unit – Low-Rise Garden

Climate Zone	Electricity Savings (kWh/Dwelling Unit)	Peak Electricity Demand Reductions (kW/Dwelling Unit)	Natural Gas Savings (therms/Dwelling Unit)	TDV Energy Savings (TDV kBtu/Dwelling Unit)
1	0	0	10.0	3,283
2	0	0	9.1	3,006
3	0	0	9.2	3,027
4	0	0	9.0	2,974
5	0	0	9.6	3,163
6	0	0	8.9	2,936
7	0	0	8.7	2,871
8	0	0	8.7	2,857
9	0	0	8.7	2,875
10	0	0	8.8	2,898
11	0	0	9.0	2,956
12	0	0	9.0	2,952
13	0	0	8.9	2,930
14	0	0	8.9	2,945
15	0	0	8.2	2,711
16	0	0	9.2	3,039

Table 27: First-Year Energy Impacts Per Dwelling Unit – Low-Rise Loaded Corridor

Climate Zone	Electricity Savings (kWh/Dwelling Unit)	Peak Electricity Demand Reductions (kW/Dwelling Unit)	Natural Gas Savings (therms/Dwelling Unit)	TDV Energy Savings (TDV kBtu/Dwelling Unit)
1	0	0	7.0	2,301
2	0	0	6.4	2,107
3	0	0	6.5	2,121
4	0	0	6.3	2,085
5	0	0	6.8	2,217
6	0	0	6.2	2,058
7	0	0	6.1	2,012
8	0	0	6.1	2,002
9	0	0	6.1	2,014
10	0	0	6.2	2,031
11	0	0	6.3	2,072
12	0	0	6.3	2,069
13	0	0	6.2	2,054
14	0	0	6.3	2,064
15	0	0	5.8	1,900
16	0	0	6.5	2,130

Table 28: First-Year Energy Impacts Per Dwelling Unit – Mid-Rise Mixed Use

Climate Zone	Electricity Savings (kWh/Dwelling Unit)	Peak Electricity Demand Reductions (kW/Dwelling Unit)	Natural Gas Savings (therms/Dwelling Unit)	TDV Energy Savings (TDV kBtu/Dwelling Unit)
1	0	0	8.0	1,922
2	0	0	7.3	1,760
3	0	0	7.4	1,772
4	0	0	7.2	1,741
5	0	0	7.7	1,852
6	0	0	7.1	1,719
7	0	0	7.0	1,681
8	0	0	6.9	1,673
9	0	0	7.0	1,689
10	0	0	7.0	1,696
11	0	0	7.2	1,730
12	0	0	7.2	1,730
13	0	0	7.1	1,715
14	0	0	7.1	1,724
15	0	0	6.6	1,587
16	0	0	7.4	1,779

Table 29: First-Year Energy Impacts Per Dwelling Unit – High-Rise Mixed Use

Climate Zone	Electricity Savings (kWh/Dwelling Unit)	Peak Electricity Demand Reductions (kW/Dwelling Unit)	Natural Gas Savings (therms/Dwelling Unit)	TDV Energy Savings (TDV kBtu/Dwelling Unit)
1	0	0	6.8	1,637
2	0	0	6.2	1,499
3	0	0	6.3	1,509
4	0	0	6.1	1,483
5	0	0	6.6	1,577
6	0	0	6.1	1,464
7	0	0	5.9	1,431
8	0	0	5.9	1,424
9	0	0	5.9	1,439
10	0	0	6.0	1,445
11	0	0	6.1	1,474
12	0	0	6.1	1,471
13	0	0	6.0	1,461
14	0	0	6.1	1,469
15	0	0	5.6	1,352
16	0	0	6.8	1,637

4.3.2 Submeasure B: Increased Insulation

Energy savings per dwelling unit for Submeasure B: Increased Insulation are presented in Table 30 through Table 33 for each prototype building. Per-dwelling unit savings for the first year are expected to range from 0.4 to 0.9 therms per year depending upon climate zone and multifamily building type.

In addition to the trends by building prototype noted in Section 4.3, the Statewide CASE Team also correlated energy savings per dwelling unit to the number of pipes impacted by the measure. The Low-Rise Garden protype has very few pipes with diameter two inches and greater, therefore very few pipes that are impacted by this measure, and therefore has less energy savings at the building level than the other prototypes.

Several factors influence the per unit energy savings including pipe surface area affected by the proposed code change, number of units per prototype, the square footage of those units, as well as compactness of the distribution system (estimated to be square footage of distribution system area per dwelling unit). These factors sometimes have competing effects on the per dwelling unit savings, meaning some raise the per unit savings while some lower the per unit savings. These effects are discussed in more detail in Section 4.3.

Table 30: First-Year Energy Impacts Per Dwelling Unit – Low-Rise Garden

Climate Zone	Electricity Savings (kWh/Dwelling Unit)	Peak Electricity Demand Reductions (kW/Dwelling Unit)	Natural Gas Savings (therms/Dwelling Unit)	TDV Energy Savings (TDV kBtu/Dwelling Unit)
1	0	0	0.5	152
2	0	0	0.4	139
3	0	0	0.4	140
4	0	0	0.4	137
5	0	0	0.4	146
6	0	0	0.4	136
7	0	0	0.4	133
8	0	0	0.4	132
9	0	0	0.4	133
10	0	0	0.4	134
11	0	0	0.4	136
12	0	0	0.4	136
13	0	0	0.4	135
14	0	0	0.4	136
15	0	0	0.4	125
16	0	0	0.4	140

Table 31: First-Year Energy Impacts Per Dwelling Unit – Low-Rise Loaded Corridor

Climate Zone	Electricity Savings (kWh/Dwelling Unit)	Peak Electricity Demand Reductions (kW/Dwelling Unit)	Natural Gas Savings (therms/Dwelling Unit)	TDV Energy Savings (TDV kBtu/Dwelling Unit)
1	0	0	0.9	279
2	0	0	0.8	255
3	0	0	0.8	257
4	0	0	0.8	253
5	0	0	0.8	268
6	0	0	0.8	249
7	0	0	0.7	244
8	0	0	0.7	243
9	0	0	0.7	244
10	0	0	0.7	246
11	0	0	0.8	251
12	0	0	0.8	251
13	0	0	0.8	249
14	0	0	0.8	250
15	0	0	0.7	230
16	0	0	0.8	258

Table 32: First-Year Energy Impacts Per Dwelling Unit – Mid-Rise Mixed Use

Climate Zone	Electricity Savings (kWh/Dwelling Unit)	Peak Electricity Demand Reductions (kW/Dwelling Unit)	Natural Gas Savings (therms/Dwelling Unit)	TDV Energy Savings (TDV kBtu/Dwelling Unit)
1	0	0	0.8	191
2	0	0	0.7	175
3	0	0	0.7	176
4	0	0	0.7	173
5	0	0	0.8	184
6	0	0	0.7	171
7	0	0	0.7	167
8	0	0	0.7	166
9	0	0	0.7	168
10	0	0	0.7	169
11	0	0	0.7	172
12	0	0	0.7	172
13	0	0	0.7	171
14	0	0	0.7	172
15	0	0	0.7	158
16	0	0	0.7	177

Table 33: First-Year Energy Impacts Per Dwelling Unit – High-Rise Mixed Use

Climate Zone	Electricity Savings (kWh/Dwelling Unit)	Peak Electricity Demand Reductions (kW/Dwelling Unit)	Natural Gas Savings (therms/Dwelling Unit)	TDV Energy Savings (TDV kBtu/Dwelling Unit)
1	0	0	0.7	167
2	0	0	0.6	153
3	0	0	0.6	154
4	0	0	0.6	151
5	0	0	0.7	161
6	0	0	0.6	149
7	0	0	0.6	146
8	0	0	0.6	145
9	0	0	0.6	147
10	0	0	0.6	147
11	0	0	0.6	150
12	0	0	0.6	150
13	0	0	0.6	149
14	0	0	0.6	150
15	0	0	0.6	138
16	0	0	0.7	167

4.3.3 Submeasure C: CPC Appendix M Pipe Sizing

Energy savings per dwelling unit for Submeasure C: CPC Appendix M Pipe Sizing are presented in Table 34 through Table 38 for each prototype building. Per-dwelling unit savings for the first year are expected to range from 1.0 to 3.1 therms per year depending upon climate zone and multifamily building type.

In addition to the trends by building prototype noted in Section 4.3, the Statewide CASE Team also correlated energy savings per dwelling unit to the number of pipes impacted by the measure. As shown in Table 34, prototypes with a greater number of pipes with large diameters have a higher percentage of surface area reduction. Table 34 along with the energy savings results in Table 34 through Table 38 show that higher the surface area reduction leads to higher energy savings.

Table 34. Plumbing Design Summary and Comparison of Surface Area Reduction from Appendix M Pipe Sizing

	Pipe Lengths Using CPC Appendix A Sizing (Hunters Curve) (ft)				Pipe Lengths Using CPC Appendix M Sizing (IAPMO WDC) (ft)			
Pipe Diameter (inches)	Low-Rise Garden	Low-Rise Loaded Corridor	Mid-Rise Mixed Use	High-Rise Mixed Use	Low-Rise Garden	Low-Rise Loaded Corridor	Mid-Rise Mixed Use	High-Rise Mixed Use
4	0	0	53	9	0	0	0	0
3	0	25	91	130	0	0	0	5
2.5	0	90	73	165	0	0	121	129
2	20	24	85	58	0	80	66	80
1.5	58	153	829	782	52	107	244	148
1	29	182	338	313	55	287	1,058	1,095
0.75	150	404	744	953	150	404	724	953
Percent Surface Area Reduction for Each Prototype					**9%**	**14%**	**19%**	**20%**

Table 35: First-Year Energy Impacts Per Dwelling Unit – Low-Rise Garden

Climate Zone	Electricity Savings (kWh/Dwelling Unit)	Peak Electricity Demand Reductions (kW/Dwelling Unit)	Natural Gas Savings (therms/Dwelling Unit)	TDV Energy Savings (TDV kBtu/Dwelling Unit)
1	0	0	1.2	406
2	0	0	1.1	372
3	0	0	1.1	374
4	0	0	1.1	368
5	0	0	1.2	391
6	0	0	1.1	363
7	0	0	1.1	355
8	0	0	1.1	353
9	0	0	1.1	356
10	0	0	1.1	358
11	0	0	1.1	366
12	0	0	1.1	365
13	0	0	1.1	363
14	0	0	1.1	364

15	0	0	1.0	335
16	0	0	1.1	376

Table 36: First-Year Energy Impacts Per Dwelling Unit – Low-Rise Loaded Corridor

Climate Zone	Electricity Savings (kWh/Dwelling Unit)	Peak Electricity Demand Reductions (kW/Dwelling Unit)	Natural Gas Savings (therms/Dwelling Unit)	TDV Energy Savings (TDV kBtu/Dwelling Unit)
1	0	0	1.7	554
2	0	0	1.5	507
3	0	0	1.6	511
4	0	0	1.5	502
5	0	0	1.6	534
6	0	0	1.5	495
7	0	0	1.5	484
8	0	0	1.5	482
9	0	0	1.5	485
10	0	0	1.5	489
11	0	0	1.5	499
12	0	0	1.5	498
13	0	0	1.5	494
14	0	0	1.5	497
15	0	0	1.4	457
16	0	0	1.6	513

Table 37: First-Year Energy Impacts Per Dwelling Unit – Mid-Rise Mixed Use

Climate Zone	Electricity Savings (kWh/Dwelling Unit)	Peak Electricity Demand Reductions (kW/Dwelling Unit)	Natural Gas Savings (therms/Dwelling Unit)	TDV Energy Savings (TDV kBtu/Dwelling Unit)
1	0	0	2.8	681
2	0	0	2.6	624
3	0	0	2.6	628
4	0	0	2.6	617
5	0	0	2.7	656
6	0	0	2.5	609
7	0	0	2.5	596
8	0	0	2.5	593
9	0	0	2.5	598
10	0	0	2.5	601
11	0	0	2.5	613
12	0	0	2.5	613
13	0	0	2.5	608
14	0	0	2.5	611
15	0	0	2.3	562
16	0	0	2.6	631

Table 38: First-Year Energy Impacts Per Dwelling Unit – High-Rise Mixed Use

Climate Zone	Electricity Savings (kWh/Dwelling Unit)	Peak Electricity Demand Reductions (kW/Dwelling Unit)	Natural Gas Savings (therms/Dwelling Unit)	TDV Energy Savings (TDV kBtu/Dwelling Unit)
1	0	0	3.1	751
2	0	0	2.8	688
3	0	0	2.9	693
4	0	0	2.8	681
5	0	0	3.0	724
6	0	0	2.8	672
7	0	0	2.7	657
8	0	0	2.7	654
9	0	0	2.7	660
10	0	0	2.7	663
11	0	0	2.8	676
12	0	0	2.8	675
13	0	0	2.8	670
14	0	0	2.8	674
15	0	0	2.6	620
16	0	0	3.1	751

5. Cost and Cost-Effectiveness

5.1 Energy Cost Savings Methodology

Energy cost savings were calculated by applying the TDV energy cost factors to the energy savings estimates that were derived using the methodology described in Section 4.1. TDV is a normalized metric to calculate energy cost savings that accounts for the variable cost of electricity and natural gas for each hour of the year, along with how costs are expected to change over the period of analysis (30 years for residential measures and nonresidential envelope measures and 15 years for all other nonresidential measures). In this case, the period of analysis used is 30 years. The TDV cost impacts are presented in nominal dollars and in 2023 present value dollars and represent the energy cost savings realized over 30 years.

5.2 Energy Cost Savings Results

Per-unit energy cost savings for newly constructed buildings that are realized over the 30-year period of analysis are presented in 2023 dollars in Table 39 through

Table 50.

5.2.1 Submeasure A: Pipe Insulation Verification

Table 39 through Table 42 provide the 30-year TDV energy cost savings for pipe insulation verification.

Table 39: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction – Low-Rise Garden

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV $)	30-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 30-Year TDV Energy Cost Savings (2023 PV $)
1	$0	$568	$568
2	$0	$520	$520
3	$0	$524	$524
4	$0	$515	$515
5	$0	$547	$547
6	$0	$508	$508
7	$0	$497	$497
8	$0	$494	$494
9	$0	$497	$497
10	$0	$501	$501

11	$0	$511	$511
12	$0	$511	$511
13	$0	$507	$507
14	$0	$510	$510
15	$0	$469	$469
16	$0	$526	$526

Table 40: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - Low-Rise Loaded Corridor

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV $)	30-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 30-Year TDV Energy Cost Savings (2023 PV $)
1	$0	$398	$398
2	$0	$364	$364
3	$0	$367	$367
4	$0	$361	$361
5	$0	$383	$383
6	$0	$356	$356
7	$0	$348	$348
8	$0	$346	$346
9	$0	$348	$348
10	$0	$351	$351
11	$0	$358	$358
12	$0	$358	$358
13	$0	$355	$355
14	$0	$357	$357
15	$0	$329	$329
16	$0	$369	$369

Table 41: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - Mid-Rise Mixed Use

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV $)	30-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 30-Year TDV Energy Cost Savings (2023 PV $)
1	$0	$332	$332
2	$0	$304	$304
3	$0	$307	$307
4	$0	$301	$301
5	$0	$320	$320

6	$0	$297	$297
7	$0	$291	$291
8	$0	$289	$289
9	$0	$292	$292
10	$0	$293	$293
11	$0	$299	$299
12	$0	$299	$299
13	$0	$297	$297
14	$0	$298	$298
15	$0	$275	$275
16	$0	$308	$308

Table 42: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - High-Rise Mixed Use

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV $)	30-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 30-Year TDV Energy Cost Savings (2023 PV $)
1	$0	$283	$283
2	$0	$259	$259
3	$0	$261	$261
4	$0	$257	$257
5	$0	$273	$273
6	$0	$253	$253
7	$0	$248	$248
8	$0	$246	$246
9	$0	$249	$249
10	$0	$250	$250
11	$0	$255	$255
12	$0	$255	$255
13	$0	$253	$253
14	$0	$254	$254
15	$0	$234	$234
16	$0	$283	$283

5.2.2 Submeasure B: Increased Insulation

Table 43 through Table 50 provide the 30-year TDV energy cost savings for increased insulation.

Table 43: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction – Low-Rise Garden

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV $)	30-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 30-Year TDV Energy Cost Savings (2023 PV $)
1	$0	$26	$26
2	$0	$24	$24
3	$0	$24	$24
4	$0	$24	$24
5	$0	$25	$25
6	$0	$23	$23
7	$0	$23	$23
8	$0	$23	$23
9	$0	$23	$23
10	$0	$23	$23
11	$0	$24	$24
12	$0	$24	$24
13	$0	$23	$23
14	$0	$24	$24
15	$0	$22	$22
16	$0	$24	$24

Table 44: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - Low-Rise Loaded Corridor

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV $)	30-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 30-Year TDV Energy Cost Savings (2023 PV $)
1	$0	$48	$48
2	$0	$44	$44
3	$0	$44	$44
4	$0	$44	$44
5	$0	$46	$46
6	$0	$43	$43
7	$0	$42	$42
8	$0	$42	$42
9	$0	$42	$42
10	$0	$43	$43
11	$0	$43	$43
12	$0	$43	$43
13	$0	$43	$43
14	$0	$43	$43
15	$0	$40	$40
16	$0	$45	$45

Table 45: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - Mid-Rise Mixed Use

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV $)	30-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 30-Year TDV Energy Cost Savings (2023 PV $)
1	$0	$33	$33
2	$0	$30	$30
3	$0	$30	$30
4	$0	$30	$30
5	$0	$32	$32
6	$0	$30	$30
7	$0	$29	$29
8	$0	$29	$29
9	$0	$29	$29
10	$0	$29	$29
11	$0	$30	$30
12	$0	$30	$30
13	$0	$30	$30

14	$0	$30	$30
15	$0	$27	$27
16	$0	$31	$31

Table 46: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - High-Rise Mixed Use

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV $)	30-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 30-Year TDV Energy Cost Savings (2023 PV $)
1	$0	$29	$29
2	$0	$26	$26
3	$0	$27	$27
4	$0	$26	$26
5	$0	$28	$28
6	$0	$26	$26
7	$0	$25	$25
8	$0	$25	$25
9	$0	$25	$25
10	$0	$25	$25
11	$0	$26	$26
12	$0	$26	$26
13	$0	$26	$26
14	$0	$26	$26
15	$0	$24	$24
16	$0	$29	$29

5.2.3 Submeasure C: CPC Appendix M Pipe Sizing

Table 47 through Table 50 provide the 30-year TDV energy cost savings for increased insulation.

Table 47: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction – Low-Rise Garden

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV $)	30-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 30-Year TDV Energy Cost Savings (2023 PV $)
1	$0	$70	$70
2	$0	$64	$64
3	$0	$65	$65
4	$0	$64	$64
5	$0	$68	$68
6	$0	$63	$63
7	$0	$61	$61
8	$0	$61	$61
9	$0	$62	$62
10	$0	$62	$62
11	$0	$63	$63
12	$0	$63	$63
13	$0	$63	$63
14	$0	$63	$63
15	$0	$58	$58
16	$0	$65	$65

Table 48: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - Low-Rise Loaded Corridor

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV $)	30-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 30-Year TDV Energy Cost Savings (2023 PV $)
1	$0	$96	$96
2	$0	$88	$88
3	$0	$88	$88
4	$0	$87	$87
5	$0	$92	$92
6	$0	$86	$86
7	$0	$84	$84
8	$0	$83	$83
9	$0	$84	$84
10	$0	$85	$85
11	$0	$86	$86
12	$0	$86	$86
13	$0	$86	$86
14	$0	$86	$86
15	$0	$79	$79
16	$0	$89	$89

Table 49: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - Mid-Rise Mixed Use

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV $)	30-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 30-Year TDV Energy Cost Savings (2023 PV $)
1	$0	$118	$118
2	$0	$108	$108
3	$0	$109	$109
4	$0	$107	$107
5	$0	$114	$114
6	$0	$105	$105
7	$0	$103	$103
8	$0	$103	$103
9	$0	$104	$104
10	$0	$104	$104
11	$0	$106	$106

12	$0	$106	$106
13	$0	$105	$105
14	$0	$106	$106
15	$0	$97	$97
16	$0	$109	$109

Table 50: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - High-Rise Mixed Use

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV $)	30-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 30-Year TDV Energy Cost Savings (2023 PV $)
1	$0	$130	$130
2	$0	$119	$119
3	$0	$120	$120
4	$0	$118	$118
5	$0	$125	$125
6	$0	$116	$116
7	$0	$114	$114
8	$0	$113	$113
9	$0	$114	$114
10	$0	$115	$115
11	$0	$117	$117
12	$0	$117	$117
13	$0	$116	$116
14	$0	$117	$117
15	$0	$107	$107
16	$0	$130	$130

5.3 Incremental First Cost

Incremental first cost is the initial cost to adopt more efficient equipment or building practices when compared to the cost of an equivalent baseline project. Therefore, it was important that the Statewide CASE Team consider first costs in evaluating overall measure cost effectiveness. Incremental first costs are based on data available today and can change over time as markets evolve and professionals become familiar with new technology and building practices.

5.3.1 Submeasure A: Pipe Insulation Verification

The Statewide CASE Team estimated the pipe insulation verification first cost based on an interview with a HERS Raters manager on the verification process and associated labor hours. Because there is currently no prescriptive requirement for field verification of pipe insulation, there is no cost for this in the baseline.

The Statewide CASE Team interviewed a former manager of a HERS Raters team that worked on new construction and retrofit projects of single family, mid-rise multifamily, and high-rise multifamily buildings. The Statewide CASE Team inquired about the typical verification process, time estimates to verify buildings of different floor areas, whether the Raters would charge an hourly rate or a flat fee per site visit, how long verification of a DHW distribution system would take, and whether construction phasing is an issue that impacts the verification process.

The Statewide CASE Team developed expected costs based on the interview with the HERS Rater manager. The Statewide CASE Team assumed that the cost for the pipe insulation verification is based on the floor area over which the verification takes place and the number of pipe risers. The Statewide CASE Team also assumed that a HERS Rater or an ATT would conduct the verification, and assumed that the costs for HERS and ATT are comparable.

Based on the interview with the HERS Rater manager, the Statewide CASE Team assumed that a HERS Rater or ATT could verify 10,000 square feet of floor area in three and a half hours and would have a labor rate of $250 per hour.

The Statewide CASE Team estimated first costs for two verification options for this measure described below. Option 1 is used for cost effectiveness and statewide impacts analysis because sampling addresses concerns about coordinating inspections with construction sequencing. Option 2 costs are presented as an alternative verification requirement with increased stringency, for comparison:

- Option 1 (used for cost effectiveness and statewide impacts analysis):
    - Inspect all pipe insulation in the mechanical/boiler room where water heating equipment resides, or all outdoor pipes if water heater is outdoors.
    - Inspect all pipe insulation on horizontal distribution pipes that function as a supply header, up the point of connection with riser pipes. Supply header is piping between the water heater and vertical risers that run up or down the building.
    - Inspect a sample of pipe insulation on vertical pipe risers. The sample rate shall be one in two risers. Riser inspection shall include the entire vertical length of DHW recirculation riser pipe, including offsets and horizontal

    - portions of recirculation loop, up to the point of connection of the branch pipe (non-recirculating) to dwelling units.
- Option 2 (alternative option, not used for cost effectiveness and statewide impacts analysis)
    - Inspect 100 percent of the distribution system.

Table 51 shows the number of hours needed to verify each prototype for both verification options based on the assumption of the floor area a HERS Rater or ATT could verify in one hour and the number of risers.

Table 51: Total Verification Hours for Two Inspection Options by Prototype

Hours	Low-Rise Garden	Low-Rise Loaded Corridor	Mid-Rise	High-Rise
Option 1 – First Level of Piping with Sampling of Risers	2	8	13	11
Option 2 – 100 Percent Inspection	3	14	40	44

Source: Statewide CASE Team

In addition to the labor cost of the verification, the Statewide CASE Team assumed the HERS Rater or ATT would travel an average of 100 miles to the building for each trip required, at a mileage rate of $0.55. This results in a cost of $55 per trip. To determine the number of trips required for each verification option and prototype, the Statewide CASE Team calculated the total number of hours needed to verify a building based on the three and a half hours per 10,000 square feet estimate above in addition to assuming a HERS Rater/ATT would spend no more than five hours on site in a day. If nine hours were needed to verify a building, the Statewide CASE Team assumed two trips. Construction phasing is also a factor that could impact the number of trips required to complete an inspection. The Statewide CASE Team added an additional two trips per building to account for potential delays associated with construction phasing. Table 52 shows the number of trips required for each prototype and verification option.

Table 52: Number of Trips Required for Two Inspection Options Verification Options 1 and 2 by Prototype

	Low-Rise Garden	Low-Rise Loaded Corridor	Mid-Rise	High-Rise
Option 1 – First Level of Piping with Sampling of Risers	3	4	5	5
Option 2 – 100 Percent Inspection	3	5	10	11

Source: Statewide CASE Team

Table 53 shows the total verification cost by building prototype based on these assumptions. Note that the total verification cost listed is the same as the incremental cost because there is no cost for piping insulation verification in the baseline. Option one costs are largest for Mid-Rise Mixed Use prototype because it has the largest number of hot water pipe risers.

Table 53: Total Verification Cost of Two Inspection Options by Prototype

		Low-Rise Garden	Low-Rise Loaded Corridor	Mid-Rise	High-Rise
Option 1 -Sampling	Total Cost	$735	$2,181	$3,640	$2,997
	Average Cost per Dwelling Unit	$92	$61	$41	$26
Option 2 – 100% Inspection	Total Cost	$806	$3,720	$10,499	$11,578
	Average Cost per Dwelling Unit	$101	$103	$119	$99

Source: Statewide CASE Team

Incremental first costs for Option 1 are used for cost effectiveness and statewide impacts analysis.

5.3.2 Submeasure B: Increased Insulation

The Statewide CASE Team determined the incremental cost for adding different amounts of piping insulation to the existing baseline piping insulation requirements.

Table 54 shows the baseline and proposed piping insulation thickness requirements. The Statewide CASE Team considered two more stringent alternatives for increasing insulation thickness for pipes greater than two inches in diameter, and found both to not be cost effective. The Statewide CASE Team used plumbing designs of each building prototype to determine the total length of insulation of each pipe and insulation thickness in the baseline and proposed designs.

Table 54: Required Insulation Thickness by Pipe Size for Baseline and Proposed Designs

Pipe Size	Baseline (from Table 120.3)	Proposed
3/8"	1"	1"
1/2"	1"	1"
3/4"	1"	1"
1"	1.5"	1.5"
1.5"	1.5"	1.5"

2"	1.5"	2"
2.5"	1.5"	2"
3"	1.5"	2"
4"	1.5"	2"

The Statewide CASE Team requested insulation costs from a mechanical contracting firm for all pipe sizes and insulation thicknesses represented in Table 56. Table 55 gives a summary of the insulation material and labor cost per linear foot. As shown in Table 55, costs for insulation two inches and thicker are significantly higher than costs for insulation two inches and thinner. This is because insulation thicknesses greater than two inches are accomplished by installing two layers of insulation on top of each other. Note that Table 55 only shows costs for pipe sizes and insulation thicknesses that are either in the baseline or one of the proposed designs for the prototype buildings.

Table 55: Insulation Cost Per Linear Foot for Different Insulation Thicknesses

	Insulation Thickness					
Pipe Size	**1"**	**1.5"**	**2"**	**2.5"**	**3"**	**3.5"**
3/8"	$12.50	NA	NA	NA	NA	NA
1/2"	$13.25	NA	NA	NA	NA	NA
3/4"	$14.00	NA	NA	NA	NA	NA
1"	$14.75	$15.75	NA	NA	NA	NA
1.5"	NA	$18.00	$21.75	NA	NA	NA
2"	NA	$18.75	$23.00	$43.00	NA	NA
2.5"	NA	$19.75	$24.00	$46.00	NA	NA
3"	NA	$21.75	$26.00	$48.00	$59.75	NA
4"	NA	$23.75	$29.25	$58.00	$63.00	$65.00

The Statewide CASE Team calculated the total insulation material costs for the baseline and proposed cases based on the amount of piping at each thickness in each prototype building and the insulation cost per linear foot. In addition to these costs, the Statewide CASE Team added 20 percent for overhead and profit, based on an estimate from the mechanical contractor. The mechanical contractor noted that the overhead and profit margin may be lowered from 20 down to five percent depending upon market competitiveness. Table 56 shows the resulting total cost to insulate piping in each prototype building. Note that the Statewide CASE Team assumes that the increased pipe insulation would have additional material costs over the baseline, but no additional labor costs.

Table 56: Insulation Materials and Labor Cost Per Prototype for the Baseline and Proposed Requirements

	Baseline	Proposed	Total Incremental Cost	Average Incremental Cost per Dwelling Unit
Low-Rise Garden	$3,976	$4,061	$85	$10.63
Low-Rise Loaded Corridor	$14,048	$14,639	$591	$16.41
Mid-Rise Mixed Use	$36,935	$38,285	$1,350	$15.34
High-Rise Mixed Use	$39,735	$41,285	$1,550	$13.25

5.3.3 Submeasure C: CPC Appendix M Pipe Sizing

The Statewide CASE Team designed plumbing systems for each of the prototype buildings according to Hunter’s curve (baseline case) and CPC Appendix M (proposed case).

Based on the plumbing designs, the Statewide CASE Team calculated the total length of horizontal and vertical pipe for each pipe size for each prototype building in the baseline case and the proposed case. Table 57 and Table 58 give the total length of each pipe size for each of the prototype buildings.

Table 57: Total Length of Each Pipe Size for Hunter’s Curve Baseline Design (Feet)

Pipe Size	Low-Rise Garden		Low-Rise Loaded Corridor		Mid-Rise Mixed Use		High-Rise Mixed Use	
	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.
3/4"	114	36	287	117	524	220	628	325
1"	29	0	65	117	118	220	53	260
1.5"	58	0	153	0	389	440	392	390
2"	20	0	24	0	85	0	58	0
2.5"	0	0	90	0	73	0	165	0
3"	0	0	25	0	91	0	5	125
4"	0	0	0	0	53	0	4	5

Table 58: Total Length of Each Pipe Size for CPC Appendix M Proposed Design (Feet)

Pipe Size	Low-Rise Garden		Low-Rise Loaded Corridor		Mid-Rise Mixed Use		High-Rise Mixed Use	
	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.

3/4"	114	36	287	117	524	200	628	325
1"	55	0	170	117	418	640	445	650
1.5"	52	0	107	0	204	40	148	0
2"	0	0	80	0	66	0	80	0
2.5"	0	0	0	0	121	0	4	125
3"	0	0	0	0	0	0	0	5

The Statewide CASE Team received piping material costs and labor hours from a mechanical contractor as shown in Table 59 and Table 60. The material costs include the piping itself as well as piping supports and other installation materials. The labor hours are those to install the piping. The costs and hours differ for horizontal piping versus vertical piping, with horizontal piping having both higher material costs and labor hours due to horizontal piping hanger installation. The mechanical contractor also provided a labor rate of $100 per hour.

Table 59: Pipe Cost Per 100 Linear Feet - Horizontal

Pipe Size	Materials	Labor Hours	Labor Rate/hour	Total
3/8"	$681	18	$100	$2,481
1/2"	$681	18	$100	$2,481
3/4"	$681	18	$100	$2,481
1"	$839	18	$100	$2,639
1.5"	$1,263	18	$100	$3,063
2"	$1,769	18	$100	$3,569
2.5"	$2,426	24	$100	$4,826
3"	$3,134	24	$100	$5,534
4"	$5,485	28	$100	$8,285
5"	$14,437	35	$100	$17,937
6"	$14,437	35	$100	$17,937

Table 60: Pipe Cost Per 100 Linear Feet - Vertical

Pipe Size	Materials	Labor Hours	Labor Rate/hour	Total
3/8"	$389	10	$100	$1,389
1/2"	$389	10	$100	$1,389
3/4"	$389	10	$100	$1,389
1"	$547	10	$100	$1,547
1.5"	$971	10	$100	$1,971
2"	$1,477	10	$100	$2,477
2.5"	$2,134	16	$100	$3,734

3"	$2,842	16	$100	$4,442
4"	$5,194	20	$100	$7,194
5"	$14,146	27	$100	$16,846
6"	$14,146	27	$100	$16,846

Using the pipe lengths in Table 57 and the piping costs in Table 59 and Table 60, the Statewide CASE Team calculated the total piping costs in the baseline and the proposed for each prototype building. The Statewide CASE Team also calculated the total piping insulation costs for the baseline and proposed cases based on the baseline insulation costs shown in Table 55.

Because Appendix M (proposed case) sometimes leads to smaller pipe sizes than Hunter’s curve (baseline case), this is a cost saving measure, with the proposed case having a lower cost than the baseline case for all prototype buildings. Table 61 shows the total cost for Hunter’s curve and Appendix M sizing including insulation costs, and the total incremental cost for each prototype is shown in Table 62.

Table 61: Total Cost for Pipe Sizing According to Hunter's Curve (Baseline) and Appendix M (Proposed)

	Hunter's Curve			Appendix M		
	Material	**Labor**	**Total**	**Materials**	**Labor**	**Total**
Low-Rise Garden	$6,278	$4,338	$10,616	$5,106	$2,286	$7,392
Low-Rise Loaded Corridor	$23,375	$14,622	$37,997	$20,898	$13,932	$34,830
Mid-Rise Mixed Use	$62,784	$34,308	$97,092	$52,978	$33,520	$86,498
High-Rise Mixed Use	$66,335	$36,400	$102,735	$56,244	$35,344	$91,588

Table 62: Total Incremental Cost for Appendix M Pipe Sizing (Proposed)

	Materials	Labor	Total
Low-Rise Garden	($1,172)	($2,052)	($3,224)
Low-Rise Loaded Corridor	($2,478)	($690)	($3,168)
Mid-Rise Mixed Use	($9,806)	($788)	($10,594)
High-Rise Mixed Use	($10,091)	($1,056)	($11,147)

5.4 Incremental Maintenance and Replacement Costs

Incremental maintenance cost is the incremental cost of replacing the equipment or parts of the equipment, as well as periodic maintenance required to keep the equipment operating relative to current practices over the 30-year period of analysis. There are no replacement costs for submeasures A, B, and C because for all three submeasures, the expected useful life of the measure and the impacted equipment is longer than the period of analysis. The periodic maintenance costs for submeasures A, B, and C are all the same as for the standard case; therefore, there are no associated incremental costs.

5.4.1 Cost Effectiveness

This measure consists of three submeasures. Submeasure A: Pipe Insulation Verification proposes a prescriptive requirement, Submeasure B: Increased Insulation proposes a mandatory requirement, and Submeasure C: CPC Appendix M Pipe Sizing proposes a compliance option. As such, a cost analysis is required to demonstrate that Submeasure A and Submeasure B are cost effective over the 30-year period of analysis. A cost analysis is not necessary for Submeasure C because the measure is not proposed to be part of the baseline level of stringency.

The Energy Commission establishes the procedures for calculating cost effectiveness. The Statewide CASE Team collaborated with Energy Commission staff to confirm that the methodology in this report is consistent with their guidelines, including which costs were included in the analysis. The incremental first cost and incremental maintenance costs over the 30-year period of analysis were included. The TDV energy cost savings from natural gas savings were also included in the evaluation.

Design costs were not included nor were the incremental costs of code compliance verification.

According to the Energy Commission's definitions, a measure is cost effective if the benefit-to-cost (B/C) ratio is greater than 1.0. The B/C ratio is calculated by dividing the cost benefits realized over 30 years by the total incremental costs, which includes maintenance costs for 30 years. The B/C ratio was calculated using 2023 PV costs and cost savings.

Results of the per-unit cost-effectiveness analyses are presented in Table 63 through Table 70 for new construction for Submeasure A: Pipe Insulation Verification and Submeasure B: Increased Insulation. Cost-effectiveness results for Submeasure C: CPC Appendix M Pipe Sizing are not presented because this submeasure is a compliance option. Submeasure C has negative incremental cost (the proposed case costs less than the baseline case) and has energy cost savings, so is cost effective for all prototypes across all climate zones.

5.4.1.1 *Submeasure A: Pipe Insulation Verification*

Cost-effectiveness results per dwelling unit for Submeasure A: Pipe Insulation Verification are presented in Table 63 through Table 66. The proposed measure saves money over the 30-year period of analysis relative to existing conditions. The proposed code change is cost effective in every climate zone.

Table 63: 30-Year Cost-Effectiveness Summary Per Dwelling Unit – New Construction - Low-Rise Garden

Climate Zone	Benefits	Costs	Benefit-to-Cost Ratio
	2023 PV $ Energy Cost Savings + Other PV Savings per Dwelling Unit	Total Incremental PV Costs	
1	$567.89	$92	6.2
2	$519.98	$92	5.7
3	$523.62	$92	5.7
4	$514.54	$92	5.6
5	$547.14	$92	6.0
6	$507.84	$92	5.5
7	$496.61	$92	5.4
8	$494.26	$92	5.4
9	$497.32	$92	5.4
10	$501.28	$92	5.5
11	$511.31	$92	5.6
12	$510.64	$92	5.6
13	$506.91	$92	5.5
14	$509.54	$92	5.5
15	$469.03	$92	5.1
16	$525.77	$92	5.7

a. **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) three percent rate. Other PV savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes PV maintenance cost savings if PV of proposed maintenance costs is less than PV of current maintenance costs.

b. **Costs: Total Incremental Present Valued Costs:** Costs include incremental equipment, replacement, and maintenance costs over the period of analysis. Costs are discounted at a real (inflation-adjusted) three percent rate and if PV of proposed maintenance costs is greater than PV of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental PV costs, the B/C ratio is infinite.

Table 64: 30-Year Cost-Effectiveness Summary Per Dwelling Unit – New Construction - Low-Rise Loaded Corridor

Climate Zone	Benefits	Costs	Benefit-to-Cost Ratio
	2023 PV $ Energy Cost Savings + Other PV Savings per Dwelling Unit	Total Incremental PV Costs	
1	$398.04	$61	6.6
2	$364.46	$61	6.0
3	$367.00	$61	6.1
4	$360.64	$61	6.0
5	$383.49	$61	6.3
6	$355.95	$61	5.9
7	$348.08	$61	5.7
8	$346.43	$61	5.7
9	$348.50	$61	5.8
10	$351.35	$61	5.8
11	$358.38	$61	5.9
12	$357.89	$61	5.9
13	$355.29	$61	5.9
14	$357.14	$61	5.9
15	$328.75	$61	5.4
16	$368.52	$61	6.1

Table 65: 30-Year Cost-Effectiveness Summary Per Dwelling Unit – New Construction - Mid-Rise Mixed Use

Climate Zone	Benefits	Costs	Benefit-to-Cost Ratio
	2023 PV $ Energy Cost Savings + Other PV Savings per Dwelling Unit	Total Incremental PV Costs	
1	$332.47	$41	8.0
2	$304.43	$41	7.4
3	$306.55	$41	7.4
4	$301.24	$41	7.3
5	$320.32	$41	7.7
6	$297.32	$41	7.2
7	$290.75	$41	7.0
8	$289.37	$41	7.0
9	$292.16	$41	7.1
10	$293.48	$41	7.1
11	$299.35	$41	7.2
12	$299.26	$41	7.2
13	$296.77	$41	7.2
14	$298.31	$41	7.2
15	$274.60	$41	6.6
16	$307.82	$41	7.4

Table 66: 30-Year Cost-Effectiveness Summary Per Dwelling Unit – New Construction - High-Rise Mixed Use

Climate Zone	Benefits	Costs	Benefit-to-Cost Ratio
	2023 PV $ Energy Cost Savings + Other PV Savings per Dwelling Unit	Total Incremental PV Costs	
1	$283.15	$26	11.1
2	$259.26	$26	10.1
3	$261.07	$26	10.2
4	$256.55	$26	10.0
5	$272.80	$26	10.6
6	$253.21	$26	9.9
7	$247.61	$26	9.7
8	$246.43	$26	9.6
9	$248.97	$26	9.7
10	$249.94	$26	9.8
11	$254.94	$26	10.0
12	$254.53	$26	9.9
13	$252.74	$26	9.9
14	$254.05	$26	9.9
15	$233.86	$26	9.1
16	$283.15	$26	11.1

5.4.1.2 *Submeasure B: Increased Insulation*

Cost-effectiveness results per dwelling unit for Submeasure B: Increased Insulation are presented in Table 67 through Table 70. The proposed measure saves money over the 30-year period of analysis relative to existing conditions. The proposed code change is cost effective in every climate zone.

Table 67: 30-Year Cost-Effectiveness Summary Per Dwelling Unit – New Construction - Low-Rise Garden

Climate Zone	Benefits	Costs	Benefit-to-Cost Ratio
	2023 PV $ Energy Cost Savings + Other PV Savings per Dwelling Unit	Total Incremental PV Costs	
1	$26.22	$10.63	2.47
2	$24.01	$10.63	2.26
3	$24.17	$10.63	2.28
4	$23.75	$10.63	2.24
5	$25.26	$10.63	2.38
6	$23.44	$10.63	2.21
7	$22.93	$10.63	2.16
8	$22.82	$10.63	2.15
9	$22.96	$10.63	2.16
10	$23.14	$10.63	2.18
11	$23.60	$10.63	2.22
12	$23.57	$10.63	2.22
13	$23.40	$10.63	2.20
14	$23.52	$10.63	2.21
15	$21.65	$10.63	2.04
16	$24.27	$10.63	2.28

a. **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) three percent rate. Other PV savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes PV maintenance cost savings if PV of proposed maintenance costs is less than PV of current maintenance costs.

b. **Costs: Total Incremental Present Valued Costs:** Costs include incremental equipment, replacement, and maintenance costs over the period of analysis. Costs are discounted at a real (inflation-adjusted) three percent rate and if PV of proposed maintenance costs is greater than PV of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental PV costs, the B/C ratio is infinite.

Table 68: 30-Year Cost-Effectiveness Summary Per Dwelling Unit – New Construction - Low-Rise Loaded Corridor

Climate Zone	Benefits	Costs	Benefit-to-Cost Ratio
	2023 PV $ Energy Cost Savings + Other PV Savings per Dwelling Unit	Total Incremental PV Costs	
1	$48.21	$16.41	2.94
2	$44.15	$16.41	2.69
3	$44.45	$16.41	2.71
4	$43.68	$16.41	2.66
5	$46.45	$16.41	2.83
6	$43.11	$16.41	2.63
7	$42.16	$16.41	2.57
8	$41.96	$16.41	2.56
9	$42.21	$16.41	2.57
10	$42.56	$16.41	2.59
11	$43.41	$16.41	2.65
12	$43.35	$16.41	2.64
13	$43.03	$16.41	2.62
14	$43.26	$16.41	2.64
15	$39.82	$16.41	2.43
16	$44.64	$16.41	2.72

Table 69: 30-Year Cost-Effectiveness Summary Per Dwelling Unit – New Construction - Mid-Rise Mixed Use

Climate Zone	Benefits	Costs	Benefit-to-Cost Ratio
	2023 PV $ Energy Cost Savings + Other PV Savings per Dwelling Unit	Total Incremental PV Costs	
1	$33.08	$15.34	2.16
2	$30.29	$15.34	1.97
3	$30.50	$15.34	1.99
4	$29.97	$15.34	1.95
5	$31.87	$15.34	2.08
6	$29.58	$15.34	1.93
7	$28.93	$15.34	1.89
8	$28.79	$15.34	1.88
9	$29.07	$15.34	1.90
10	$29.20	$15.34	1.90
11	$29.78	$15.34	1.94
12	$29.77	$15.34	1.94
13	$29.53	$15.34	1.92
14	$29.68	$15.34	1.93
15	$27.32	$15.34	1.78
16	$30.62	$15.34	2.00

Table 70: 30-Year Cost-Effectiveness Summary Per Dwelling Unit – New Construction - High-Rise Mixed Use

Climate Zone	Benefits	Costs	Benefit-to-Cost Ratio
	2023 PV $ Energy Cost Savings + Other PV Savings per Dwelling Unit	Total Incremental PV Costs	
1	$28.87	$13.25	2.18
2	$26.43	$13.25	2.00
3	$26.62	$13.25	2.01
4	$26.16	$13.25	1.97
5	$27.81	$13.25	2.10
6	$25.82	$13.25	1.95
7	$25.25	$13.25	1.91
8	$25.13	$13.25	1.90
9	$25.38	$13.25	1.92
10	$25.48	$13.25	1.92
11	$25.99	$13.25	1.96
12	$25.95	$13.25	1.96
13	$25.77	$13.25	1.95
14	$25.90	$13.25	1.96
15	$23.84	$13.25	1.80
16	$28.87	$13.25	2.18

6. First-Year Statewide Impacts

6.1 Statewide Energy and Energy Cost Savings

The Statewide CASE Team calculated the first-year statewide savings for new construction by multiplying the per-unit savings, which are presented in Section 4.3, by assumptions about the percentage of newly constructed buildings that would be impacted by the proposed code. The statewide new construction forecast for 2023 is presented in Appendix A as are the Statewide CASE Team's assumptions about the percentage of new construction that would be impacted by the proposal (by climate zone and building type).

The first-year energy impacts represent the first-year annual savings from all buildings that were completed in 2023. The 30-year energy cost savings represent the energy cost savings over the entire 30-year analysis period. The statewide savings estimates do not take naturally occurring market adoption or compliance rates into account.

Sections 6.1.1 and 6.1.2 present the first-year statewide energy and energy cost savings from newly constructed buildings by climate zone for Submeasure A: Pipe Insulation Verification and Submeasure B: Increased Insulation, respectively. First-year statewide savings for Submeasure C: CPC Appendix M Pipe Sizing are not presented because this submeasure is a compliance option.

6.1.1 Submeasure A: Pipe Insulation Verification

Table 71: Statewide Energy and Energy Cost Impacts - New Construction

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023	First-Year[a] Electricity Savings	First-Year Peak Electrical Demand Reduction	First-Year Natural Gas Savings	30-Year Present Valued Energy Cost Savings
	(multifamily dwelling units)	(GWh)	(MW)	(MMTherms)	(PV$ million in 2023)
1	209	0	0	0.002	$0.07
2	1,241	0	0	0.009	$0.39
3	6,021	0	0	0.043	$1.93
4	3,137	0	0	0.022	$0.99
5	557	0	0	0.004	$0.19
6	2,659	0	0	0.018	$0.83
7	2,859	0	0	0.019	$0.87
8	3,739	0	0	0.025	$1.13

9	8,778	0	0	0.059	$2.68
10	3,101	0	0	0.021	$0.95
11	885	0	0	0.006	$0.28
12	4,999	0	0	0.035	$1.56
13	1,459	0	0	0.010	$0.45
14	663	0	0	0.005	$0.21
15	432	0	0	0.003	$0.12
16	268	0	0	0.002	$0.09
Total	41,006	0	0	0.283	$12.72

a. First-year savings from all buildings completed statewide in 2023.

6.1.2 Submeasure B: Increased Insulation

Table 72: Statewide Energy and Energy Cost Impacts - New Construction

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023	First-Year[a] Electricity Savings	First-Year Peak Electrical Demand Reduction	First-Year Natural Gas Savings	30-Year Present Valued Energy Cost Savings
	(multifamily dwelling units)	(GWh)	(MW)	(MMTherms)	(million 2023 PV$)
1	209	0	0	0.0002	$0.01
2	1,241	0	0	0.0009	$0.04
3	6,021	0	0	0.0044	$0.20
4	3,137	0	0	0.0022	$0.10
5	557	0	0	0.0004	$0.02
6	2,659	0	0	0.0019	$0.09
7	2,859	0	0	0.0020	$0.09
8	3,739	0	0	0.0026	$0.12
9	8,778	0	0	0.0061	$0.28
10	3,101	0	0	0.0022	$0.10
11	885	0	0	0.0006	$0.03
12	4,999	0	0	0.0036	$0.16
13	1,459	0	0	0.0010	$0.05
14	663	0	0	0.0005	$0.02
15	432	0	0	0.0003	$0.01
16	268	0	0	0.0002	$0.01
Total	41,006	0	0	0.0290	$1.31

a. First-year savings from all buildings completed statewide in 2023.

6.2 Statewide Greenhouse Gas (GHG) Emissions Reductions

The Statewide CASE Team calculated avoided GHG emissions assuming the emissions factors specified in the United States Environmental Protection Agency (U.S. EPA) Emissions & Generation Resource Integrated Database (eGRID) for the Western Electricity Coordination Council California (WECC CAMX) subregion. Avoided GHG emissions from natural gas savings attributable to sources other than utility-scale electrical power generation are calculated using emissions factors specified in U.S. EPA's Compilation of Air Pollutant Emissions Factors (AP-42). See Appendix C for additional details on the methodology used to calculate GHG emissions. In short, this analysis assumes an average electricity emission factor of 240.4 metric tons CO2e per GWh based on the average emission factors for the CACX EGRID subregion.

Table 73 presents the estimated first-year avoided GHG emissions of the proposed code change. During the first year, GHG emissions of 3,979 metric tons of carbon dioxide equivalents (metric tons CO2e CO2e) would be avoided.

Table 73: First-Year Statewide GHG Emissions Impacts

Measure	Electricity Savings[a] (GWh/yr)	Reduced GHG Emissions from Electricity Savings[a] (Metric Tons CO2e)	Natural Gas Savings[a] (MMTherms/yr)	Reduced GHG Emissions from Natural Gas Savings[a] (Metric Tons CO2e)	Total Reduced CO_2e Emissions[a,b] (Metric Tons CO2e)
Pipe Insulation Verification	0	0	0.28	1,544	1,544
Increased Insulation	0	0	0.03	158	158
CPC Appendix M Pipe Sizing	0	0	0.09	515	515
TOTAL	**0**	**0**	0.40	2,217	2,217

a. First-year savings from all buildings completed statewide in 2023.

b. Assumes the following emission factors: 240.4 MTCO2e/GWh and 5,454.4 MTCO2e/MMTherms.

6.3 Statewide Water Use Impacts

The proposed code change would not result in water savings. Pipe size reductions resulting from the CPC Appendix M Submeasure do not impact pipes in the dwelling unit that influence hot water wait times, so there are no reductions in behavioral waste.

6.4 Statewide Material Impacts

Submeasure A: Insulation Quality Verification does not have any material impacts.

Submeasure B: Increased Insulation would result in an increased use of insulation in multifamily buildings.

Increased use of insulation would result in increased material impacts for quartz sand, cullet, feldspar, soda, borax, dolomite, urea formaldehyde, quicklime, sodium sulfate, and other materials used in the manufacturing of fiberglass and elastomeric pipe insulation (Norris 1999).

Table 74: First-Year Statewide Impacts on Material Use

Measure	Material	Impact (I, D, or NC)[a]	Impact on Material Use (pounds)	
			Per-Unit Impacts	First-Year[b] Statewide Impacts
Increased Insulation	Fiberglass	I	1.5	61,558
CPC App M Pipe Sizing	Copper	D	(13.6)	(558,122)

a. Material Increase (I), Decrease (D), or No Change (NC) compared to base case (lbs/yr).

b. First-year savings from all buildings completed statewide in 2023.

Appendix M Pipe Sizing would result in decreased usage of materials required to manufacture copper pipe and piping specialties.

6.5 Other Non-Energy Impacts

CPC Appendix A pipe oversizing leads to a larger volume of water that needs to be expelled before hot water could reach a fixture. As such, CPC Appendix M sizing leads to improved (shorter) hot water wait times while still meeting peak hot water demand in the building.

7. Proposed Revisions to Code Language

7.1 Guide to Markup Language

The Energy Commission is planning consolidation of low-and high-rise multifamily requirements under a new multifamily section(s) in 2022 Title 24, Part 6. Restructuring the standards for multifamily building may also result in revisions to the ACM Reference Manual, reference appendices, compliance manuals, and compliance documents. Location and section numbering of the 2022 Standards and supporting documents for multifamily buildings depend on the Energy Commission's approach to and acceptance of a unified multifamily section(s). For clarity, the changes proposed in this CASE Report are demonstrated in terms of the 2019 structure and language.

The proposed changes to the standards, Reference Appendices, and the ACM Reference Manual are provided below. Changes to the 2019 documents are marked with red underlining (new language) and ~~strikethroughs~~ (deletions).

7.2 Standards

7.2.1 Submeasure A: Pipe Insulation Verification

SUBCHAPTER 8 LOW-RISE RESIDENTIAL BUILDINGS - PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES

SECTION 150.1 – PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES FOR LOW-RISE RESIDENTIAL BUILDINGS

[Item (c)8]

8. **Domestic Water-Heating Systems.** Water-heating systems shall meet the requirements of either A B or C. For recirculation distribution systems serving individual dwelling unit, only Demand Recirculation Systems with manual on/off control as specified in the Reference Appendix RA4.4.9 shall be used:

    A. For systems serving individual dwelling units, the water heating system shall meet the requirement of either i, ii, iii, iv, or v:

        i. One or more gas or propane instantaneous water heater with an input of 200,000 Btu per hour or less and no storage tank.

        ii. A single gas or propane storage type water heater with an input of 75,000 Btu per hour or less, rated volume less than or equal to 55 gallons and that meets the requirements of Sections 110.1 and 110.3. The dwelling unit shall have installed fenestration products with a weighted average U-factor no greater than 0.24, and in addition one of the following shall be installed:

            a. A compact hot water distribution system that is field verified as specified in the Reference Appendix RA4.4.16; or

b. A drain water heat recovery system that is field verified as specified in the Reference Appendix RA3.6.9.

iii. A single gas or propane storage type water heater with an input of 75,000 Btu per hour or less, rated volume of more than 55 gallons.

iv. A single heat pump water heater. The storage tank shall be located in the garage or conditioned space. In addition, one of the following:

a. A compact hot water distribution system as specified in the Reference Appendix RA4.4.6 and a drain water heat recovery system that is field verified as specified in the Reference Appendix RA3.6.9; or

b. For Climate Zones 2 through 15, a photovoltaic system capacity of 0.3 kWdc larger than the requirement specified in Section 150.1(c)14; or

c. For Climate Zones 1 and 16, a photovoltaic system capacity of 1.1 kWdc larger than the requirement specified in Section 150.1(c)14.

v. A single heat pump water heater that meets the requirements of NEEA Advanced Water Heater Specification Tier 3 or higher. The storage tank shall be located in the garage or conditioned space. In addition, for Climate Zones 1 and 16, a photovoltaic system capacity of 0.3 kWdc larger than the requirement specified in Section 150.1(c)14 or a compact hot water distribution system as specified in the Reference Appendix RA4.4.6.

B. For systems serving multiple dwelling units, a central water-heating system that includes the following components shall be installed:

i. Gas or propane water heating system; and

ii. A recirculation system that meets the requirements of Sections 110.3(c)2 and 110.3(c)5, includes two or more separate recirculation loops serving separate dwelling units, and is capable of automatically controlling the recirculation pump operation based on measurement of hot water demand and hot water return temperature; and

EXCEPTION to Section 150.1(c)8Bii: Buildings with eight or fewer dwelling units may use a single recirculation loop.

iii. Recirculation system piping insulation quality shall be field verified and shall meet the criteria specified in Reference Appendix RA3.6.x.; and

~~iii~~ iv. A solar water-heating system meeting the installation criteria specified in Reference Residential Appendix RA4 and with a minimum solar savings fraction of either a or b below:

a. A minimum solar savings fraction of 0.20 in Climate Zones 1 through 9 or a minimum solar savings fraction of 0.35 in Climate Zones 10 through 16; or

b. A minimum solar savings fraction of 0.15 in Climate Zones 1 through 9 or a minimum solar savings fraction of 0.30 in Climate Zones 10 through 16.

In addition, a drain water heat recovery system that is field verified as specified in the Reference Appendix RA3.6.9.

C. A water-heating system serving multiple dwelling units determined by the Executive Director to use no more energy than the one specified in Subsection B above.

7.2.2 Submeasure B: Increased Insulation

SUBCHAPTER 3 NONRESIDENTIAL, HIGH-RISE RESIDENTIAL, HOTEL/MOTEL OCCUPANCIES, AND COVERED PROCESSES—MANDATORY REQUIREMENTS

SECTION 120.3 – REQUIREMENTS FOR PIPE INSULATION

[Table 120.3-A]

TABLE 120.3-A PIPE INSULATION THICKNESS

Fluid Operating Temperature Range (°F)	**Insulation Conductivity**			**Nominal Pipe Diameter (in inches)**						
	Conductivity (in Btu·in/h·ft^2·°F)	**Mean Rating Temperature (°F)**		**< 1**		**1 to <1.5**		**1.5 to < 4**	**4 to < 8**	**8 and larger**
Space heating and Service Water Heating Systems (Steam, Steam Condensate, Refrigerant, Space Heating, Service Hot Water)				**Minimum Pipe Insulation Required (Thickness in inches or R-value)**						
Above 350	0.32-0.34	250	Inches	4.5		5.0		5.0	5.0	5.0
			R-value	R 37		R 41		R 37	R 27	R 23
251-350	0.29-0.32	200	Inches	3.0		4.0		4.5	4.5	4.5
			R-value	R 24		R 34		R 35	R 26	R 22
201-250	0.27-0.30	150	Inches	2.5		2.5		2.5	3.0	3.0
			R-value	R 21		R 20		R 17.5	R 17	R 14.5
141-200	0.25-0.29	125	Inches	1.5		1.5		2.0	2.0	2.0
			R-value	R 11.5		R 11		R 14	R 11	R 10
105-140	0.22-0.28	100	Inches	1.0		1.5		1.5	1.5	1.5
			R-value	R 7.7		R 12.5		R 11	R 9	R 8
				Nominal Pipe Diameter (in inches)						
				< 1		**1 to <1.5**		**1.5 to < 4**	**4 to < 8**	**8 and larger**
Space cooling systems (chilled water, refrigerant and brine)				**Minimum Pipe Insulation Required (Thickness in inches or R-value)[1]**						
40-60	0.21-0.27	75	Inches	Nonres 0.5	Res 0.75	Nonres 0.5	Res 0.75	1.0	1.0	1.0
			R-value	Nonres R 3	Res R 6	Nonres R 3	Res R 5	R 7	R 6	R 5
Below 40	0.20-0.26	50	Inches	1.0		1.5		1.5	1.5	1.5
			R-value	R 8.5		R 14		R 12	R 10	R 9
				Minimum Pipe Insulation Required (Thickness in inches or R-value)						
				< 1		1 to <1.5		1.5 to < 4	4 to < 8	8 and larger
Multifamily Domestic Hot Water Systems										
105-140[2]	0.22-0.28	100	Inches	1.0		1.5		2.0	2.0	2.0
			R-value	R 7.7		R 12.5		R 16	R 12.5	R 11

Footnote to TABLE 120.3-A:

1. These thickness are based on energy efficiency considerations only. Issues such as water vapor permeability or surface condensation sometimes require vapor retarders or additional insulation.
2. Multifamily domestic hot water systems with water temperature above 140°F shall use the row in table 120.3-A for the applicable water temperature.

EXCEPTION 1 to Section 120.3: Factory-installed piping within space-conditioning equipment certified under Section 110.1 or 110.2.

EXCEPTION 2 to Section 120.3: Piping that conveys fluids with a design operating temperature range between 60°F and 105°F.

EXCEPTION 3 to Section 120.3: Where the heat gain or heat loss to or from piping without insulation will not increase building source energy use.

EXCEPTION 4 to Section 120.3: Piping that penetrates framing members shall not be required to have pipe insulation for the distance of the framing penetration. Metal piping that penetrates metal framing shall use grommets, plugs, wrapping or other insulating material to assure that no contact is made with the metal framing.

NOTE: Authority: Sections 25213, 25218, 25218.5, 25402 and 25402.1, Public Resources Code. Reference: Sections 25007, 25008, 25218.5, 25310, 25402, 25402.1, 25402.4, 25402.5, 25402.8, and 25943, Public Resources Code.

SUBCHAPTER 7 LOW-RISE RESIDENTIAL BUILDINGS – MANDATORY FEATURES AND DEVICES

SECTION 150.0 – MANDATORY FEATURES AND DEVICES

[Item (j)]

(j) Insulation for Piping and Tanks

1. **Storage tank insulation.** Unfired hot water tanks, such as storage tanks and backup storage tanks for solar water-heating systems, shall be externally wrapped with insulation having an installed thermal resistance of R-12 or greater or have internal insulation of at least R-16 and a label on the exterior of the tank showing the insulation R-value.
2. **Water piping, solar water-heating system piping, and space conditioning system line insulation thickness and conductivity.** Piping shall be insulated as follows:
   - A. All single family domestic hot water piping shall be insulated as specified in Section 609.11 of the California Plumbing Code. In addition, the following piping conditions shall have a minimum insulation wall thickness of 1 inch or a minimum insulation R-value of 7.7:
     - i. The first 5 feet (1.5 meters) of cold-water pipes from the storage tank.

ii. All hot water piping with a nominal diameter equal to or greater than 3/4 inch (19 millimeter) and less than 1 inch.

iii. All hot water piping with a nominal diameter less than 3/4 inch that is:

   a. Associated with a domestic hot water recirculation system;

   b. From the heating source to the kitchen fixtures;

   c. From the heating source to a storage tank or between storage tanks; or

   d. Buried below grade.

B. Piping for multifamily domestic hot water systems, space conditioning systems, solar water-heating system collector loop, and distribution piping for steam and hydronic heating system, shall meet the requirements of Section 120.3(c).

EXCEPTION 1 to Section 150.0(j)2: Factory-installed piping within space-conditioning equipment certified under Section 110.1 or 110.2.

EXCEPTION 2 to Section 150.0(j)2: Piping that penetrates framing members shall not be required to have pipe insulation for the distance of the framing penetration. Piping that penetrates metal framing shall use grommets, plugs, wrapping or other insulating material to assure that no contact is made with the metal framing. Insulation shall abut securely against all framing members.

EXCEPTION 3 to Section 150.0(j)2: Piping installed in interior or exterior walls shall not be required to have pipe insulation if all of the requirements are met for compliance with Quality Insulation Installation (QII) as specified in the Reference Residential Appendix RA3.5.

EXCEPTION 4 to Section 150.0(j)2: Piping surrounded with a minimum of 1 inch of wall insulation, 2 inches of crawlspace insulation, or 4 inches of attic insulation, shall not be required to have pipe insulation.

3. **Insulation Protection.** Pipe insulation shall meet the insulation protection requirements of Section 120.3(b).

7.2.3 Submeasure C: CPC Appendix M Sizing

There are no proposed changes to the standards.

7.2.4 Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

SUBCHAPTER 8 LOW-RISE RESIDENTIAL BUILDINGS - PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES

SECTION 150.1 – PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES FOR LOW-RISE RESIDENTIAL BUILDINGS

[Item (c)8B ii]

8. **Domestic Water-Heating Systems.** Water-heating systems shall meet the requirements of either A B or C. For recirculation distribution systems serving individual dwelling unit, only Demand Recirculation Systems with manual on/off control as specified in the Reference Appendix RA4.4.9 shall be used:

   A. For systems serving individual dwelling units, the water heating system shall meet the requirement of either i, ii, iii, iv, or v:

      i. One or more gas or propane instantaneous water heater with an input of 200,000 Btu per hour or less and no storage tank.

      ii. A single gas or propane storage type water heater with an input of 75,000 Btu per hour or less, rated volume less than or equal to 55 gallons and that meets the requirements of Sections 110.1 and 110.3. The dwelling unit shall have installed fenestration products with a weighted average U-factor no greater than 0.24, and in addition one of the following shall be installed:

         a. A compact hot water distribution system that is field verified as specified in the Reference Appendix RA4.4.16; or

         b. A drain water heat recovery system that is field verified as specified in the Reference Appendix RA3.6.9.

      iii. A single gas or propane storage type water heater with an input of 75,000 Btu per hour or less, rated volume of more than 55 gallons.

      iv. A single heat pump water heater. The storage tank shall be located in the garage or conditioned space. In addition, one of the following:

         a. A compact hot water distribution system as specified in the Reference Appendix RA4.4.6 and a drain water heat recovery system that is field verified as specified in the Reference Appendix RA3.6.9; or

         b. For Climate Zones 2 through 15, a photovoltaic system capacity of 0.3 kWdc larger than the requirement specified in Section 150.1(c)14; or

         c. For Climate Zones 1 and 16, a photovoltaic system capacity of 1.1 kWdc larger than the requirement specified in Section 150.1(c)14.

      v. A single heat pump water heater that meets the requirements of NEEA Advanced Water Heater Specification Tier 3 or higher. The storage tank shall be located in the garage or conditioned space. In addition, for Climate Zones 1 and 16, a photovoltaic system capacity of 0.3 kWdc larger than the requirement specified in Section 150.1(c)14 or a compact hot water distribution system as specified in the Reference Appendix RA4.4.6.

   B. For systems serving multiple dwelling units, a central water-heating system that includes the following components shall be installed:

      i. Gas or propane water heating system; and

      ii. A recirculation system that meets the requirements of Sections 110.3(c)2 and 110.3(c)5~~, includes two or more separate recirculation loops serving separate dwelling units,~~ and is capable of automatically controlling the recirculation pump operation based on measurement of hot water demand and hot water return temperature~~; and~~

~~EXCEPTION to Section 150.1(c)8Bii: Buildings with eight or fewer dwelling units may use a single recirculation loop.~~

iii. A solar water-heating system meeting the installation criteria specified in Reference Residential Appendix RA4 and with a minimum solar savings fraction of either a or b below:

   a. A minimum solar savings fraction of 0.20 in Climate Zones 1 through 9 or a minimum solar savings fraction of 0.35 in Climate Zones 10 through 16; or

   b. A minimum solar savings fraction of 0.15 in Climate Zones 1 through 9 or a minimum solar savings fraction of 0.30 in Climate Zones 10 through 16. In addition, a drain water heat recovery system that is field verified as specified in the Reference Appendix RA3.6.9.

C. A water-heating system serving multiple dwelling units determined by the Executive Director to use no more energy than the one specified in Subsection B above.

7.3 Reference Appendices

Changes described to the Reference Appendices below apply specifically to multifamily buildings and do not suggest application to single family or nonresidential buildings types. These changes may be included in new sections within the Residential Appendices, or new Multifamily Appendices. For simplicity, proposed changes are described through mark-up to sections of the Residential Appendices. Where field verification and diagnostic testing scope is conducted by either a HERS Rater or by an ATT for compliance with 2019 Title 24, Part 6, the Statewide CASE Team recommends field verification or testing remain with the same entity. Where new field verification or testing scope is introduced through the 2022 proposal, the Statewide CASE Team recommends allowing choice of HERS Rater or ATT, rather than specifying one or the other.

7.3.1 Submeasure A: Pipe Insulation Verification

RA2.2 Measures that Require Field Verification and Diagnostic Testing

Table RA2-1 describes the measures that require installer certification and HERS Rater field verification and diagnostic testing. It identifies the protocol or test procedure in the Residential Appendices that shall be used for completing installer and HERS Rater field verification and diagnostic testing.

Table RA2-1 – Summary of Measures Requiring Field Verification and Diagnostic Testing

Measure Title	Description	Procedure(s)
	Duct Measures	
Duct Sealing	Component Packages require that space conditioning ducts be sealed. If sealed and tested ducts are claimed for compliance, field verification and diagnostic testing is required to verify that approved duct system materials are utilized, and that duct leakage meets the specified criteria.	RA3.1.4.3
Duct Location, Surface Area and R-value	Compliance credit can be taken for improved duct location, surface area and R-value. Field verification is required to verify that the duct system was installed according to the design, including location, size and length of ducts, duct insulation R-value and installation of buried ducts.[1] For buried ducts measures, Duct Sealing and High Quality Insulation Installation (QII) is required.	RA3.1.4.1
Verification of low leakage ducts located entirely in conditioned space	Duct system location shall be verified by visual inspection and diagnostic testing. Compliance credit can be taken for verified duct systems with low air leakage to the outside when measured in accordance with Reference Residential Appendix Section RA3.1.4.3.8. Field Verification for ducts in conditioned space is required. Duct sealing is required.	RA3.1.4.3.8
Low Leakage Air-handling Units	Compliance credit can be taken for installation of a factory sealed air handling unit tested by the manufacturer and certified to the Commission to have met the requirements for a Low Leakage Air-Handling Unit. Field verification of the air handler's model number is required. Duct Sealing is required.	RA3.1.4.3.9
Verification of Return Duct Design	Verification to confirm that the return duct design conform to the criteria given in TABLE 150.0-B or TABLE 150.0-C.	RA3.1.4.4
Verification of Air Filter Device Design	Verification to confirm that the air filter devices conform to the requirements given in Standards Section 150.0(m)12.	RA3.1.4.5
Verification of Prescriptive Bypass Duct Requirements	Verification to confirm zonally controlled systems comply with the bypass duct requirements in Section 150.1(c)13.	RA3.1.4.6
	Air Conditioning Measures	
Improved Refrigerant Charge	Component Packages require in some climate zones that air-cooled air conditioners and air-source heat pumps be diagnostically tested in the field to verify that the system has the correct refrigerant charge. For the performance method, the Proposed Design is modeled with less efficiency if diagnostic testing and field verification is not performed. The system must also meet the prerequisite minimum System Airflow requirement.	RA3.3 RA3.2 RA1.2
Installation of Fault Indicator Display	Component Packages specify that a Fault Indicator Display can be installed as an alternative to refrigerant charge testing. The existence of a Fault Indicator Display has the same calculated benefit as refrigerant charge testing. Field verification is required.	RA3.4.2
Verified System Airflow	When compliance requires verified system airflow greater than or equal to a specified criterion, field verification and diagnostic testing is required.	RA3.3
Air-handling Unit Fan Efficacy	When compliance requires verified fan efficacy (Watt/cfm) less than or equal to a specified criterion, field verification and diagnostic testing is required.	RA3.3
Verified Energy Efficiency Ratio (EER)	Compliance credit can be taken for increased EER by installation of specific air conditioner or heat pump models. Field verification is required.[2]	RA3.4.3 RA3.4.4.1

Verified Seasonal Energy Efficiency Ratio (SEER)	HERS Rater field verification of the SEER rating is required for some systems.	RA3.4.3 RA3.4.4.1
Rated Heat Pump Capacity Verification	When performance compliance uses a heat pump, the rated capacity of the installed system shall be verified to be greater than or equal to the specified value.	RA3.4.4.2
Evaporatively Cooled Condensers	Compliance credit can be taken for installation of evaporatively cooled condensers. Field verification of duct leakage is required. Field verification of refrigerant charge is required. Field verification of EER is required.	RA3.1.4.3, RA3.2 RA3.4.3. RA3.4.4.1
	Ventilation Cooling Measures	
Whole House Fan	When performance compliance uses a whole house fan, the installed whole house fan airflow rate (cfm) and fan efficacy (W/cfm) shall be verified to be equal to or better than the specified values.	RA3.9
Central Fan Ventilation Cooling System	When performance compliance uses a central fan ventilation cooling system (CFVCS), the installed CFVCS ventilation airflow rate (cfm) and fan efficacy (W/cfm) shall be verified to be equal to or better than the specified values.	RA3.3.4
	Mechanical Ventilation Measures for Improved Indoor Air Quality	
Continuous Whole-Building Mechanical Ventilation Airflow	Measurement of whole-building mechanical ventilation is mandatory for newly constructed buildings.	RA3.7.4.1
Intermittent Whole-Building Mechanical Ventilation Airflow	Measurement of whole-building mechanical ventilation is mandatory for newly constructed buildings.	RA3.7.4.2
	Building Envelope Measures	
Building Envelope Air Leakage	Compliance credit can be taken for reduced building envelope air leakage. Field verification and diagnostic testing is required.	RA3.8
Quality Insulation Installation (QII)	Compliance Software recognizes standard and improved envelope construction. Quality Insulation Installation is a prescriptive measure in all climate zones for newly constructed buildings and additions greater than 700 square feet, except low-rise multifamily buildings in Climate Zone 7. Field verification is required.	RA3.5
Quality Insulation Installation for Spray Polyurethane Foam (SPF) Insulation	A HERS Rater shall verify the installation of SPF insulation whenever R-values other than the default R-value per inch are used for compliance.	RA3.5.6
	Single Family Domestic Hot Water Measures	
Verified Pipe Insulation Credit (PIC-H)	Inspection to verify that all hot water piping in non-recirculating systems is insulated and that corners and tees are fully insulated. No piping should be visible due to insulation voids with the exception of the last segment of piping that penetrate walls and delivers hot water to the sink, appliance, etc.	RA3.6.3.
Verified Parallel Piping (PP-H)	Inspection that requires that the measured length of piping between the water heater and single central manifold does not exceed five feet	RA3.6.4
Verified Compact Hot Water Distribution System Expanded Credit (CHWDS-H-EX)	Field verification to insure that the eligibility criteria specified in RA 3.6.5 are met.	RA3.6.5

Demand Recirculation: Manual Control (RDRmc-H)	Inspection to verify that all recirculating hot water piping is insulated and that corners and tees are fully insulated. No piping should be visible due to insulation voids	RA3.6.6
Demand Recirculation: Sensor Control(RDRsc-H)	Inspection to verify that all recirculating hot water piping is insulated and that corners and tees are fully insulated. No piping should be visible due to insulation voids.	RA3.6.7
Verified Drain Water Heat Recovery System (DWHR-H)	Inspection to verify that the DWHR unit(s) and installation configuration match the compliance document and the DWHR(s) is certified to the Commission to have met the requirements.	RA3.6,9
	Multi Family Domestic Hot Water Heating Measures	
Multiple Recirculation Loop Design for DHW Systems Serving Multiple Dwelling Units	Inspection that a central DHW system serving a building with more than eight dwelling units has at least two recirculation loops, each serving roughly the same number of dwelling units. These recirculation loops may the same water heating equipment or be connected to independent water heating equipment.	RA3.6.8
Verified Drain Water Heat Recovery System (DWHR-H)	Inspection to verify that the DWHR unit(s) and installation configuration match the compliance document and the DWHR(s) is certified to the Commission to have met the requirements.	RA3.6.9
Domestic Hot Water Recirculation System Pipe Insulation Verification	Inspection to verify that domestic hot water recirculation systems are insulated including pipes, fittings, valves, pumps, and other piping devices. Metallic piping should be thermally isolated from pipe hangers. No piping should be visible due to insulation voids except piping specifically exempted in the California Plumbing Code or Title 24, Part 6.	RA3.6.x

1. Note: Compliance credit for increased duct insulation R-value (not buried ducts) may be taken without field verification if the R-value is the same throughout the building, and for ducts located in crawlspaces and garages where all registers are either in the floor or within 2 feet of the floor. These two credits may be taken subject only to enforcement agency inspection.

2. Note: The requirement for verification of a high EER does not apply to equipment rated only with an EER.

RA3.6 Field Verification of Water Heating Systems

Section 3.6.x HERS or ATT – Verified Pipe Insulation Installation for Domestic Hot Water Recirculation Systems

The HERS Rater or ATT shall verify that pipe insulation within the domestic hot water recirculation system is installed in accordance with the requirements in RA4.4.x. Field verifications shall include visual inspection of the following portions of the recirculation system:

(a) All pipe insulation in the mechanical/boiler room where water heating equipment resides, or all outdoor pipes if water heater is outdoors.

(b) All pipe insulation on horizontal distribution pipes that function as a supply header, up the point of connection with riser pipes. Supply header is piping between the water heater and vertical risers that run up or down the building.

(c) A sample of pipe insulation on vertical pipe risers: The sample rate shall be one in two risers. Riser inspection shall include the entire vertical length of DHW recirculation riser pipe, including offsets and horizontal portions of recirculation loop, up to the point of connection of the branch pipe (non-recirculating) to dwelling units.

If field verification of pipe insulation in any of the three portions results in a failure, the HERS Rater or ATT shall enter the failure into the HERS or ATT data registry. Installers shall take corrective action, and the HERS Rater or ATT shall re-check the corrective action.

If field verification of sampled vertical pipe risers results in a failure, the building then becomes subject to verification of 100 percent of remaining pipe risers that are still visually accessible. The building passes if the HERS Rater or ATT verifies that the corrective action was successful during re-check, and if all risers remaining visually accessible meet the verification requirements.

Section RA4.4.x Proper Installation of Pipe Insulation for Domestic Hot Water Recirculation Systems

Unless otherwise stated, insulation must meet the applicable requirements for coverage and thickness specified in Section 120.3. Pipe insulation shall fit tightly to the pipe, and all elbows, tees, valves, pumps, and other piping devices, shall be fully insulated. No piping shall be visible due to insulation voids. Metal pipe hangers supporting metal pipe shall have thermal isolation between the hanger and pipe.

7.3.2 Submeasure B: Increased Insulation

The proposed code change would not modify the Reference Appendices documents.

7.3.3 Submeasure C: CPC Appendix M Sizing

The proposed code change would not modify the Reference Appendices documents.

7.3.4 Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

RA2.2 Measures that Require Field Verification and Diagnostic Testing

Table RA2-1 – Summary of Measures Requiring Field Verification and Diagnostic Testing

Measure Title	Description	Procedure(s)
	Multi Family Domestic Hot Water Heating Measures	
Multiple Recirculation Loop Design for DHW Systems Serving Multiple Dwelling Units	Inspection that a central DHW system serving a building ~~with more than eight dwelling units~~ has at least two recirculation loops, each serving roughly the same number of dwelling units. These recirculation loops may have the same water heating equipment or be connected to independent water heating equipment.	RA3.6.8

RA3.6.8 HERS-Multiple Recirculation Loop Design for DHW Systems Serving Multiple Dwelling Units

The visual inspection shall verify that a central DHW system ~~serving a building with more than eight dwelling units~~ has at least two recirculation loops. ~~, each serving roughly the same number of dwelling. Unique building sections may have additional recirculation loops.~~ These recirculation loops may be connected to the same water heating equipment or be connected to independent water heating equipment. The HERS inspector shall verify that there are at least two recirculation loops each serving roughly the same number of dwelling units. Unique sections of the building may have separate loops. ~~Ideally each loop will have its own pump and controls.~~

7.4 ACM Reference Manual

7.4.1 Submeasure A: Pipe Insulation Verification

Two versions of ACM edits are shown below, first with changes related to only Submeasure A, and a second version that combines changes related to Submeasure A: Pipe Insulation Verification and Submeasure C: CPC Appendix M. A combined version is included because both Submeasure A and Submeasure B impact equation 22.

ACM changes for Submeasure A if Submeasure C is not adopted:

Residential ACM Appendix B – Water Heating Calculation Method

B5.1 Hourly Recirculation Loop Pipe Heat Loss Calculation

UA_n = Heat loss rate of section n (Btu/hr-°F), see Equation 20

$$UA_n = Len_n \times min(U_{bare,n}, f_{UA,n} \times U_{insul,n})$$

Equation 20

where

Len_n = Section n pipe length (ft); for the proposed design, use user input; for the Standard Design, see Equation 31

$U_{bare,n}$, $U_{insul,n}$ = Heat ~~L~~loss rates for bare, uninsulated pipe, $U_{bare,n}$, and insulated pipe, $U_{insul,n}$, (Btu/hr-ft-°F), evaluated using Equation 21 ~~with section-specific values, as follows:~~

$$U_{bare,n} = h_n \times \pi \times Dia_{o,n}/12$$

Equation 21

$$U_{insul,n} = \frac{\pi}{\frac{ln(Dia_{x,n}/Dia_{o,n})}{2 \times Cond_n/12} + \frac{12}{h_n \times Dia_{x,n}}}$$

$$Dia_{o,n} = Dia_n + 0.125$$

$$Dia_{x,n} = Dia_{o,n} + 2 \times Thick_n$$

where

$Dia_{o,n}$ = Outer diameter of pipe section n

$Dia_{x,n}$ = Outer diameter of pipe insulation for pipe section n

Dia_n = Section n pipe nominal diameter (inch); for the proposed design, use user input; for the Standard Design, see Equation 32

$Thick_n$ = Pipe insulation minimum thickness (inch) as defined in the Title 24, Part 6 Section 120.3, Table 120.3-A for service hot water system

$Cond_n$ = Insulation conductivity shall be assumed = 0.26 (Btu inch/h·sf·F)

h_n = Section n combined convective/radiant surface coefficient (Btu/hr-ft2-F) assumed = 1.5

~~f_{UA} =~~ ~~Correction factor to reflect imperfect insulation installation, insulation material degradation over time, and additional heat transfer through~~

~~connected branch pipes that is not reflected in branch loss calculations. It is assumed to be 2.0.~~

$$f_{UA,n} = 2.0 \times f_{U,n}$$

Equation 22

$f_{UA,n}$ = Correction factor to reflect imperfect insulation installation, insulation material degradation over time, and additional heat transfer through connected branch pipes that is not reflected in branch heat loss calculations. This correction factor can be reduced through improved insulation quality.

where

$f_{U,n}$ = Correction factor to reflect pipe insulation quality. For the Standard Design it is assumed to be 0.8. The default value for proposed design is 1.0 but it is reduced to 0.8 if pipe insulation installation is verified per Reference Residential Appendix RA 3.6.x.

~~$Dia_{o,n} = Dia_n + 0.125$~~

~~$U_{bare,n} = h_n \times \pi \times Dia_{o,n}/12$~~

~~Equation 21~~

~~$Dia_{x,n} = Dia_{o,n} + 2 \times Thick_n$~~

~~$U_{insul,n} = \dfrac{\pi}{\dfrac{ln(Dia_{x,n}/Dia_{o,n})}{2 \times Cond_n/12} + \dfrac{12}{h_n \times Dia_{x,n}}}$~~

ACM changes for Submeasure A and Submeasure C combined:

Residential ACM Appendix B – Water Heating Calculation Method

B5.1 Hourly Recirculation Loop Pipe Heat Loss Calculation

UA_n = Heat loss rate of section n (Btu/hr-°F), see Equation 20

$$UA_n = Len_n \times min(U_{bare,n}, f_{UA,n} \times U_{insul,n})$$

Equation 20

where

Len_n = Section n pipe length (ft); for the proposed design, use user input; for the Standard Design, see Equation 31

$U_{bare,n}$, $U_{insul,n}$ = Heat ~~L~~loss rates for bare, uninsulated pipe, $U_{bare,n}$, and insulated pipe, $U_{insul,n}$, (Btu/hr-ft-°F), evaluated using Equation 21 ~~with section-specific values, as follows:~~

$$U_{bare,n} = h_n \times \pi \times Dia_{o,n}/12 \qquad \text{Equation 21}$$

$$U_{insul,n} = \frac{\pi}{\frac{ln\left(Dia_{x,n}/Dia_{o,n}\right)}{2 \times Cond_n/12} + \frac{12}{h_n \times Dia_{x,n}}}$$

$$Dia_{o,n} = Dia_n + 0.125$$

$$Dia_{x,n} = Dia_{o,n} + 2 \times Thick_n$$

where

$Dia_{o,n}$ = Outer diameter of pipe section n

$Dia_{x,n}$ = Outer diameter of pipe insulation for pipe section n

Dia_n = Section n pipe nominal diameter (inch); for the proposed design, use user input; for the Standard Design, see Equation 32

$Thick_n$ = Pipe insulation minimum thickness (inch) as defined in the Title 24, Part 6 Section 120.3, Table 120.3-A for service hot water system

$Cond_n$ = Insulation conductivity shall be assumed = 0.26 (Btu inch/h·sf·F)

h_n = Section n combined convective/radiant surface coefficient (Btu/hr-ft2-F) assumed = 1.5

~~f_{UA} = Correction factor to reflect imperfect insulation installation, insulation material degradation over time, and additional heat transfer through connected branch pipes that is not reflected in branch loss calculations. It is assumed to be 2.0.~~

$$f_{UA,n} = 2.0 \times \left(f_{U,n} \times f_{A,n}\right) \qquad \text{Equation 22}$$

$f_{UA,n}$ = Correction factor to reflect imperfect insulation installation, insulation material degradation over time, and additional heat transfer through connected branch pipes that is not reflected in branch heat loss calculations. This correction factor can be reduced through improved insulation quality and pipe surface area reduction.

where

$f_{U,n}$ = Correction factor to reflect pipe insulation quality. For the Standard Design it is assumed to be 0.8. The default value for proposed design is 1.0 but it is reduced to 0.8 if pipe insulation installation is verified per Reference Residential Appendix RA 3.6.x.

$f_{A,n}$ = Correction factor to reflect improvement through pipe surface area reduction. pipe size reduction by using California Plumbing Code Appendix M to size recirculation pipes. This correction factor only affects supply pipes. The default value is 1.0 for both the Standard Design and proposed design. If recirculation pipes are sized according to California Plumbing Code Appendix M, $f_{A,n}$ for recirculation supply pipes (n = 1, 2, or 3) shall be:

- 0.85 for $Nunit_k <= 8$,
- $0.85 – 0.1×(Nunit_k -8)/112$ for $8 < Nunit_k < 120$,
- or 0.75 for $Nunit_k >= 120$

where $Nunit_k$ is number of dwelling units served by water heating system k.

~~$Dia_{o,n} = Dia_n + 0.125$~~

~~$U_{bare,n} = h_n \times \pi \times Dia_{o,n}/12$~~

~~Equation 21~~

~~$Dia_{x,n} = Dia_{o,n} + 2 \times Thick_n$~~

~~$U_{insul,n} = \dfrac{\pi}{\dfrac{ln(Dia_{x,n}/Dia_{o,n})}{2 \times Cond_n/12} + \dfrac{12}{h_n \times Dia_{x,n}}}$~~

7.4.2 Submeasure B: Increased Insulation

The proposed code change would not modify the ACM Reference Manual.

Pipe insulation minimum thickness (inch), $Thick_n$, is determined according to Title 24, Part 6 Section 120.3, Table 120.3-A and applied in Equation 20 presented in prior section. The proposed changes would update Table 120.3-A (see Section 7.2) and, therefore, indirectly affect pipe insulation assumptions in ACM Reference Manual.

7.4.3 Submeasure C: CPC Appendix M Pipe Sizing

Using CPC Appendix M to size recirculation systems allows designs with lower diameter supply pipes. The Statewide CASE Team proposes applying a correction factor ($f_{A,n}$) to the formula for pipe heat loss rate to reflect the benefit of this change.

Both Submeasure C and Submeasure A impact Equation 22. Section 7.4.1 above shows combined ACM changes if both Submeasure C and Submeasure A are adopted.

Residential ACM Appendix B – Water Heating Calculation Method

B5.1 Hourly Recirculation Loop Pipe Heat Loss Calculation

UA_n = Heat loss rate of section n (Btu/hr-°F), see Equation 20

$$UA_n = Len_n \times min\left(U_{bare,n}, f_{UA,n} \times U_{insul,n}\right)$$

Equation 20

where

Len_n = Section n pipe length (ft); for the proposed design, use user input; for the Standard Design, see Equation 31

$U_{bare,n}$, $U_{insul,n}$ = Heat ~~L~~loss rates for bare, uninsulated pipe, $U_{bare,n}$, and insulated pipe, $U_{insul,n}$, (Btu/hr-ft-°F), evaluated using Equation 21 ~~with section-specific values, as follows:~~

$$U_{bare,n} = h_n \times \pi \times Dia_{o,n}/12$$

Equation 21

$$U_{insul,n} = \frac{\pi}{\frac{ln\left(Dia_{x,n}/Dia_{o,n}\right)}{2 \times Cond_n/12} + \frac{12}{h_n \times Dia_{x,n}}}$$

$$Dia_{o,n} = Dia_n + 0.125$$

$$Dia_{x,n} = Dia_{o,n} + 2 \times Thick_n$$

where

$Dia_{o,n}$ = Outer diameter of pipe section n

$Dia_{x,n}$ = Outer diameter of pipe insulation for pipe section n

Dia_n = Section n pipe nominal diameter (inch); for the proposed design, use user input; for the Standard Design, see Equation 32

$Thick_n$ = Pipe insulation minimum thickness (inch) as defined in the Title 24, Part 6 Section 120.3, Table 120.3-A for service hot water system

$Cond_n$ = Insulation conductivity shall be assumed = 0.26 (Btu inch/h·sf·F)

h_n = Section n combined convective/radiant surface coefficient (Btu/hr-ft2-F) assumed = 1.5

~~fUA = Correction factor to reflect imperfect insulation installation, insulation material degradation over time, and additional heat transfer through~~

~~connected branch pipes that is not reflected in branch loss calculations. It is assumed to be 2.0.~~

$$f_{UA,n} = f_{UA} \times f_{A,n} \qquad \text{Equation 22}$$

$f_{UA,n}$ = Correction factor to reflect imperfect insulation installation, insulation material degradation over time, and additional heat transfer through connected branch pipes that is not reflected in branch heat loss calculations.

where

fUA = Correction factor to reflect imperfect insulation installation. It is assumed to be 2.0.

$f_{A,n}$ = Correction factor to reflect improvement through pipe surface area reduction. pipe size reduction by using California Plumbing Code Appendix M to size recirculation pipes. This correction factor only affects supply pipes. The default value is 1.0 for both the Standard Design and proposed design. If recirculation pipes are sized according to California Plumbing Code Appendix M, $f_{A,n}$ for recirculation supply pipes (n = 1, 2, or 3) shall be:

- 0.85 for $Nunit_k <= 8$,
- $0.85 – 0.1×(Nunit_k -8)/112$ for $8 < Nunit_k < 120$,
- or 0.75 for $Nunit_k >= 120$

where $Nunit_k$ is number of dwelling units served by water heating system k.

~~$Dia_{o,n} = Dia_n + 0.125$~~

~~$U_{bare,n} = h_n \times \pi \times Dia_{o,n}/12$~~

~~Equation 21~~

~~$Dia_{x,n} = Dia_{o,n} + 2 \times Thick_n$~~

~~$U_{insul,n} = \dfrac{\pi}{\dfrac{ln(Dia_{x,n}/Dia_{o,n})}{2 \times Cond_n/12} + \dfrac{12}{h_n \times Dia_{x,n}}}$~~

7.4.4 Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

APPENDIX B2. WATER HEATING SYSTEMS

B5.3 Recirculation System Plumbing Design

A recirculation system ~~can have one or multiple recirculation loops. Each recirculation loop~~ consists of many pipe sections, which are connected in sequence to form a loop. Each pipe section could have different pipe diameter, length, and location. The compliance software shall use six pipe sections, with three supply pipe sections and three return pipe sections, to represent a recirculation loop. When multiple recirculation loops exist, all recirculation loops are assumed to be identical. The compliance software shall provide default and standard recirculation system designs based on building geometry according to the procedures described in the following sections. The default design reflects typical recirculation loop design practices. The standard~~s~~ design is based on one ~~or two~~ loop~~s~~, as described in the following paragraph, and is used to set recirculation loop heat loss budget.

The first step of establishing recirculation system designs is to determine the number of recirculation loops, $Nloop_k$, in water heating system k. The standard design has one recirculation loop, $Nloop_k$ =1~~, when Nunit <= 8, or two recirculation loops, Nloopk =2 for buildings with Nunit > 8~~. The proposed design ~~is allowed to~~ can specify more than one loop only if the design is verified by a HERS rater. Otherwise, the proposed design can only be specified to have one recirculation loop.

[*Continuation of Section B5.3 is omitted for clarity*]

7.5 Compliance Manuals

7.5.1 Submeasure A: Pipe Insulation Verification

CHAPTER 5 Water Heating Requirements
SECTION 5.3 Mandatory Requirements for Water Heating
5.3.5 Mandatory Requirements for Hot Water Distribution Systems
5.3.5.3 Distribution Systems Serving Multiple Dwelling Units – with Recirculation Loops

The proposed change would add descriptions of benefits, procedures, and tips for carrying out pipe insulation verification. Sampling procedures would be described with text and graphics that distinguish DHW distribution pipe sections in the Residential Appendices. The new text and graphics would diagram distribution systems and illustrate how to distinguish between pipes that are part of the recirculation system, horizontal header pipes, vertical riser pipes, and the point of connection between recirculation pipes and non-recirculating branch pipes that serve the dwelling units.

7.5.2 Submeasure B: Increased Insulation

CHAPTER 5 Water Heating Requirements
SECTION 5.3 Mandatory Requirements for Water Heating
5.3.5 Mandatory Requirements for Hot Water Distribution Systems
5.3.5.1 Pipe Insulation for All Buildings

The proposed changes would add clarifying language and reference to applicable code sections, including describing that multifamily insulation requirements are referenced to section 120.3 rather than section 150.

7.5.3 Submeasure C: CPC Appendix M Sizing

CHAPTER 5 Water Heating Requirements

SECTION 5.4 Prescriptive Requirements for Water Heating
5.4.2 Multiple Dwelling Units: Multifamily, Motel/Hotels, and High-Rise Residential

The proposed compliance option would add a new Section 5.4.2.x to describe benefits, procedures, and useful resources for Appendix M sizing methodology.

7.5.4 Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

CHAPTER 5 Water Heating Requirements
SECTION 5.4 Prescriptive Requirements for Water Heating
5.4.2 Multiple Dwelling Units: Multifamily, Motel/Hotels, and High-Rise Residential
5.4.2.1 Dual-Loop Recirculation System Design

The proposed changes would delete the dual-loop prescriptive requirement in Section 5.4.2.1 and add clarifying language that dual-loop systems is a performance option that requires HERS verification.

7.6 Compliance Documents

7.6.1 Submeasure A: Pipe Insulation Verification

The proposed changes would require updates to the following compliance forms:

- CF2R-PLB-01a-NonHERS-MultifamilyCentralHotWaterSystemDistribution
- CF2R-PLB-21a-HERS-MultifamilyCentralHotWaterSystemDistribution
- CF3R-PLB-21a-HERS-MultifamilyCentralHotWaterSystemDistribution
- NRCI-PLB-02-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution
- NRCI-PLB-21-HERS-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution

- NRCV-PLB-21-HERS-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution

Minor updates to the CF1R-NCB-01-E, CF1R-PRF-E, NRCC-PLB-E, and NRCC-PRF-01-E forms may be needed accordingly.

The proposed code change would add descriptions on the scope and instructions for HERS or ATT Verification of recirculation pipe insulation. An example of edits to compliance forms, specific to multifamily buildings, is shown below.

A.	**Domestic Hot Water Recirculation System Pipe Insulation Verification**	
01	Recirculation pipe insulation must meet the applicable requirements specified in § 120.3.	
02	All pipes, fittings, and piping devices shall be insulated, including all elbows, tees, valves, pumps, and other piping devices	
03	Metal pipe hangers supporting metal pipe shall have thermal isolation between the hanger and pipe.	
04	Visual verifications shall cover: • All piping and insulation in the mechanical/boiler room where water heating equipment resides, or all outdoor pipes if water heater is outdoors. • All pipe insulation on horizontal distribution pipes that function as a supply header, up the point of connection with riser pipes. Supply header is piping between the water heater and vertical risers that run up or down the building. • A sample of pipe insulation on vertical pipe risers: the sample rate shall be one in two risers. Riser inspection shall include the entire vertical length of DHW recirculation riser pipe, including offsets and horizontal portions of recirculation loop, up to the point of connection of the branch pipe (non-recirculating) to dwelling units. If field verification of pipe insulation in any of the three portions results in a failure, the HERS Rater or ATT shall enter the failure into the HERS or ATT data registry. Installers shall take corrective action, and the HERS Rater or ATT shall re-check the corrective action. If field verification of sampled vertical pipe risers results in a failure, the building then becomes subject to verification of 100 percent of remaining pipe risers that are still visually accessible. The building passes if the HERS Rater or ATT verifies that the corrective action was successful during re-check, and if all risers remaining visually accessible meet the verification requirements.	
05	Verification Status:	☐ Pass - all applicable requirements are met; or

		☐ Fail - one or more applicable requirements are not met. Enter reason for failure in corrections notes field below; or ☐ All N/A - This entire table is not applicable
	Correction Notes:	
The responsible person’s signature on this compliance document affirms that all applicable requirements in this table have been met.		

7.6.2 Submeasure B: Increased Insulation

The proposed changes would require updates to the following compliance forms:

- CF2R-PLB-01a-NonHERS-MultifamilyCentralHotWaterSystemDistribution
- CF2R-PLB-21a-HERS-MultifamilyCentralHotWaterSystemDistribution
- CF3R-PLB-21a-HERS-MultifamilyCentralHotWaterSystemDistribution
- NRCI-PLB-02-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution
- NRCI-PLB-21-HERS-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution
- NRCV-PLB-21-HERS-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution

Minor updates to the CF1R-NCB-01-E, CF1R-PRF-E, NRCC-PLB-E, and NRCC-PRF-01-E forms may be needed accordingly.

The propose code change would update the multifamily pipe insulation code reference to section 120.3(A) only. Current 2019 cycle insulation requirements inconsistently refer to CPC via section 150 and to section 120.3.

7.6.3 Submeasure C: CPC Appendix M Sizing

The proposed code change would add a table to an existing CF-1R and NRCC-PRF-01-E Certificate of Compliance forms. An example of edits to compliance forms specific to multifamily buildings, is shown below.

A. Pipe Size based on CPC Appendix M calculations
Location of Appendix M pipe sizing calculations.
[pull down menu with two options] a) In construction documents, b) attached.
[if item a is selected, prompt for:] Plan set sheet name or specification document name:

7.6.4 Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

The proposed changes would require minor updates to the following compliance forms:

- CF2R-PLB-21a-HERS-MultifamilyCentralHotWaterSystemDistribution

- CF3R-PLB-21a-HERS-MultifamilyCentralHotWaterSystemDistribution
- NRCI-PLB-21-HERS-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution
- NRCV-PLB-21-HERS-HighRiseResHotelMotel-MultifamilyCentral-HWSystemDistribution

Minor updates to the CF1R-NCB-01-E, CF1R-PRF-E, NRCC-PLB-E, and NRCC-PRF-01-E forms may be needed accordingly.

The proposed code change would update compliance forms so that multiple loop is a compliance option. An example of edits to compliance forms is shown below.

H. HERS-Verified Multiple Recirculation Loops for DHW Systems Serving Multiple Dwelling Units ~~Requirements~~ ~~All distribution systems listed on this compliance document shall comply with these requirements.~~		
01	The buildings with ~~8 or more dwelling units~~ have a minimum of 2 recirculation loops.	
02	Each loop roughly serves the same number of dwellings.	
03	Verification Status:	☐ Pass - all applicable requirements are met; or ☐ Fail - one or more applicable requirements are not met. Enter reason for failure in corrections notes field below; or ☐ All N/A - This entire table is not applicable
04	Correction Notes:	
The responsible person’s signature on this compliance document affirms that all applicable requirements in this table have been met.		

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Appendix A: Statewide Savings Methodology

The Statewide CASE Team estimated statewide impacts for the first year by multiplying per-dwelling unit savings estimates by statewide construction forecasts of new dwelling units that the Energy Commission provided (California Energy Commission 2019). The Statewide CASE Team assumed that all newly constructed multifamily dwelling units with central water heating in all climate zones would be impacted by the proposed code change and assumed that no (0 percent) existing dwelling units in any climate zone would be impacted by the proposed code change.

The Statewide CASE Team used project data from energy consultants and from the HERS registry to determine the fraction of dwelling units served by central water heating for each prototype. The project data showed individual buildings, number of stories, number of dwelling units, and DHW configuration (central or individual). The Statewide CASE Team associated each building in the dataset with prototypes based on the number of stories. Table 75 shows the number of stories associated with each prototype, as well as the number of buildings and dwelling units represented in the data for each prototype.

Table 75: Classification of Project Data into CASE Prototypes by Number of Stories

Prototype	Number of Stories	Number of Buildings Represented	Number of Dwelling Units Represented
Low-Rise Garden	1-2	474	4,720
Low-Rise Loaded Corridor	3	404	7,882
Mid-Rise Mixed Use	4-6	56	4,296
High-Rise Mixed Use	7+	20	3,125

Source: Statewide CASE Team

The Statewide CASE Team totaled the number of dwelling units with central water heating and individual water heating from both the energy consultant data and the HERS Registry data. The Statewide CASE Team used the resulting fraction of the dwelling units with central water heating as the fraction of all newly constructed multifamily dwelling units with central water heating in each climate zone. Table 76 shows the results of this analysis.

Table 76: Central Versus Individual Water Heating by Prototype

Prototype	Individual Water Heating	Central Water Heating
Low-Rise Garden	63%	37%
Low-Rise Loaded Corridor	51%	49%
Mid-Rise Mixed Use	3%	97%
High-Rise Mixed Use	0%	100%

Source: Statewide CASE Team

Table 77 presents the number of dwelling units, both newly constructed and existing, that the Statewide CASE Team assumed would be impacted by the proposed code change during the first year the 2022 code is in effect.

Table 77: Estimated New Construction and Existing Building Stock for Multifamily Buildings by Climate Zone

Building Climate Zone	New Construction in 2023 (dwelling units)			Existing Building Stock in 2023 (dwelling units)		
	Total Dwelling Units Completed in 2023 [A]	Percent of New Dwelling Units Impacted by Proposal [B]	Dwelling Units Impacted by Proposal in 2023 C = A x B	Total Existing Dwelling Units in 2023 [D]	Percent of New Dwelling Units Impacted by Proposal [E]	Dwelling Units Impacted by Proposal in 2023 F = D x E
1	265	79%	209	17,126	0%	0%
2	1,573	79%	1,241	101,721	0%	0%
3	7,630	79%	6,021	530,089	0%	0%
4	3,975	79%	3,137	278,535	0%	0%
5	706	79%	557	44,816	0%	0%
6	3,370	79%	2,659	315,784	0%	0%
7	3,623	79%	2,859	291,804	0%	0%
8	4,738	79%	3,739	489,337	0%	0%
9	11,124	79%	8,778	1,086,699	0%	0%
10	3,930	79%	3,101	316,384	0%	0%
11	1,122	79%	885	81,820	0%	0%
12	6,335	79%	4,999	455,265	0%	0%
13	1,849	79%	1,459	154,048	0%	0%
14	840	79%	663	79,142	0%	0%

15	547	79%	432	40,033	0%	0%
16	339	79%	268	27,505	0%	0%
TOTAL	51,966	79%	41,006	4,310,108	0%	0%

Appendix B: Embedded Electricity in Water Methodology

There are no on-site water savings associated with the proposed code change.

Appendix C: Environmental Impacts Methodology

Greenhouse Gas (GHG) Emissions Factors

As directed by Energy Commission staff, GHG emissions were calculated making use of the average emissions factors specified in the United States Environmental Protection Agency (U.S. EPA) Emissions & Generation Resource Integrated Database (eGRID) for the Western Electricity Coordination Council California (WECC CAMX) subregion (United States Environmental Protection Agency 2018). This ensures consistency between state and federal estimations of potential environmental impacts. The electricity emissions factor calculated from the eGRID data is 240.4 metric tonnes CO2e per GWh. The Summary Table from eGrid 2016 reports an average emission rate of 529.9 pounds CO2e/MWh for the WECC CAMX subregion. This value was converted to metric tons CO2e/GWh.

Avoided GHG emissions from natural gas savings attributable to sources other than utility-scale electrical power generation are calculated using emissions factors specified in Chapter 1.4 of the U.S. EPA's Compilation of Air Pollutant Emissions Factors (AP-42) (United States Environmental Protection Agency 1995). The U.S. EPA's estimates of GHG pollutants that are emitted during combustion of one million standard cubic feet of natural gas are: 120,000 pounds of CO_2 (Carbon Dioxide), 0.64 pounds of N_2O (Nitrous Oxide) and 2.3 pounds of CH_4 (Methane). The emission value for N_2O assumed that low NOx burners are used in accordance with California air pollution control requirements. The carbon equivalent values of N_2O and CH_4 were calculated by multiplying by the global warming potentials (GWP) that the California Air Resources Board used for the 2000-2016 GHG emission inventory, which are consistent with the 100-year GWPs that the Intergovernmental Panel on Climate Change used in the fourth assessment report (AR4). The GWP for N_2O and CH_4 are 298 and 25, respectively. Using a nominal value of 1,000 Btu per standard cubic foot of natural gas, the carbon equivalent emission factor for natural gas consumption is 5,454.4 metric tons CO2e per MMTherms.

GHG Emissions Monetization Methodology

The 2022 TDV energy cost factors used in the lifecycle cost-effectiveness analysis include the monetary value of avoided GHG emissions based on a proxy for permit costs (not social costs). To demonstrate the cost savings of avoided GHG emissions, the Statewide CASE Team disaggregated the value of avoided GHG emissions from the other economic impacts. The authors used the same monetary values that are used in the TDV factors – \$106/$MTCO_2e$.

Water Use and Water Quality Impacts Methodology

There are no impacts to water quality or water use.

Appendix D: California Building Energy Code Compliance (CBECC) Software Specification

Introduction

The purpose of this appendix is to present proposed revisions to CSE that would impact CBECC for both commercial and residential buildings (CBECC- Com and CBECC-Res) along with the supporting documentation that the Energy Commission staff and the technical support contractors would need to approve and implement the software revisions.

Technical Basis for Software Change

This CASE study focuses on efficiency measures to improve pipe insulation and reduce pipe sizes of central recirculation systems. The proposed measures introduce changes to modeling assumptions for central recirculation systems as summarized below. The CASE study does not propose any changes to the overall model method for central recirculation systems.

Submeasure A: Pipe Insulation Verification

The existing ACM Reference Manual uses a correction factor, f_{UA}, to reflect the difference between an ideal pipe heat loss model and actual field performance of recirculation systems. This correction factor captures the combined effect of imperfect insulation, insulation material degradation over time, and additional heat transfer through connected branch pipes, and has a value of 2.0 in the existing ACM Reference Manual. Insulation verification procedures can help to improve the quality of insulation installations and, therefore, lead to a reduced correction factor. The Statewide CASE Team proposes that a new correction factor, f_U, be added to the calculation of pipe heat loss rate to reflect the impact of improvement through insulation verification. CSE needs to be updated to incorporate the new correction factor values for central recirculation systems. In particular, the correction factor value for the Standard Design should be based on a reduced value reflecting the improvement achieved through the new prescriptive requirement of insulation installation verification.

The Statewide CASE Team developed detailed recirculation performance models in an external spreadsheet calculator for the four prototype multifamily buildings to evaluate recirculation system heat loss. The Statewide CASE Team used these models to assess the improvement achieved through insulation verification and developed assumptions for f_U accordingly. Assessment of the impact of imperfect pipe insulation was based on the percentage of the distribution system that is uninsulated, referred as [Percent_uninsulated], provided in Appendix G Table 84. For each prototype building, the Statewide CASE Team performed the following steps of modeling analysis to obtain an estimated f_U:

1. Set f_{UA} = 2.0 and [Percent_uninsulated] = 0 to obtain the baseline recirculation system heat loss, referred as [Heat loss with all field effects].
2. Set f_{UA} = 1.0 and [Percent_uninsulated] = 0 to obtain recirculation system heat loss without any field installation effects, referred as [Heat loss of ideal recirculation].
3. Set f_{UA} = 1.0 and [Percent_uninsulated] = value in Table 84 to obtain recirculation system heat loss with imperfect pipe insulation but without other field effects, referred as [Heat loss with imperfect pipe insulation but without other field effects]
4. Calculate recirculation system heat loss due to imperfect pipe insulation as below:
   [Pipe heat loss due to imperfect pipe insulation] =
   [Heat loss with imperfect pipe insulation but without other field effects] - [Heat loss of ideal recirculation]
5. Calculate recirculation system heat loss with perfect pipe insulation and other field factors as below:
   [Pipe heat loss with perfect pipe insulation and other field effects] =
   [Heat loss with all field effects] (from step 1) - [Pipe heat loss due to imperfect pipe insulation] (from step 4)
6. Perform modeling analysis using different f_{UA} values with [Percent_uninsulated] = 0 until the resulting recirculation system heat loss equals to [Pipe heat loss with perfect pipe insulation and other field factors]. The corresponding f_{UA} values is referred as [corrected f_{UA}].
7. f_U = [corrected f_{UA}] / 2.0

Note that step 5 ignores the interaction between imperfect pipe insulation and other field effects. Improving insulation increases recirculation temperature and, therefore, increases the impact of other field effects. However, the interactive effect is secondary and, therefore, can be neglected. Estimated f_U values for the four prototype buildings are listed below. The Statewide CASE Team proposed to use the average value, 0.8, as the default value for recirculation systems with insulation verification.

- Low-Rise Garden: 0.798
- Low-Rise Loaded Corridor: 0.76
- Mid-Rise Mixed Use: 0.794
- High-Rise Mixed Use: 0.804

Submeasure B: Increased Insulation

This submeasure requires CBECC to be updated to incorporate the updated minimum pipe insulation thickness values. Preliminary tests with CSE indicated that the Title 24, Part 6 mandatory pipe insulation requirements provided in Table 120.3-A were not implemented correctly according to the size of each recirculation pipe section. These errors should also be corrected along with updating the minimum pipe insulation thickness values according to Table 120.3-A in the adopted 2022 Title 24, Part 6.

Submeasure C: CPC Appendix M Pipe Sizing

CPC Appendix M provides an alternative method to size recirculation pipes. Compared to the default pipe sizing method provided by the CPC, Appendix M allows smaller pipes to be used to reduce pipe surface area and, therefore, pipe heat loss. More specifically, Appendix M allows designs with smaller supply pipes based on a more accurate characterization of peak hot water demand from fixtures. The estimates in the default sizing method are considered overly conservative. Appendix M does not affect the size of return pipes, which is determined based on flow requirements to achieve acceptable temperature drop along the recirculation path. The Statewide CASE Team proposes that a new correction factor, f_A, be added to the calculation of pipe heat loss rate to reflect the impact of reduced pipe surface area achieved by following the Appendix M pipe sizing method.

The Statewide CASE Team developed detailed recirculation system designs using both the default pipe sizing method and the Appendix M method for the four multifamily prototype buildings. Calculations predicting the performance of systems with reduced pipe surface areas, calculated following the Appendix M method, were performed to identify the modeling assumptions of f_A.

Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

The change requires the Standard Design to have one recirculation loop, instead of two. The corresponding assumption for the Standard Design in CBECC software needs to be updated accordingly.

Description of Software Change

Background Information for Software Change

Submeasure A: Pipe Insulation Verification

The existing compliance software uses a correction factor to capture the impact on pipe heat loss by multiple system design and installation issues, including imperfect pipe insulation. Improved insulation installation, verified by a HERS Rater or ATT technician, would reduce the impact of imperfect pipe insulation. Accordingly, the pipe heat loss correction factor should be reduced to reflect this improvement. The Statewide CASE Team assessed common recirculation insulation quality issues (Appendix G) and estimated the possible improvement through field verification of installation quality. The Statewide CASE Team further estimated the corresponding reduction of the pipe heat loss correction factor based on modeling analysis. The reduced pipe heat loss correction factor would be incorporated in CBECC and used for buildings with verified recirculation system insulation.

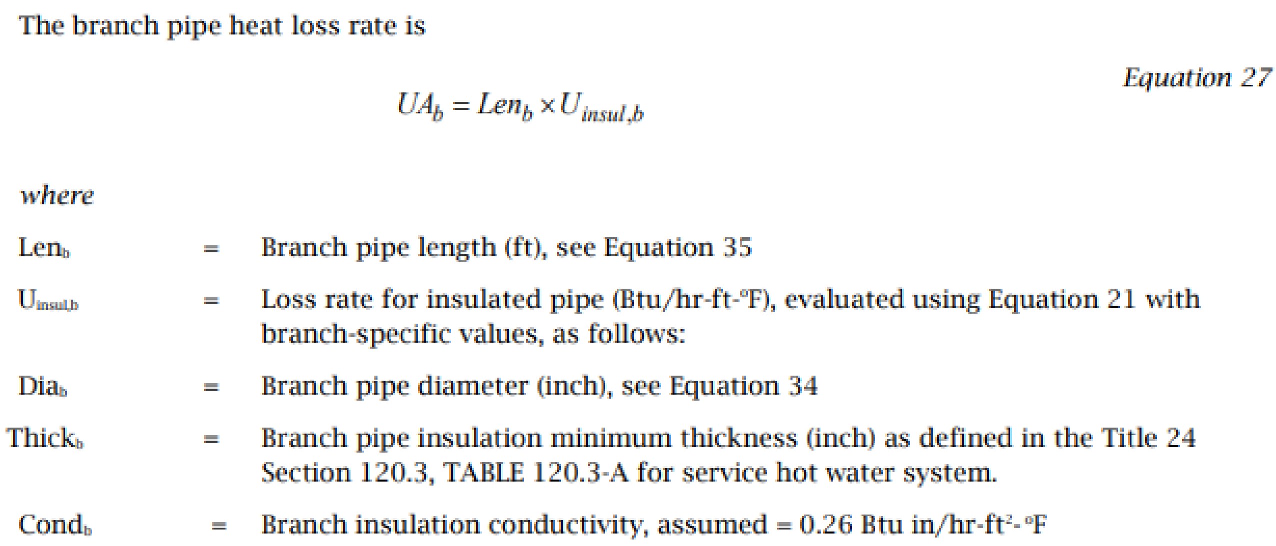
Submeasure B: Increased Insulation

The Statewide CASE Team found that the current CBECC-Res and CBECC-Com do not appear to correctly apply the insulation thickness levels specified in the ACM Reference Manual. The Statewide CASE Team proposes to increase the mandatory minimum pipe insulation for recirculation systems. CBECC needs to incorporate these mandatory insulation requirements, specified according to pipe sizes, for both the standard and proposed designs.

Summary of CBECC-Res and CBECC-Com issues related to insulation thickness follows:

The Statewide CASE Team modeled the low-rise garden and mid-rise mixed use prototypes using CBECC-Res and CBECC-Com, respectively, to determine how insulation is applied to central DHW distribution systems by CSE.

The 2019 Residential ACM Reference Manual Appendix B describes water heating calculation methods. Equation 27 shows how branch pipe heat loss is calculated shown in Figure 4. According to this equation, the insulation thickness variable is specified in Title 24 Part 6 Section 120.3, Table 120.3-A. For reference, Table 120.3-A is presented in Section 7.2.2.



The branch pipe heat loss rate is

Equation 27

$$UA_b = Len_b \times U_{insul,b}$$

where

Len_b = Branch pipe length (ft), see Equation 35

$U_{insul,b}$ = Loss rate for insulated pipe (Btu/hr-ft-°F), evaluated using Equation 21 with branch-specific values, as follows:

Dia_b = Branch pipe diameter (inch), see Equation 34

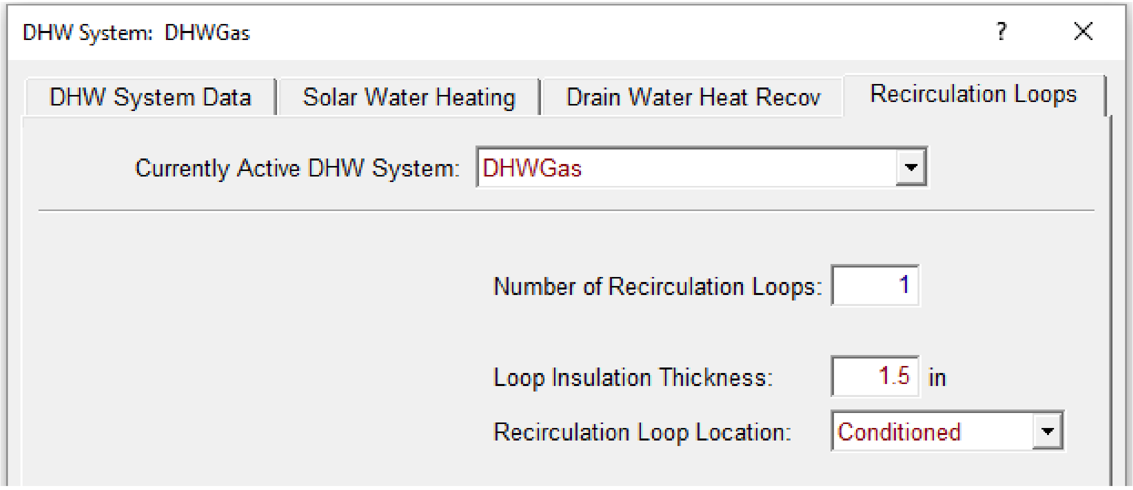
$Thick_b$ = Branch pipe insulation minimum thickness (inch) as defined in the Title 24 Section 120.3, TABLE 120.3-A for service hot water system.

$Cond_b$ = Branch insulation conductivity, assumed = 0.26 Btu in/hr-ft²-°F

Figure 4: Residential ACM Reference Manual Appendix B, Equation 27 - branch pipe heat loss.

Source: (CEC, Residential ACM Reference Manual 2019)

The Statewide CASE Team found that 1.5 inch insulation is applied in the baseline model to each of the six pipe segments comprising the supply and return pipe sections in the DHW distribution system in the low-rise garden prototype. The proposed insulation thickness is applied based on a user input in the CBECC-Res graphical user interface shown in Figure 5 if the user models a central distribution system with a recirculation loop. The insulation defined in this user input is applied to all six pipe segments regardless of pipe diameter. Therefore, CBECC-Res applies insulation thickness differently than what is described in the ACM Reference Manual.



Currently Active DHW System: DHWGas

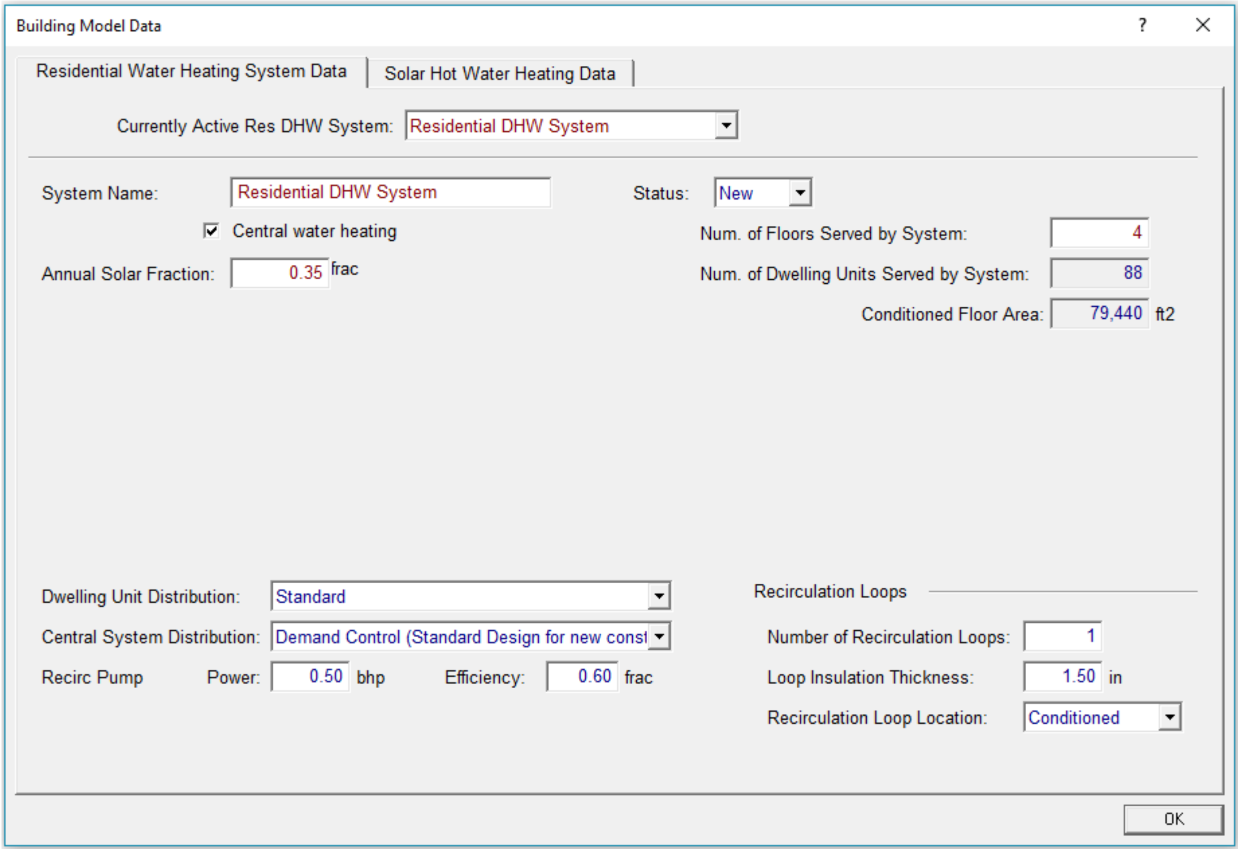
Number of Recirculation Loops: 1

Loop Insulation Thickness: 1.5 in

Recirculation Loop Location: Conditioned

Figure 5: CBECC-Res graphical user interface – insulation thickness input.

The Statewide CASE Team found that CBECC-Com applies insulation to DHW distribution systems with a user input for the baseline and proposed cases to all six pipe sections shown in the CBECC-Com user interface in Figure 6 when the building is modeled with central water heating system and a recirculation distribution system. The same insulation thickness is applied to the baseline and standard models leading to no energy savings if insulation thicker than code requirements is installed and modeled. This insulation thickness specification does not follow the ACM Reference Manual description of how insulation thickness is determined.



Currently Active Res DHW System: Residential DHW System

System Name: Residential DHW System

Status: New

☑ Central water heating

Num. of Floors Served by System: 4

Annual Solar Fraction: 0.35 frac

Num. of Dwelling Units Served by System: 88

Conditioned Floor Area: 79,440 ft2

Dwelling Unit Distribution: Standard

Central System Distribution: Demand Control (Standard Design for new const

Recirc Pump Power: 0.50 bhp Efficiency: 0.60 frac

Number of Recirculation Loops: 1

Loop Insulation Thickness: 1.50 in

Recirculation Loop Location: Conditioned

Figure 6: CBECC-Com user interface recirculation loop insulation thickness user input.

Submeasure C: CPC Appendix M Pipe Sizing

Pipe sizing based on CPC Appendix M yields smaller recirculation supply pipes and, therefore, smaller pipe surface area. The Statewide CASE Team assessed the supply pipe surface area reduction achieved by using the Appendix M pipe sizing method for the four prototype buildings. The results, as shown in Figure 7, indicate a linear correlation between supply pipe area reduction and number of dwelling units, as shown by the lineal curve-fit solid line in Figure 7. The dashed red line (almost overlapping with the solid line) shows a simple linear approximation assuming that pipe area reduction increases linearly from 15 percent for an 8-unit multifamily building to 25 percent for a 120-unit multifamily building.

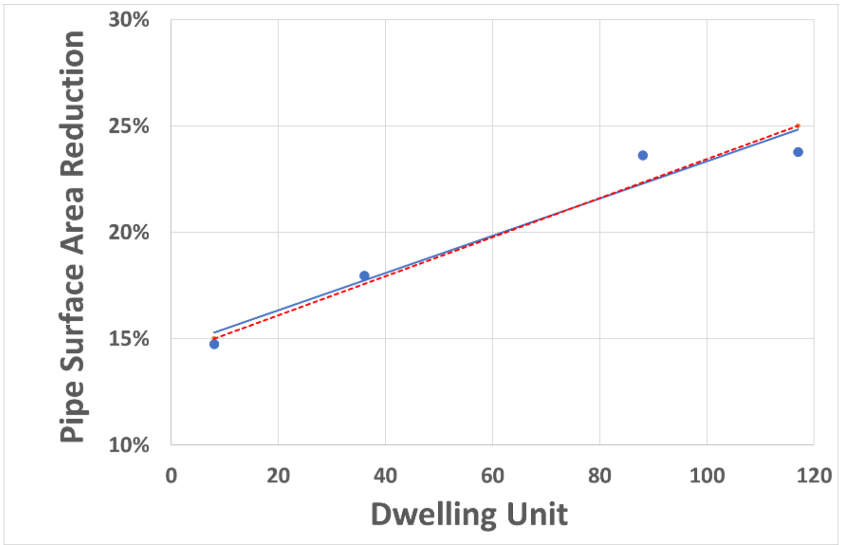


Figure 7: Recirculation supply pipe area reduction using CPC Appendix M.

The Statewide CASE Team used this correlation to develop a pipe surface area correction factor (f_A, described in Section 2.6.4.1) to be applied to the pipe heat loss rate calculation. The Statewide CASE Team also proposes that the supply pipe surface area reduction is set to 15 percent for buildings with fewer than eight (8) dwelling units and capped at 25 percent for buildings with more than 120 dwelling units.

Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

CBECC-Com and CBECC-Res would be updated to use a default of one recirculation loop in the baseline model.

Existing CBECC- Com and CBECC-Res Modeling Capabilities

Submeasure A: Pipe Insulation Verification

The existing CBECC software includes the modeling capabilities to model performance degradation due to imperfect pipe insulation.

Submeasure B: Increased Insulation

The existing CBECC software includes the modeling capabilities to model thicker pipe insulation.

Submeasure C: CPC Appendix M Pipe Sizing

The existing CBECC software follows algorithms provided in ACM Reference Manual Appendix B Section B5 to model recirculation system heat loss. Pipe heat loss is determined by pipe heat loss rate (UA value) and temperature difference between the water temperature and ambient temperature. The former depends on both pipe insulation conditions and pipe surface area. The existing ACM Reference Manual algorithms can be used to assess pipe heat loss for recirculation systems with reduced pipe sizes, but do not include a method to determine pipe sizes based on CPC Appendix M. However, this modeling capability can be achieved through a minor change to the existing ACM Reference Manual algorithms for recirculation pipe heat loss calculation.

Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

The existing CBECC software includes the modeling capabilities to model multiple-loop designs.

Summary of Proposed Revisions to CBECC-Com and CBECC-Res

The Statewide CASE Team proposes the following changes to California Simulation Engine (CSE) to improve modeling capabilities for central DHW recirculation systems.

- Modify the calculation formula and assumptions for pipe heat loss rate:
  - Add a new option for pipe heat loss correction factor (f_U) to reflect the insulation improvement achieved through installation verification described in 7.4.1 Submeasure A: Pipe Insulation Verification.
  - Update pipe insulation minimum thickness values ($Thick_n$) according to related update of Title 24, Part 6 Section 120.3, Table 120.3-A.
  - Add a new correction factor (f_A) to reflect the improvement due to pipe size reduction described in 7.4.3 Submeasure C: CPC Appendix M Pipe Sizing.
- Modify the assumption for the Standard Design by setting the number of recirculation loops to 1.
- Add two Boolean input fields (True or False) used to determine the correct values for the correction factors f_U and f_A, respectively. The text for the Boolean input fields should read as follows:
  - Is the recirculation system insulation verified by a HERS Rater or ATT?
  - Is CPC Appendix M used for pipe sizing?

User Inputs to CBECC-Com and CBECC-Res

Submeasure A: Pipe Insulation Verification

This submeasure requires a user input to indicate if pipe insulation is verified by a HERS Rater or ATT.

Input message/question: Is the recirculation system insulation verified by a HERS Rater or ATT?

Input value option: Yes or No.

Submeasure B: Increased Insulation

This submeasure does not require new user input.

Submeasure C: CPC Appendix M Pipe Sizing

This submeasure requires a user input to indicate if the supply pipes in the recirculation loop were sized following the default option or Appendix M in the CPC.

Input message/question: Is CPC Appendix M used for pipe sizing?

Input value option: Yes or No.

Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

This submeasure does not require new user input.

Simulation Engine Inputs

EnergyPlus/California Simulation Engine Inputs

Section 7.4 provides detailed information on changes to ACM Reference Manual. CSE updates should follow the revised ACM Reference Manual Appendix B Section B.5.

Calculated Values, Fixed Values, and Limitations

Submeasure A: Pipe Insulation Verification

The CSE update for this submeasure requires adding a Boolean specifying whether the building would have verified insulation installation. A negative (False) input would lead to the use of the default pipe insulation correction factor (f_U) of 1.0 and a positive (True) input would lead to the use of a low pipe insulation correction factor (f_U) defined in the ACM Reference Manual.

Submeasure B: Increased Insulation

This submeasure does not involve new CSE input.

Submeasure C: CPC Appendix M Pipe Sizing

The CSE update for this submeasure requires adding a Boolean input specifying whether the proposed design uses CPC Appendix M to determine recirculation pipe sizes. A negative (False) input would lead to the use of the default pipe surface area correction factor (f_A) of 1.0 and a positive (True) input would lead to the use of a low pipe surface area correction factor (f_A) defined in the ACM Reference Manual.

Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

This submeasure does not involve new CSE input.

Alternate Configurations

The proposed measures do not require any alternative configurations related to recirculation distribution systems.

Simulation Engine Output Variables

Submeasure A: Pipe Insulation Verification

If pipe insulation verification is performed and the corresponding CBECC user input is “Yes”, Hourly recirculation loop pipe heat loss (HRLL) is expected to decrease by approximately 20 percent.

Submeasure B: Increased Insulation

This Submeasure does not involve new CBECC output.

Submeasure C: CPC Appendix M Pipe Sizing

If recirculation pipes are sized according to CPC Appendix M and the corresponding CBECC user input is “Yes”, Hourly recirculation loop pipe heat loss (HRLL) would be reduced by 15 percent to 25 percent depending on number of dwelling units served by the water heating system.

Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

This submeasure does not involve new CBECC output.

Compliance Report

Submeasure A: Pipe Insulation Verification

CBECC would generate a new compliance form shown in Section 7.6.1 when the prescriptive requirement for Pipe Insulation Verification is selected.

Submeasure B: Increased Insulation

The submeasure does not require any changes to compliance reports.

Submeasure C: CPC Appendix M Pipe Sizing

CBECC would generate a new table in the compliance forms as shown in Section 7.6.3 when the compliance option alternative pipe sizing based on CPC Appendix M is selected.

Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

The submeasure does not require any changes to compliance reports.

Compliance Verification

Submeasure A: Pipe Insulation Verification

Compliance with this submeasure would be verified by a HERS Rater or ATT.

Submeasure B: Increased Insulation

This submeasure would be verified through normal building inspection process, which should include verification of pipe insulation according to building code requirements.

Submeasure C: CPC Appendix M Pipe Sizing

This submeasure would be verified through a building plan review and a new entry in the compliance forms with indicate the location of the CPC Appendix M pipe sizing on the plans.,

Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

This submeasure does not require new compliance verification.

Testing and Confirming CBECC-Com and CBECC-Res Modeling

The Statewide CASE Team found that the existing CBECC-Res and CBECC-Com software may have some errors (see the section on Description of Software Change). These errors need to be corrected before testing and validating new modeling capabilities for implementing the submeasures proposed by this CASE Report. Ideally, the full modeling capabilities of central recirculation systems need to be tested and validated to ensure consistency with the model algorithms specified in the ACM Reference Manual Appendix B Section B5.

The modeling analysis conducted by the Statewide CASE Team was based on detailed recirculation system designs, not simplified recirculation models according to ACM Reference Manual. Therefore, energy impact analysis results provided by the Statewide CASE Team are not suitable for testing and validating CBECC-Res and CBECC-Com modeling capabilities. Separate analysis based on ACM Reference Manual needs to be conducted to provide data to support testing and validation of CBECC-Res and CBECC-Com software. For example, based on rules provided in the ACM Reference Manual, Excel spreadsheet based recirculation performance model for the four prototype buildings can be developed. The corresponding modeling output can be used to validate CBECC-Res and CBECC-Com software. This approach was used during 2013 Title 24, Part 6 development to support the development of existing central recirculation system model used in CSE.

Using the Excel spreadsheet-based recirculation performance model, testing cases for each submeasure can be developed, as listed below.

Submeasure A: Pipe Insulation Verification

Two cases with different f_U values: 1 and reduced value for insulation verification, for each prototype building

Submeasure B: Increased Insulation

One case for each prototype building using pipe insulation specification provided in Title 24, Part 6 Table 120.3-A

Submeasure C: CPC Appendix M Pipe Sizing

Two cases with different f_A values: 1 and reduced value according to the ACM Reference Manual specification, for each prototype building

Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

Two cases for each prototype buildings: one using one-loop design and the other using two-loop design.

Validate that the Standard Design provides the same output as the one-loop design.

Description of Changes to ACM Reference Manual

Changes to the ACM Reference Manual are in Section 7.4 of this report.

Appendix E: Impacts of Compliance Process on Market Actors

This appendix discusses how the recommended compliance process, which is described in Section 2.5, could impact various market actors. Table 78 identifies the market actors who would play a role in complying with the proposed change, the tasks for which they would be responsible, their objectives in completing the tasks, how the proposed code change could impact their existing work flow, and ways negative impacts could be mitigated. The information contained in Table 78 is a summary of key feedback the Statewide CASE Team received when speaking to market actors about the compliance implications of the proposed code changes. Appendix F summarizes the stakeholder engagement that the Statewide CASE Team conducted when developing and refining the code change proposal, including gathering information on the compliance process.

Pipe Insulation Verification

Pipe insulation verification builds on an existing pipe insulation compliance credit available only to single family and low-rise multifamily buildings. The proposed measure requires field verification of pipe insulation quality for DHW recirculation piping. The scale and required coverage in verifying multifamily DHW pipe insulation adds time and complexity to the construction and installation process. Multiple verification visits may be needed as plumbing insulation is often phased with other trades on site, particularly for larger buildings. HERS Raters or ATTs would require initial training to familiarize with verification procedures and scope. Management of the proposed compliance forms and data registry follows existing protocols.

Increased Insulation

Overall increasing insulation for pipe diameters two inches and larger entails similar compliance and enforcement activities as currently required. The proposed insulation increase applies to larger pipe diameters used primarily for recirculation and not in-unit portions of DHW piping. Alignment of multifamily pipe insulation levels regardless of building height provide consistency for enforcement. Compliance processes for market actors remain the same beyond updating reference insulation thickness requirements.

Appendix M Pipe Sizing

Allowing Appendix M Sizing methodology via incorporating the information in existing compliance forms introduces minimal changes to compliance and enforcement activities. Plumbing designers would provide additional design documentations if they choose to exercise this compliance option and submit the CF1R-PLB form as part of the permit application documents.

Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option

Feedback from Statewide CASE Team’s interviews with plumbing designers show there exists general confusion over the definition and practicality of implementing multiple-loop DHW recirculation systems. Beyond changing this from a prescriptive requirement to a performance credit, there are no compliance or enforcement changes.

Table 78: Roles of Market Actors in the Proposed Compliance Process

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Submeasure A: Pipe Insulation Verification				
Plumbing Designer	Plumbing designers note requirement for HERS verification and provide compliance form on drawings when prescriptive approach is used.	Demonstrate compliance.	NA	Designer notes serve as a prompt to the General Contractor to anticipate HERS verification coordination.
Energy Consultant	Energy consultants make the desired pipe insulation verification selection (Y/N) in the compliance software for the project if taking the performance approach.	Demonstrate compliance with modeling results.	Minor increased in efforts.	NA
Contractor/ Installers	• GC coordinates with trades for verification visits, whether grouped with QII and other measures or standalone. • Insulation installers follow GC instructions to enable visual inspections.	• Quickly and easily determine requirements based on scope (covered on form). • Quickly complete compliance documents. • Streamline coordination with other team members.	Increased needs for coordination to time and schedule verification visits.	Pipe insulation certification of installation forms (CF2R) can be signed off by trades or by GC to streamline the process.
HERS Rater	HERS Raters perform new HERS verification for pipe insulation quality	• Quickly complete compliance documents. • Easily identify noncompliant installation. • Minimize coordination during construction.	Increased needs for coordination to schedule verification visits.	Verification visits may be grouped with other HERS measures as feasible.
Submeasure B: Increased Insulation				

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Plumbing Designer	Designers who issue specifications that include a table of insulation thicknesses would need to update their specifications to reflect new insulation thickness requirements.	• Demonstrate compliance • Clearly communicate requirements to contractors.	Minor increase in requirement detail initially.	Insulation requirements are housed in the same multifamily table, whereas they previously followed two different tables based on the building's low-rise or high-rise designation.
Contractor/ Installers	Installer needs to install increased insulation thickness on pipes larger than 2 inches, and confirm on CR2R compliance forms.	• Quickly and easily determine requirements. • Quickly complete compliance documents. • Streamline coordination with other team members.	Increase in observing and following requirement change initially.	Plumbers may need to change practices to allow clearance around the piping for the 2-inch thick insulation.
Submeasure C: CPC Appendix M Sizing				
Plumbing Designer	Plumbing designers have the option to perform pipe sizing calculations and design tasks and would submit the Certificate of Compliance form accordingly.	• Quickly and easily determine requirements based on scope. • Streamline coordination with other team members. • Clearly communicate system requirements to contractors.	Designers need expertise in the new methodology if electing to use the compliance method for credit.	NA
Energy Consultant	Energy consultants make the desired CPC Appendix M Sizing selection (Y/N) in the compliance software if taking the compliance credit.	• Demonstrate compliance with modeling results. • Streamline coordination with other team members.	Minor increase in effort.	NA
Plans Examiner	Plan Examiner reviews the Certificate of Compliance on pipe sizing.	Check for information and documentation completeness and accuracy.	Increase level of effort.	NA
Change Existing Requirement for Two-Loop Recirculation Systems to a Compliance Option				

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Plumbing Designer	Plumbing designers continue to exercise design options in terms of recirculation system layout.	• Quickly and easily determine requirements based on scope. • Streamline coordination with other team members. • Clearly communicate system requirements to contractors.	NA	NA
Energy Consultant	Energy consultants make the desired multiple recirculation loop selection (Y/N) in the compliance software if taking the compliance credit.	• Demonstrate compliance with modeling results. • Streamline coordination with other team members.	Minor increase in effort.	NA
HERS Rater	HERS Raters perform verification when this compliance option is taken.	• Quickly complete compliance documents. • Easily identify noncompliant substitutions. • Minimize coordination during construction.	Decrease in level of effort due to the measure changing from a prescriptive requirement to a compliance option.	NA.

Appendix F: Summary of Stakeholder Engagement

Collaborating with stakeholders that might be impacted by proposed changes is a critical aspect of the Statewide CASE Team's efforts. The Statewide CASE Team aims to work with interested parties to identify and address issues associated with the proposed code changes so that the proposals presented to the Energy Commission in this CASE Report are generally supported. Public stakeholders provide valuable feedback on draft analyses and help identify and address challenges to adoption including: cost effectiveness; market barriers; technical barriers; compliance and enforcement challenges; or potential impacts on human health or the environment. Some stakeholders also provide data that the Statewide CASE Team uses to support analyses.

This appendix summarizes the stakeholder engagement that the Statewide CASE Team conducted when developing and refining the recommendations presented in this report.

Utility-Sponsored Stakeholder Meetings

Utility-sponsored stakeholder meetings provide an opportunity to learn about the Statewide CASE Team's role in the advocacy effort and to hear about specific code change proposals that the Statewide CASE Team is pursuing for the 2022 code cycle. The goal of stakeholder meetings is to solicit input on proposals from stakeholders early enough to ensure the proposals and the supporting analyses are vetted and have as few outstanding issues as possible. To provide transparency in what the Statewide CASE Team is considering for code change proposals, during these meetings the Statewide CASE Team asks for feedback on:

- Proposed code changes
- Draft code language
- Draft assumptions and results for analyses
- Data to support assumptions
- Compliance and enforcement, and
- Technical and market feasibility

The Statewide CASE Team hosted two stakeholder meetings for multifamily domestic hot water measures via webinar. Please see below for dates and links to event pages on Title24Stakeholders.com. Materials from each meeting. Such as slide presentations, proposal summaries with code language, and meeting notes, are included in the bibliography section of this report (Statewide CASE Team 2019).

Table 79: Stakeholder Meetings

Meeting Name	Meeting Date	Event Page from Title24stakeholders.com
Multifamily and Nonresidential Water Heating Utility-Sponsored Stakeholder Meeting	Tuesday, October 3, 2019	https://title24stakeholders.com/event/multifamily-water-heating-utility-sponsored-stakeholder-meeting/
Water Heating and Multifamily All Electric Package Stakeholder Meeting	Tuesday, March 17, 2020	https://title24stakeholders.com/event/water-heating-and-multifamily-all-electric-package/

The first round of utility-sponsored stakeholder meetings occurred from September to November 2019 and were important for providing transparency and an early forum for stakeholders to offer feedback on measures being pursued by the Statewide CASE Team. The objectives of the first round of stakeholder meetings were to solicit input on the scope of the 2022 code cycle proposals; request data and feedback on the specific approaches, assumptions, and methodologies for the energy impacts and cost-effectiveness analyses; and understand potential technical and market barriers. The Statewide CASE Team also presented initial draft code language for stakeholders to review.

The second round of utility-sponsored stakeholder meetings occurred from March to May 2020 and provided updated details on proposed code changes. The second round of meetings introduced early results of energy, cost effectiveness, and incremental cost analyses, and solicited feedback on refined draft code language.

Utility-sponsored stakeholder meetings were open to the public. For each stakeholder meeting, two promotional emails were distributed from info@title24stakeholders.com One email was sent to the entire Title 24 Stakeholders listserv, totaling over 1,900 individuals, and a second email was sent to a targeted list of individuals on the listserv depending on their subscription preferences. The Title 24 Stakeholders' website listserv is an opt-in service and includes individuals from a wide variety of industries and trades, including manufacturers, advocacy groups, local government, and building and energy professionals. Each meeting was posted on the Title 24 Stakeholders' LinkedIn page[11] (and cross-promoted on the Energy Commission LinkedIn page) two weeks before each meeting to reach out to individuals and larger organizations and channels outside of the listserv. The Statewide CASE Team conducted extensive personal outreach to stakeholders identified in initial work plans who had not yet opted into the listserv. Exported webinar meeting data captured attendance numbers and individual comments,

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[11] Title 24 Stakeholders' LinkedIn page can be found here: https://www.linkedin.com/showcase/title-24-stakeholders/.

and recorded outcomes of live attendee polls to evaluate stakeholder participation and support.

Statewide CASE Team Communications

The Statewide CASE Team held personal communications over email and phone with numerous stakeholders shown in Table 80 when developing this report.

Table 80: Domestic Hot Water Distribution Stakeholders

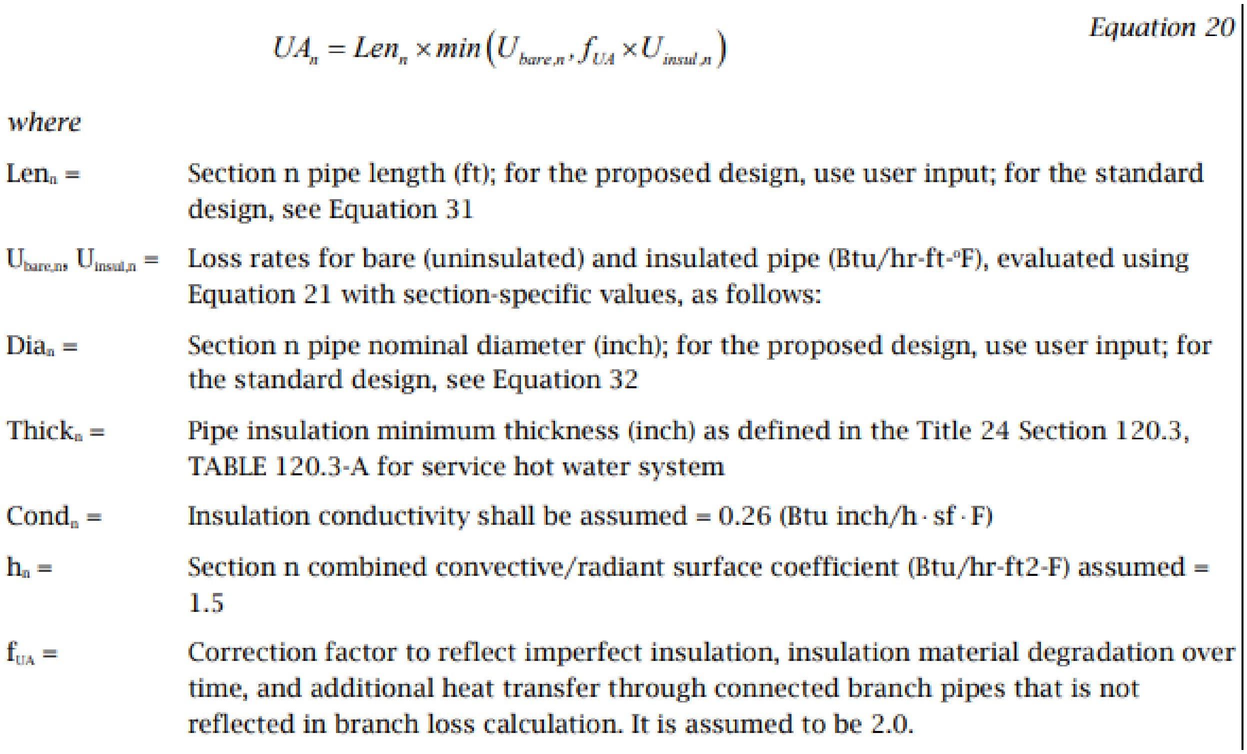
Organization	Person	Role
Gabel Energy	Gina Rodda	Consultant
Gary Klein and Associates	Gary Klein	Consultant
Guttman & Blaevoet Consulting Engineers	Ted Tiffany	Engineer/Designer
Guttman & Blaevoet Consulting Engineers	Steve Guttmann	Engineer/Designer
Guttman & Blaevoet Consulting Engineers	Jeff Blaevoet	Engineer/Designer
Hot Water Research	Jim Lutz	Consultant
Integral Group	Miguel Garcia	Engineer/Designer
Integral Group	Andy Reilman	Engineer/Designer
P2S Inc	Kent Peterson	Engineer/Designer
P2S Inc	Cindy Callaway	Engineer/Designer
P2S Inc	Nathan Ho	Engineer/Designer
P2S Inc	Hye Jin Kim	Engineer/Designer
Smith Group	Stet Sanborn	Engineer/Designer
Taylor Engineering	Bill Stahl	Engineer/Designer
TEP Engineering	Tim Souza	Engineer/Designer
UC Davis	David Vernon	Researcher

Appendix G: Insulation Quality Data Collection Results

This appendix includes a summary of the current ACM Reference Manual, a summary of data collection activities and results performed by the Statewide CASE Team, and an overview of the calculations that were completed to generate energy calculation inputs for pipe insulation quality.

Current ACM

The 2019 ACM Reference Manual requires the inclusion of a correction factor of two for pipe insulation U-factor, effectively doubling the heat loss from pipes compared to perfect insulation. The 2019 ACM Reference Manual describes in Equation 20 of Appendix B the correction factor as a “Correction factor to reflect imperfect insulation, insulation material degradation over time, and additional heat transfer through connected branch pipes that is not reflected in branch loss calculation. It is assumed to be 2.0.” Please see Figure 8 for reference.



Equation 20

$$UA_n = Len_n \times min\left(U_{bare,n}, f_{UA} \times U_{insul,n}\right)$$

where

Len_n = Section n pipe length (ft); for the proposed design, use user input; for the standard design, see Equation 31

$U_{bare,n}$, $U_{insul,n}$ = Loss rates for bare (uninsulated) and insulated pipe (Btu/hr-ft-°F), evaluated using Equation 21 with section-specific values, as follows:

Dia_n = Section n pipe nominal diameter (inch); for the proposed design, use user input; for the standard design, see Equation 32

$Thick_n$ = Pipe insulation minimum thickness (inch) as defined in the Title 24 Section 120.3, TABLE 120.3-A for service hot water system

$Cond_n$ = Insulation conductivity shall be assumed = 0.26 (Btu inch/h · sf · F)

h_n = Section n combined convective/radiant surface coefficient (Btu/hr-ft2-F) assumed = 1.5

f_{UA} = Correction factor to reflect imperfect insulation, insulation material degradation over time, and additional heat transfer through connected branch pipes that is not reflected in branch loss calculation. It is assumed to be 2.0.

Figure 8: 2019 ACM Reference Manual Appendix B Equation 20 insulation derating formula.

Source: (CEC, Residential ACM Reference Manual 2019)

The current correction factor was adopted in 2013 Title 24, Part 6 as a result of the 2013 PIER Report "Multifamily Central Domestic Hot Water Distribution Systems" (PIER 2013). The 2013 PIER study did not collect sufficient data to provide a breakdown of the percentage of heat losses that occurs through the three mechanisms mentioned in the ACM Reference Manual, although the study and subject matter experts on the Statewide CASE Team who participated in the PIER study suggest that a significant portion is due to imperfect insulation.

Insulation Quality Issues

The Statewide CASE Team determined the following issues to be commonly found in piping insulation:

- Missing insulation on fittings, valves, pumps, and straight pipe
- Damaged and poorly installed insulation
- Metal hangers that are not thermally isolated from metal pipe

The Association for Energy Affordability (AEA) and Taylor Engineering (a mechanical design firm) provided photos of these piping insulation issues they have seen in buildings. AEA's photos came from various multifamily buildings that had completed a utility incentive program, while Taylor Engineering's photos came from a dormitory building that they designed at UC Merced. The Statewide CASE Team also conducted a site visit of a small commercial building under construction and documented similar issues. Figure 9 through Figure 15 show some of these examples. Figure 10 is a thermal image of an uninsulated valve, illustrating heat losses due to a lack of insulation.

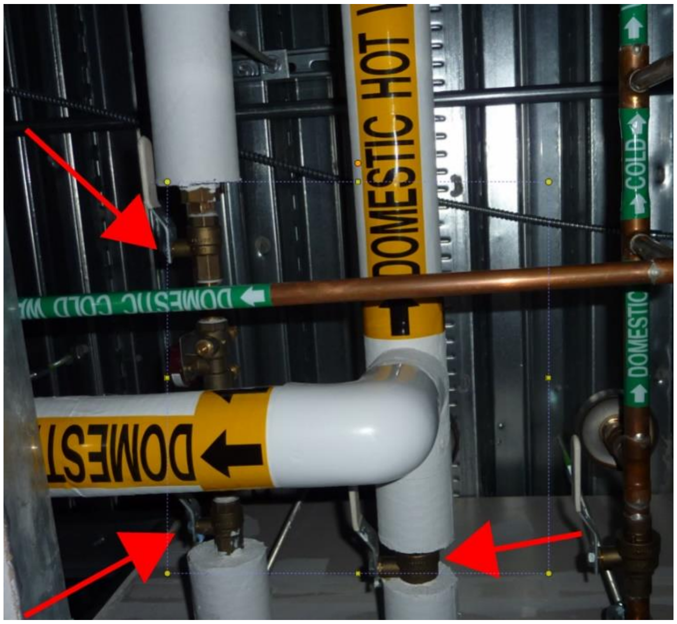


Figure 9: Uninsulated valves.

Source: (Taylor Engineering n.d.).

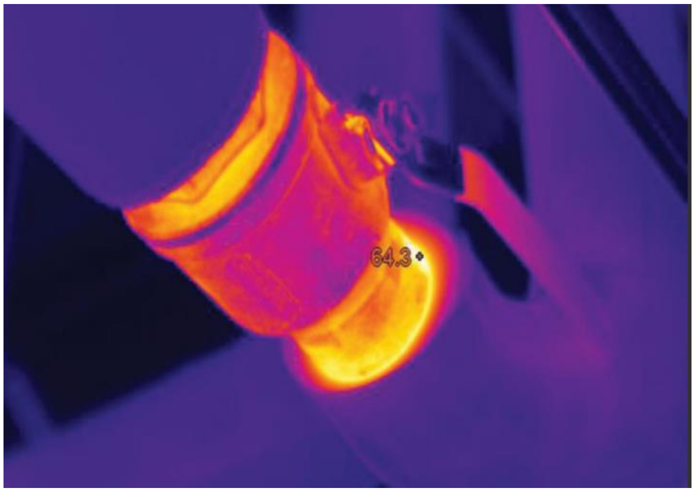


Figure 10: Thermal image of uninsulated valve.

Source: (Center for the Build Environment n.d.).

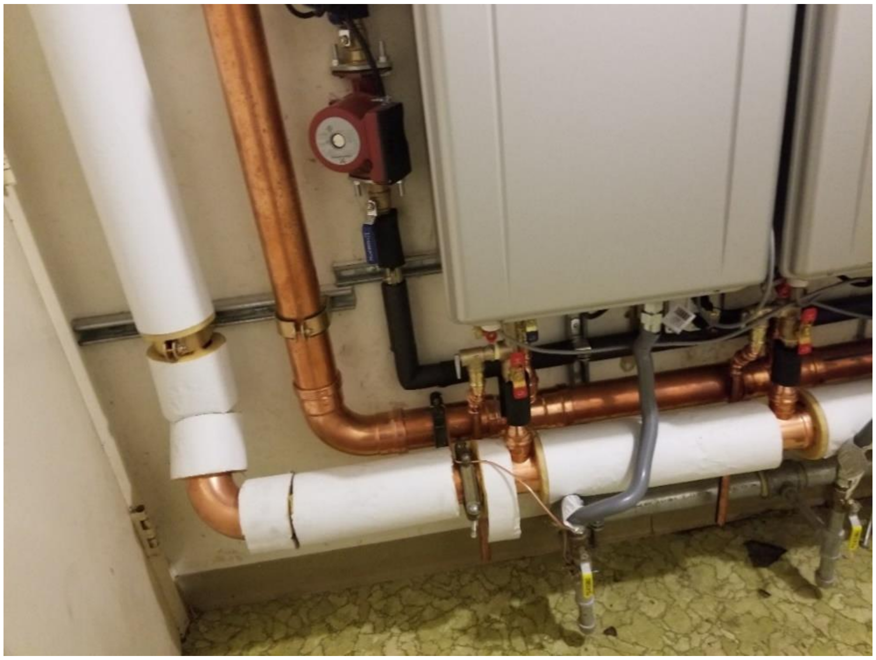


Figure 11: Uninsulated fittings and valves.

Source: (AEA n.d.).

Figure 12: Metal hangers not thermally isolated from metal pipe.

Source: (Statewide CASE Team n.d.).

Figure 13: Metal hangers not thermally isolated from metal pipe.

Source: (Taylor Engineering n.d.).

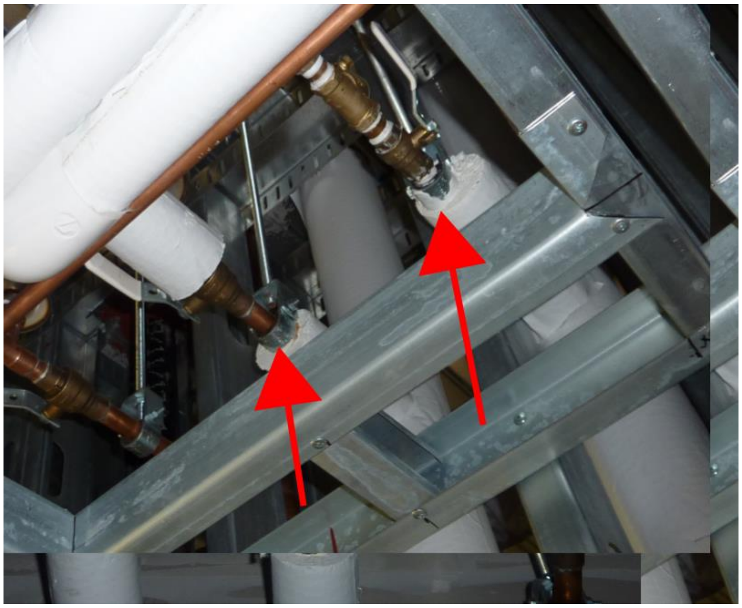


Figure 14: Metal hangers not thermally isolated from metal pipe, uninsulated valves, and gaps in insulation.

Source: (Taylor Engineering n.d.).

Figure 15: Poorly installed insulation.

Source: (AEA n.d.).

Frequency of Insulation Quality Issues

The Statewide CASE Team developed and distributed a web-based survey to construction managers and designers in order to determine how frequently each of the insulation quality issues described above occurred. The Statewide CASE Team developed a list of potential survey respondents through existing Statewide CASE Team relationships and industry contacts. The Statewide CASE Team sent out the survey to nine individuals representing seven different organizations and fifteen individuals responded. One of the interviewees distributed the survey inside their organization which led to a higher number of responses than the number of individuals to which the Statewide CASE Team distributed the survey. Some respondents did not respond to all questions, so the number of respondents that answered each question varies.

The survey asked two questions regarding the respondent's industry experience. Figure 16 shows the types of multifamily building with which the respondents typically work. Note that respondents were instructed to choose all that applied. Figure 17 shows the approximate number of projects in which the respondents have observed the quality of DHW pipe insulation.

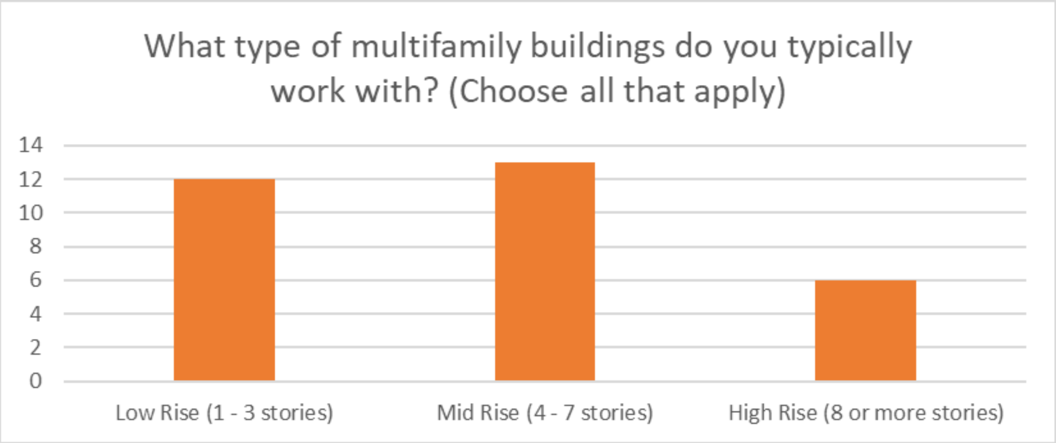


Figure 16: Type of multifamily building with which respondents work.

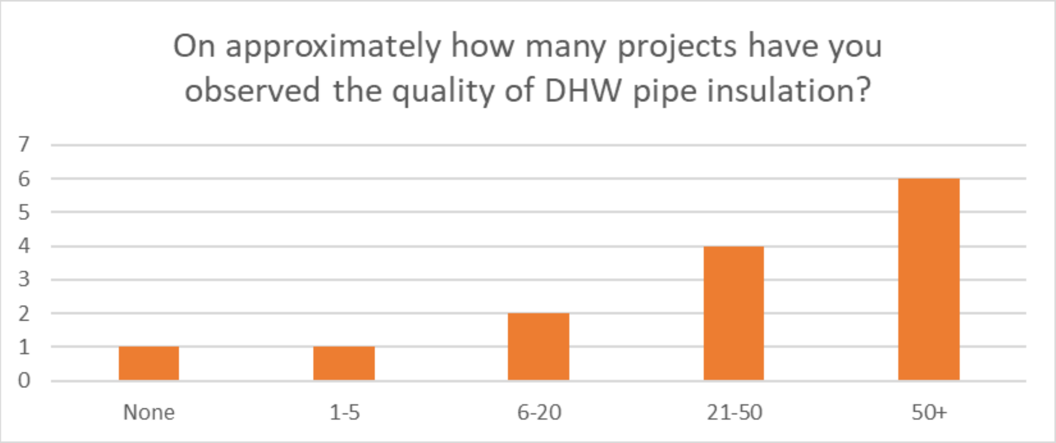


Figure 17: Approximate number of projects in which respondent has observed the quality of DHW pipe insulation.

The survey asked respondents how often pipe insulation is not installed correctly, with the following multiple-choice answers:

a. Never
b. <25% of projects have deficiencies
c. 25%-50% of projects have deficiencies
d. 50%-75% of projects have deficiencies
e. >75% of projects have deficiencies

Figure 18 gives a summary of the responses.

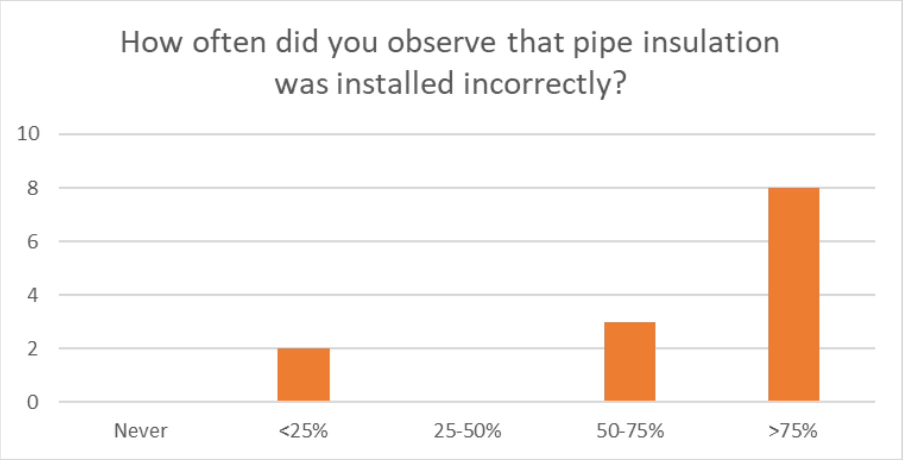


Figure 18: How often respondents observe deficiencies in pipe insulation installation.

Lastly, the survey asked for projects where insulation was installed incorrectly, what proportion of the insulation installation had the following issues:

- Valves are not insulated
- Fittings are not insulated
- Hangers are not thermally isolated from pipe (horizontal pipes)
- Pipe insulation is poorly installed
- Insulation is damaged
- Run outs are not insulated when specified or required by code
- Pumps are not insulated

For each issue, respondents were to select a frequency from the following range:

- 0%
- <20%
- 20-40%
- 40-60%
- 60-80%

- >80%

Table 81 summarizes the responses and presents the weighted average prevalence of each issue.

Table 81: Percent of Projects with Insulation Quality Issues by Insulation Quality Issue

Percent of Installation with Issue	0%	< 20%	20 - 40%	40 - 60%	60 - 80%	> 80%	Weighted Average
Valves are not insulated	0	0	1	0	3	7	79%
Fittings are not insulated	0	1	0	1	5	4	70%
Hangers are not thermally isolated from pipe (horizontal pipes)	0	0	2	1	3	5	70%
Pipe insulation is poorly installed	0	1	1	3	4	2	59%
Insulation is damaged	1	2	4	0	2	2	42%
Run outs are not insulated when specified or required by code	0	2	2	5	2	0	43%
Pumps are not insulated	0	1	0	0	1	9	81%

Source: Statewide CASE Team

In addition to the survey of construction managers and designers, the Statewide CASE Team collected data on the frequency of insulation quality issues through interviews of designers, polls during a stakeholder meeting, and conversations with other stakeholders and subject matter experts.

A summary of the data source, the questions asked, and the responses received are described below. These responses corroborated the results of the survey of construction managers and designers. Therefore, the Statewide CASE Team used the results of the survey of construction managers and designers in its quantitative analysis, as described below.

The Statewide CASE Team conducted interviews with plumbing designers from six different design and construction management firms. The interviewees have worked on a range of building types, including low-rise multifamily, mid-rise multifamily, and high-rise multifamily, as well as nonresidential buildings. The Statewide CASE Team asked designers to respond specifically about multifamily buildings. The questions asked and a summary of the responses are provided below:

Question 1: Are valves and fittings typically insulated? If so, how is this typically done?

Summary of Responses to Question 1: The majority of interviewees said that valves and fittings should be insulated but often are not. One designer mentioned that they add this item to a punch list, and it is often not fixed afterwards. Another designer mentioned that the reason for this issue is that insulation contractors are more expensive, so plumbing contractors insulate themselves and don’t insulate fully or correctly.

Question 2: Are hangers typically thermally isolated from the piping? If so, how is this typically done?

Summary of Responses to Question 2: The interviewees responded that hangers are typically thermally isolated from piping and it is done with pieces of “Therma Cell” insulation, plastic insulators, or calcium silicate inserts in the hangers.

Question 3: How often is insulation not installed correctly? For projects where it is incorrectly installed, what are the typical issues? Gaps? Damaged insulation? Uninsulated fittings or valves? Does this vary by multifamily building type: low-, mid-, and high-rise?

Summary of Responses to Question 3: The Statewide CASE Team received a variety of responses on this question with some designers flagging certain issues and other designers flagging other issues. All but one interviewee responded that insulation quality issues are common. The interviewees responded that it is uncommon to see portions of pipe totally uninsulated, but it was very common to see fittings, or valves uninsulated as well as small gaps on various portions of the DHW Distribution system.

The Statewide CASE Team also conducted a poll during the first stakeholder meeting, which was held on October 3, 2019. The results are summarized in Figure 19 and Figure 20. The first question asked about how often projects have insulation deficiencies. The second question asked what the most common deficiencies are.

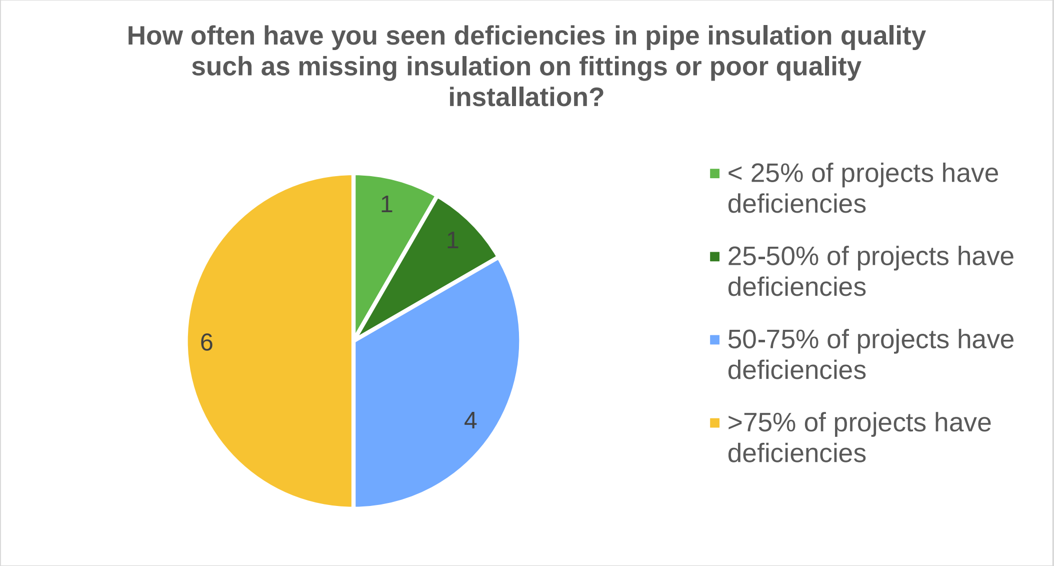


Figure 19: Stakeholder meeting question 1: frequency of insulation deficiency.

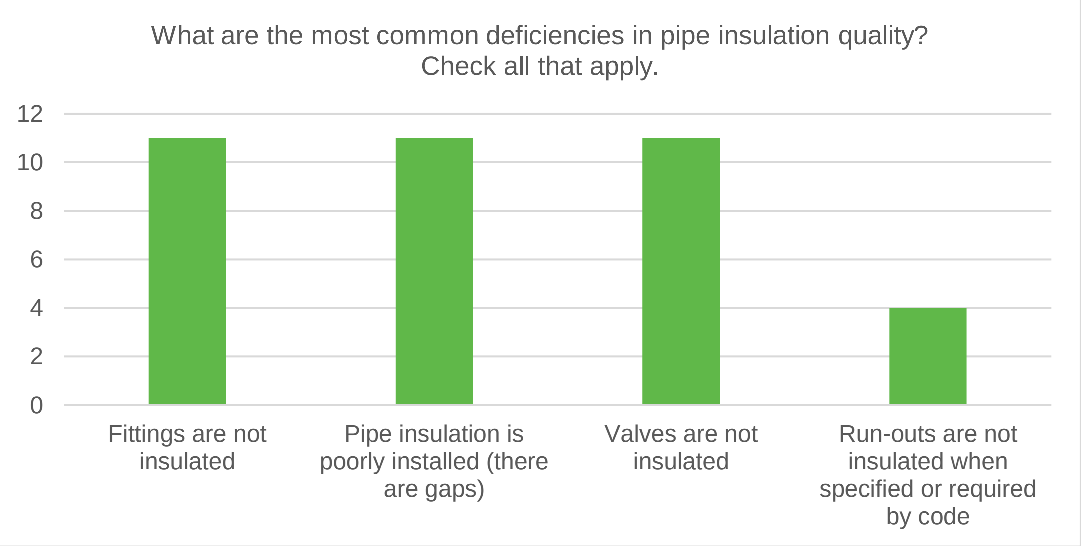


Figure 20: Stakeholder meeting question 2: frequency of common deficiencies.

Additionally, a member of the Statewide CASE Team did an informal survey of a classroom of residential building inspectors, asking how well contractors were doing insulating hot water pipes. Their response was that about 50 percent insulate hot water pipes well, meaning that they insulated all joints, elbows and wall penetrations when appropriate. The other 50 percent have a tendency to only insulate straight runs and do not insulate joints, elbows nor wall penetrations well.

The Statewide CASE Team found the results from the designer interviews, stakeholder meeting poll, and the informal classroom survey to be consistent with the results of the construction manager and designer survey, therefore the Statewide CASE Team used the results of the construction manager and designer survey in the energy savings calculations described below.

Calculations and Energy Modeling Inputs

This section describes the methodology the Statewide CASE Team used to determine the energy model inputs that account for energy losses due to insulation quality issues. Since the compliance software does not allow a user to model varying levels of insulation quality, the Statewide CASE Team performed energy analysis in an external spreadsheet calculator as described in Section 4.2.

The external spreadsheet calculator is not able to explicitly model piping specialties without insulation or other insulation quality issues, but the external spreadsheet calculator can model a percentage of the distribution system without insulation. The Statewide CASE Team therefore determined an equivalent fraction of surface area of the distribution system to model without insulation to represent the piping quality issues.

The primary input for this analysis is a percentage of the distribution system that is uninsulated in the baseline case. This section describes how the Statewide CASE Team developed the percentage of the distribution system that is uninsulated for each prototype. First, the Statewide CASE Team generated assumptions for the number of piping specialties in multifamily DHW distribution systems and in hot water plants for each of the four prototypes. Second, the Statewide CASE Team determined frequency of missing insulation and insulation quality based on the construction managers and designers survey results described above. Lastly, the Statewide CASE Team calculated the total surface area of straight pipe, fittings, and piping specialties, and applied the percentages of missing insulation determined in the second step for each of the four prototypes in order to determine an equivalent fraction of surface area of the distribution system to model without insulation. The Statewide CASE Team used this fraction without insulation for each prototype as an input for the external spreadsheet calculator.

Step 1: Generate Input Assumptions for Pipe Fittings and Piping specialties

The Statewide CASE Team did takeoffs of the hot water distribution system designs for each multifamily prototype building to determine the number of piping specialties in a hot water distribution system. See Appendix H for details. An HVAC and plumbing Design/Build contractor member of the Statewide CASE Team estimated that the number of elbows would realistically be 50 percent higher in the actual installation than the takeoffs showed due to routing pipes around each other, while the number of tees would be similar. This is reflected in the calculations of elbow counts for each prototype building.

To determine the number of shutoff valves in the distribution system, the Statewide CASE Team reviewed the drawings from a 24-unit low-rise multifamily project that participated in the California Multifamily New Homes Program. Based on the findings, the Statewide CASE Team assumed one hot-water shutoff valve for each dwelling unit in the prototype buildings. Using the same multifamily construction drawings, the Statewide CASE Team found that there is consistently one shutoff valve per hot water riser. Using the riser counts from the drawings, the Statewide CASE Team accounted for one shutoff valve per hot water riser in the prototype buildings. The Statewide CASE Team added this to the count of valves in Table 82.

To determine the number of piping specialties in a hot water plant, the Statewide CASE Team did takeoffs of the same low-rise multifamily project in the California Multifamily New Homes Program mentioned above. The Statewide CASE Team also reviewed construction documents from three other multifamily buildings and determined that they had similar uses of piping specialties at the hot water plant. Therefore, the Statewide CASE Team used the 24-unit low-rise project as a basis for determining the number of piping specialties in the hot water plant for each prototype building.

The Statewide CASE Team assigned diameters of the piping specialties as follows:

- The tees in the distribution system of each prototype are distributed evenly across the diameters of pipe represented in each prototype. For example, the low-rise garden prototype has five different pipe sizes (diameters of 0.75”, 1”, 1.25”, 1.5”, and 2”). The Statewide CASE Team assumed the same number of tees on each of these pipe sizes.
- A shutoff valve is installed at the bottom of each riser, sized according to the riser size for each prototype.
- Hot water plant valves and fittings are assigned to the two largest diameters in each prototype. For example, the largest pipe diameters in the low-rise garden prototype are one and a half and two inch, so the Statewide CASE Team assigned all hot water plant valves and fittings to these two pipe sizes.
- Hot water shutoff valves at each dwelling unit have a one-inch inlet diameter for all prototypes.

The resulting number of piping specialties in the various parts of a hot water system is shown in Table 82 for the low-rise garden multifamily prototype.

Table 82: Low-Rise Garden Prototype Piping Specialties Count

	In Distribution System				At Plant		
Diameter (inches)	**Riser Valves**	**Unit Shutoff Valve**	**Elbows**	**Tees**	**Valves**	**Elbows**	**Tees**
2	2	0	5	1	8	11	4
1.5	4	0	3	2	5	0	0

1.25	0	0	0	2	0	0	0
1	0	8	0	2	0	0	2
0.75	0	0	0	1	0	0	0

Step 2: Generate Input Assumptions for Missing Insulation and Poor Insulation Quality

The Statewide CASE Team used the results of the survey of construction manager and designers on the frequency of common insulation quality issues shown in Table 83. The Statewide CASE Team assumed that the weighted average results of the survey represent the rate of missing insulation for each piping specialty, valves, fittings, and pumps. Survey results for poorly installed insulation, damaged insulation, and pipe hangers that are not thermally isolated do not directly translated to a fraction of missing insulation, so the Statewide Case Team developed a combined estimate for these factors as discussed in Step 3.

Table 83: Percent of Projects with Insulation Quality Issues by Insulation Quality Issue Used in the Calculation of Energy Model Inputs

Percent of Projects with Deficiencies	0%	< 20%	20 - 40%	40 - 60%	60 - 80%	> 80%	Weighted Average
Valves are not insulated	0	0	1	0	3	7	79%
Fittings are not insulated	0	1	0	1	5	4	70%
Pumps were not insulated	0	1	0	0	1	9	81%
Hangers are not thermally isolated from pipe (horizontal pipes)	0	0	2	1	3	5	70%
Pipe insulation is poorly installed	0	1	1	3	4	2	59%
Insulation is damaged	1	2	4	0	2	2	42%

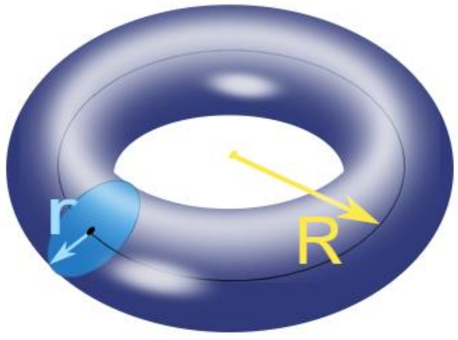
Source: Statewide CASE Team

Step 3: Generate Insulation Quality Baseline

The Statewide CASE Team used the number of piping specialties in a distribution system and the percent frequency each fitting and device is uninsulated to calculate a percentage of the total surface area of a distribution system that is uninsulated. To accomplish this, the Statewide CASE Team made simplifying assumptions to calculate the surface area of each fitting and device.

For valves, the Statewide CASE Team estimated the surface area to be the same as a piece of pipe with the same length and outer diameter of the valve. The exact measurements for length and outer diameter of various valves came from McMaster-Carr. The Statewide CASE Team used standard female-to-female nominal pipe thread bronze on/off ball valves as reference (McMaster-Carr n.d.).

For elbows, the Statewide CASE Team calculated the surface area as one quarter of a toroid, an image of which and the surface area formula for which are shown in Figure 21. Using data from a tunnel and pipelines manufacturer, the Statewide CASE Team determined that walls on copper fittings range from 0.065 to 0.134 inches thick for the pipe sizes of interest in the prototypes (Peterson Product Company 2020). Based on this finding, the Statewide CASE Team assumed that the wall thickness of the elbows is negligible.



$$\text{Surface Area} = 4 \times \pi^2 \times R \times r$$

Figure 21: Equation for the surface area of a pipe elbow.

Source: (Math is Fun 2017).

For tees, the Statewide CASE Team assumed that the surface area is three times the surface area of one “leg” of the tee. For example, for the tee shown in Figure 22, the Statewide CASE Team would assume that L, L_1, and L_2 are the same length, and would calculate the surface area per the equation in the figure.

$$Area = 6\pi rL, where\ L = L_1 = L_2$$

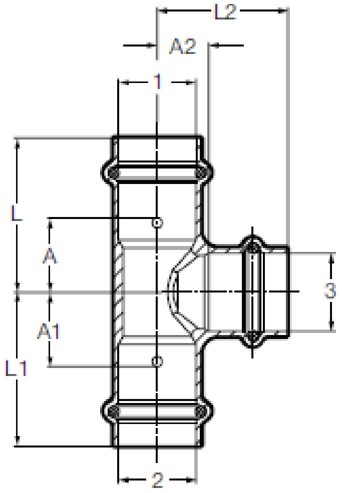


Figure 22: Example of a tee fitting.

Source: (Viega ProPress Fittings Dimensional 2020).

The Statewide CASE Team accounted for heat loss from the portion of pipe that is insulated next to the uninsulated piping specialty. The Statewide CASE Team assumed that for each uninsulated piping specialty, there is uninsulated straight pipe of the same length as the diameter of the piping specialty. For example, if there is a four-inch uninsulated tee in the distribution system, the Statewide CASE Team modeled an additional, accompanying four-inch piece of uninsulated pipe. This factor applies to elbows, tees, and valves in the distribution system (see Figure 22 for reference).

For pumps, the Statewide CASE Team assumed the relevant surface area to be the surface area of the impeller housing, which comprises most of the surface area that has direct contact with the hot water. The Statewide CASE Team simplified the geometry of an impeller housing to that of a two-inch-long cylinder (including the top and bottom sections), with a diameter that is 10 times the pipe diameter.

The Statewide CASE Team calculated the surface area of the entire distribution system by summing the surface area of all piping specialties and the surface area of straight pipe in the hot water distribution system designs for each prototype (see Appendix H).

Poorly insulated pipe and damaged insulation are issues difficult to translate into an equivalent length of uninsulated pipe due to not knowing the extent to which the insulation was damaged or poorly installed. The thermal impact of hangers not thermally isolated from pipe is difficult to convert into an equivalent length of uninsulated pipe without a detailed heat loss model. The Statewide CASE Team conservatively assumed that 10 percent of pipe length would be uninsulated to account for these insulation quality issues. This is a conservative assumption given that the PIER Study resulted in a factor of two derating described at the beginning of this Appendix.

To determine the equivalent fraction of surface area of the distribution system to model without insulation, the Statewide CASE Team applied the weighted average percentage of pipe and piping specialties that are uninsulated according to Table 83. Finally, the Statewide CASE Team calculated the percentage of the distribution system that is uninsulated by dividing uninsulated surface area by total surface area, the result of which is shown in Table 84.

The inputs in the energy model are based on surface area; however, Table 84 also shows the proportion of the length of the distribution system that is uninsulated because these values may be more easily compared to real distribution systems.

Table 84: Percentage of Distribution System Uninsulated by Surface Area and Percentage of Distribution System Length without Insulation

	Low-Rise Garden	Low-Rise Loaded Corridor	Mid-Rise Mixed Use	High-Rise Mixed Use
Percentage of distribution system uninsulated by surface area	19%	19%	15%	15%
Percentage of distribution system uninsulated by length	15%	15%	13%	13%

The Statewide CASE Team proposes using a single averaged value for the insulation quality correction factor in the ACM Reference Manual, since the results differ by building size. Calculations to determine the ACM Reference Manual value are described in Appendix D.

Appendix H: Prototype Building Domestic Hot Water Distribution Designs

The Statewide CASE Team generated hot water distribution plumbing designs for the four prototype buildings using standard engineering approaches for layout and pipe sizing. Statewide CASE Team member, Ecotope provided the design expertise and documented the layouts in the following report. These designs are used throughout this CASE Report.

2022 Multifamily CASE – Plumbing Distribution Piping Analysis

ECOTOPE

Final Report

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Table of Contents

TABLE OF TABLES

TABLE OF FIGURES

Figure 1 - Low-Rise Garden Style Piping Comparison 5
Figure 2 - Mid-Rise Loaded Corridor Piping Comparison 6
Figure 3 - Mid-Rise Mixed-Use Piping Comparison 7
Figure 4 - High-Rise Mixed-Use Piping Comparison 8
Figure 5 - Low-Rise Garden Style Isometric 9
Figure 6 - Low-Rise Garden Style Baseline Distribution Piping 10
Figure 7 - Low-Rise Garden Style Proposed Distribution Piping 11
Figure 8 - Low-Rise Garden Style Recirculation Piping 12
Figure 9 - Mid-Rise Loaded Corridor Isometric 13
Figure 10 - Mid-Rise Loaded Corridor Baseline Distribution Piping 14
Figure 11 - Mid-Rise Loaded Corridor Proposed Distribution Piping 15

1. INTRODUCTION

This analysis is written to support the 2022 California Codes and Standards Enhancement (CASE) topic for energy code measure proposals on multifamily domestic hot water systems. To properly determine the effectiveness of these various measure proposals, we have designed plumbing distribution systems that align with a set of predefined prototype building designs.

This analysis also addresses drain water heat recovery as an additional design element on the plumbing distribution system.

2. GLOSSARY

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASPE	American Society of Plumbing Engineers
CW	Cold Water
DHW	Domestic Hot Water
DWHR	Drain Water Heat Recovery
F	Fahrenheit
GPM	Gallons Per Minute
HPWH	Heat Pump Water Heater
HW	Hot Water
UPC	Uniform Plumbing Code
WDC	Water Demand Calculator
WSFU	Water Supply Fixture Units

3. METHODOLOGY

Assumptions

Building Characteristics Assumptions

1. It is assumed that this analysis is based on the CASE team approved prototype multifamily buildings (TRC Advanced Energy 2019).
    b. The *Low-Rise Garden Style* is a two-story, eight-unit building with dwelling unit entry from the building exterior.
    c. The *Mid-Rise Loaded Corridor* is a three-story, 36-unit building with dwelling unit entry off an interior corridor, common laundry, gym, and business center.
    d. The *Mid-Rise Mixed-Use* is a five-story, 96-unit building with one story of retail and common spaces under four stories of residential space.
    e. The *High-Rise Mixed-Use* is a 10-story, 108-unit building with one story of retail and common space under nine stories of residential space.
    f. Each building consists of a mix of studio, one-bedroom, two-bedroom, and (all but low-rise building) three-bedroom units.
2. It is assumed that the studio, one-bedroom, and two-bedroom units have one bathroom and that the three-bedroom units have two bathrooms.
3. It is assumed that the building floor plans are arranged so that the bathrooms are directly above one another and all plumbing stacks up.

Plumbing System Design Assumptions

1. It is assumed that the cold-water distribution piping uses UPC approved piping materials including CPVC Schedule 80, Stainless Steel Schedule 10, Copper Type L, PEX A with NSF rating.
2. It is assumed that all piping downstream of the in-unit plumbing manifold is flexible tubing made from cross-linked polyethylene (PEX).
3. For the Hunter's Curve sizing, it is assumed that the "bathroom group" diversity factor reduction can be used as described in the Uniform Plumbing Code (UPC) Section C303.2 and Table C303.1(1) Note 1. A bathroom group consists of a water closet (toilet), up to two lavatories (bathroom sinks), and the bath/shower.
4. It is assumed that the maximum demand for the recirculation piping is 0.5 GPM for each vertical riser. This assumption is based on practical experience.
5. It is assumed that the maximum water velocity is 5 feet per second for hot water in copper pipe. This value is standard practice and is less than the maximum velocity given in UPC Section A107.1.

6. It is assumed that the maximum water velocity is 3 feet per second for hot water recirculation in copper pipe. This value is standard practice and is less than the maximum velocity given in UPC Section A107.1.

Baseline Plumbing Design

The baseline plumbing design relies on the traditional approach using “Hunter’s Curve” (Hunter 1940) that was developed in 1940. This methodology predicts the peak flow required in gallons per minute (GPM) in a plumbing system based on the number of fixtures, how often each fixture is operated, and the period for each operation. However, hot water metering field studies performed by Ecotope have shown these pipe sizes to be very conservative. This method also does not consider the lower flow requirements in contemporary plumbing fixtures. Regardless, this traditional approach is still used today since it is straightforward and remains well accepted in the industry.

The following procedure was used to find pipe diameters for all segments of the baseline plumbing system.

1. Use UPC Table A103.1 “Water Supply Fixture Units (WSFU) and Minimum Fixture Branch Pipe Sizes” to assign the appropriate quantity of water supply fixture units (WSFU) for all non-bathroom fixtures. The hot water fixture unit value is assigned per Note 3 of this table.
2. Use UPC Table C303.1(1) “Water Supply Fixture Units (WSFU) for Bathroom Groups” to assign the appropriate quantity of WSFU for all bathroom groups.
3. Use UPC Chart A103.1(2) “Enlarged Scale Demand Load” (also known as Modified Hunter’s Curve) to convert the quantity of fixture units to the equivalent demand in gallons per minute (GPM).
4. Determine the total demand on each piping segment of the hot water distribution system by summing the flow rates of all fixtures that are fed by that segment.
5. Determine the total demand for the recirculation piping by multiplying the total quantity of plumbing risers by a demand factor of 0.5 GPM per riser.
6. Use UPC Chart A105.1(1) “Friction Loss in Head Per 100-Foot Length” to find the diameter of each piping segment in the hot water supply and recirculation piping.

Proposed Plumbing Design

The proposed plumbing design uses the UPC Appendix M "Peak Water Demand Calculator" (WDC) that was first released in the 2018 edition of the UPC (IAPMO 2018). The WDC can be used when plumbing fixtures are less than the maximum design flow rates specified in UPC Table M102.1. The traditional sizing method described in the previous section does not account for water-conserving plumbing fixtures that are now commonplace in contemporary new construction. Therefore, the WDC is more appropriate for plumbing designs that incorporate low-flow fixtures and translates directly into smaller piping diameters.

The following procedure was used to find pipe diameters for all segments of the proposed plumbing system. Please note that this procedure is discussed in detail in UPC Appendix M and requires download of the IAPMO Water Demand Calculator (WDC) available at http://www.iapmo.org/water-demand-calculator/. This analysis uses version 1.01 of the calculator.

1. For each segment of the hot water distribution piping, enter the total number of fixtures that are fed by that segment into the WDC.
2. Determine the demand on each piping segment of the hot water distribution system by iterating the WDC for each segment.
3. Determine the total demand for the recirculation piping by multiplying the total quantity of plumbing risers by a demand factor of 0.5 GPM per riser.
4. Use UPC Chart A105.1(1) "Friction Loss in Head Per 100-Foot Length" to find the diameter of each segment in the hot water distribution and recirculation piping.

4. FINDINGS

Summaries of the total length of piping required for the baseline (Hunter's Curve) and proposed (Appendix M) designs are shown below.

Table 1 - Low-Rise Garden Style Piping Lengths

Pipe Diameter (inches)	Pipe Length (feet)	
	Hunter's Curve	*Appendix M*
0.75"	168	168
1"	29	55
1.5"	58	52
2"	20	0
2.5"	0	0
3"	0	0

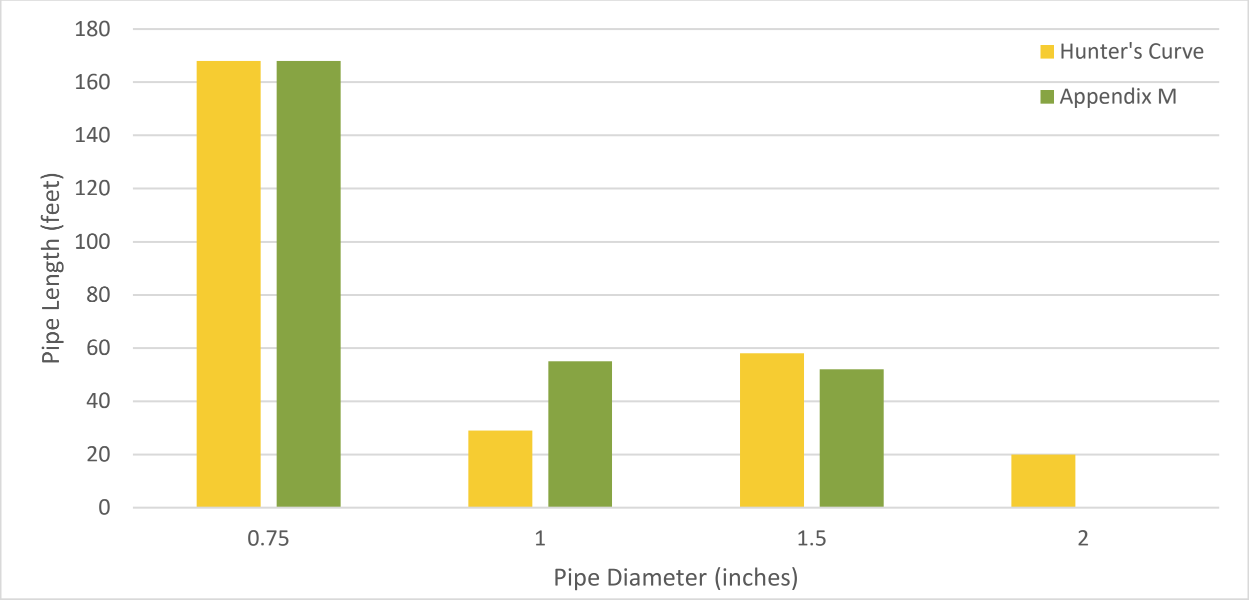

Figure 1 - Low-Rise Garden Style Piping Comparison

Table 2 - Mid-Rise Loaded Corridor Piping Lengths

Pipe Diameter (inches)	**Pipe Length (feet)**	
	Hunter's Curve	***Appendix M***
0.75”	449	449
1”	182	287
1.5”	153	107
2”	24	80
2.5”	90	0
3”	25	0

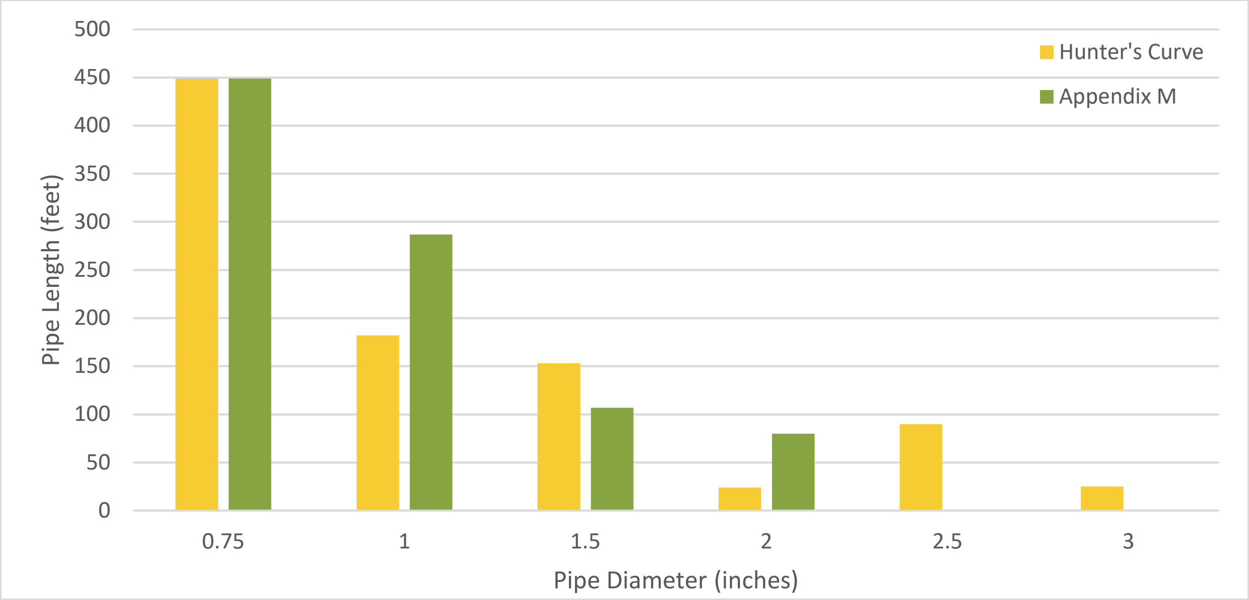

Figure 2 - Mid-Rise Loaded Corridor Piping Comparison

Table 3 - Mid-Rise Mixed-Use Piping Lengths

Pipe Diameter (inches)	Pipe Length (feet)	
	Hunter's Curve	*Appendix M*
0.75”	744	724
1”	338	1158
1.5”	939	254
2”	85	66
2.5”	73	121
3”	91	0
0.75”	53	0

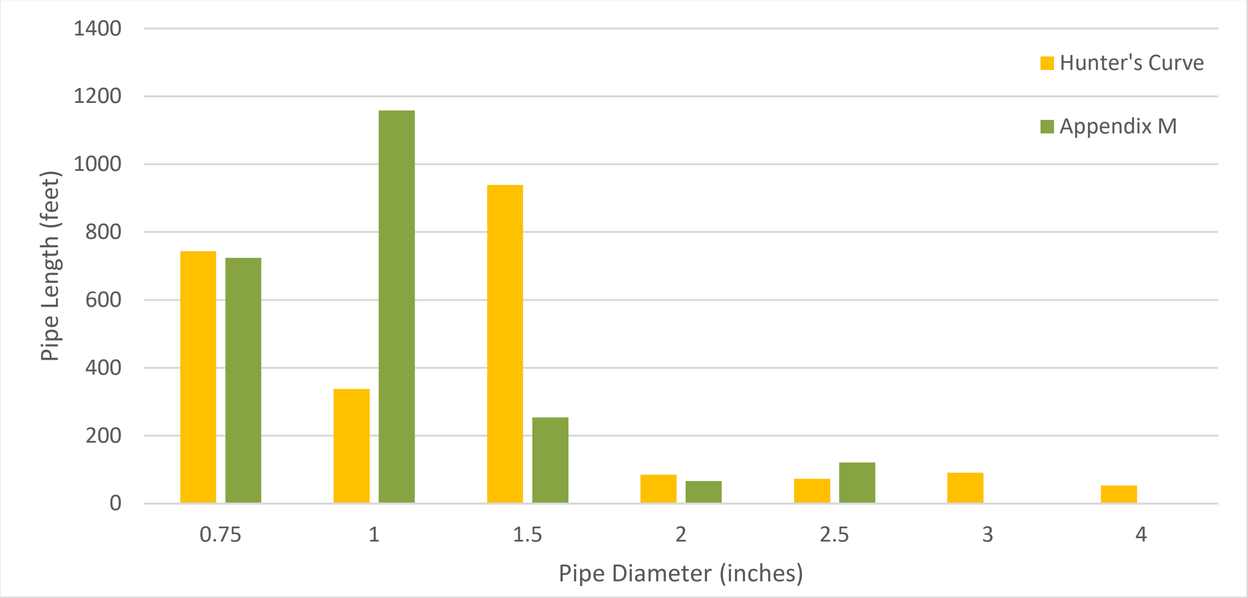

Figure 3 - Mid-Rise Mixed-Use Piping Comparison

Table 4 - High-Rise Mixed-Use Piping Lengths

Pipe Diameter (inches)	Pipe Length (feet)	
	Hunter's Curve	*Appendix M*
0.75”	1408	1408
1”	573	1745
1.5”	1172	148
2”	58	80
2.5”	165	129
3”	130	5
0.75”	9	0

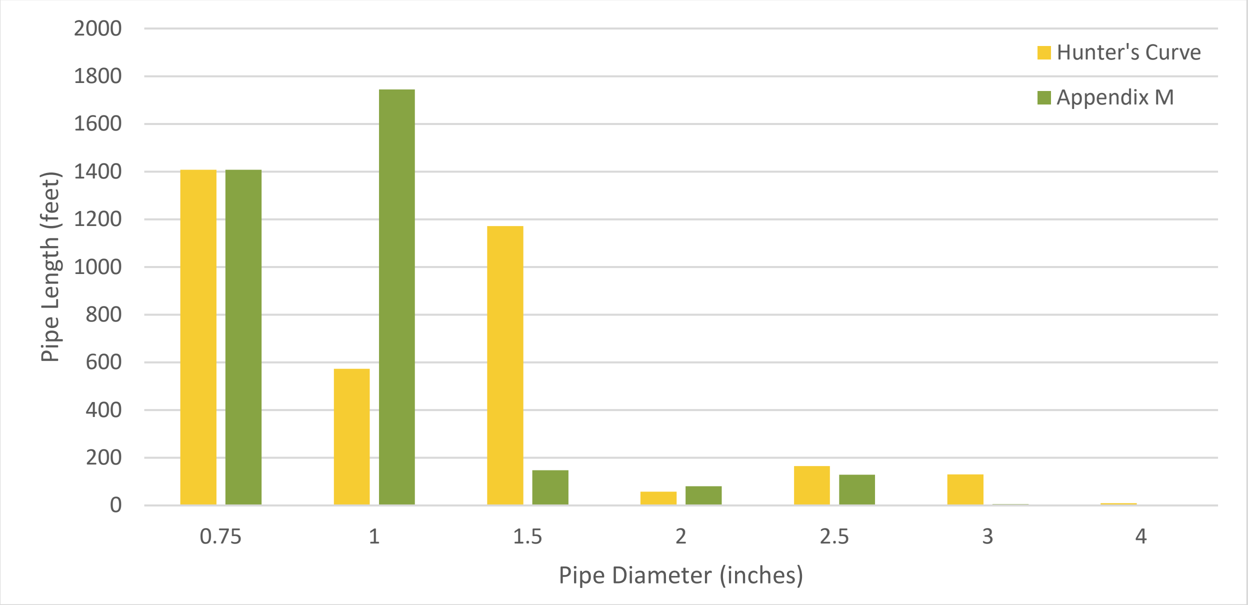

Figure 4 - High-Rise Mixed-Use Piping Comparison

5. PIPING DISTRIBUTION DRAWINGS

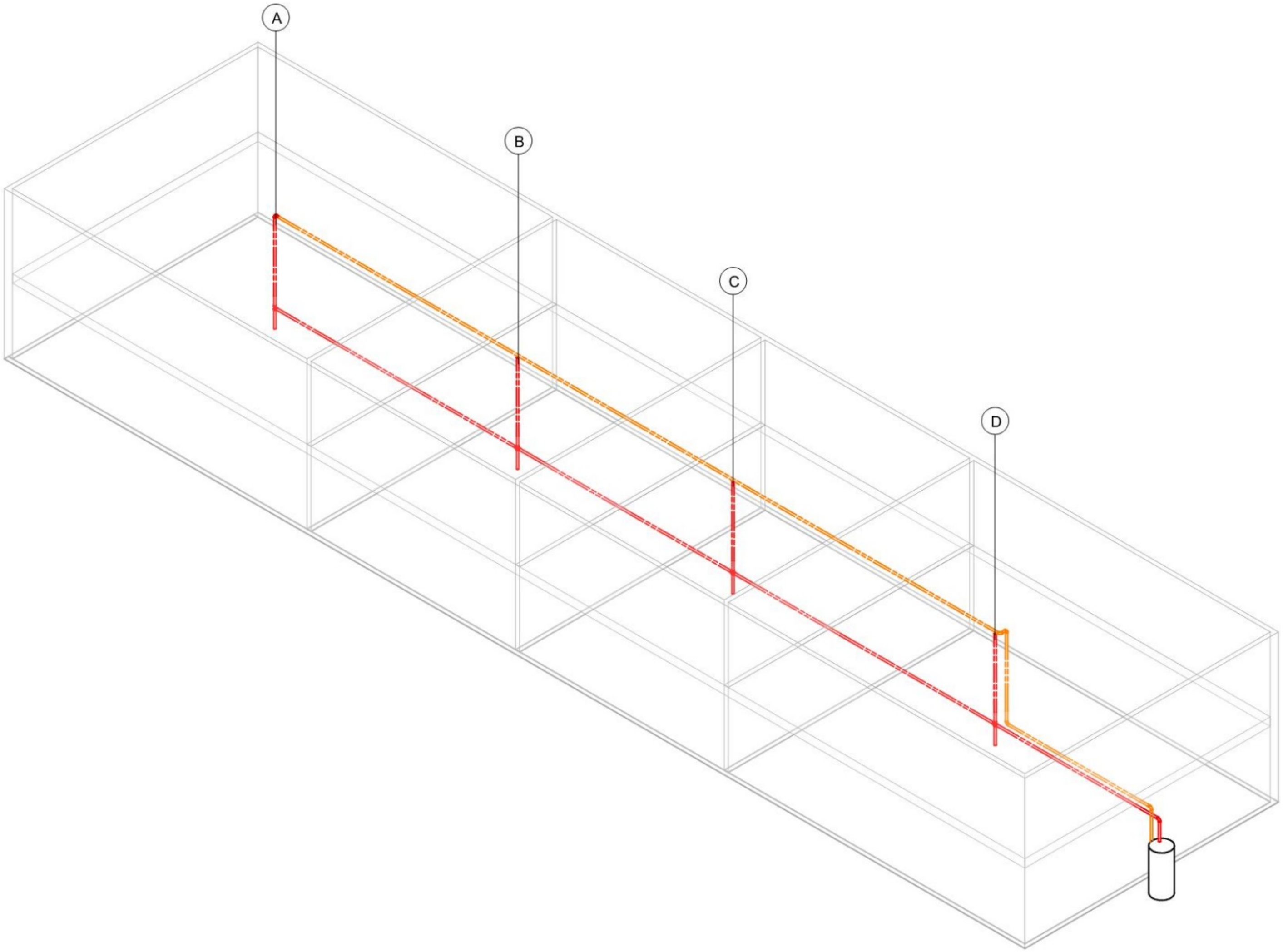

Figure 5 - Low-Rise Garden Style Isometric

Hunters Curve:
1 & 2 Bedroom Units Contain 1 Bathroom

1 Bathroom - 7.5 FU

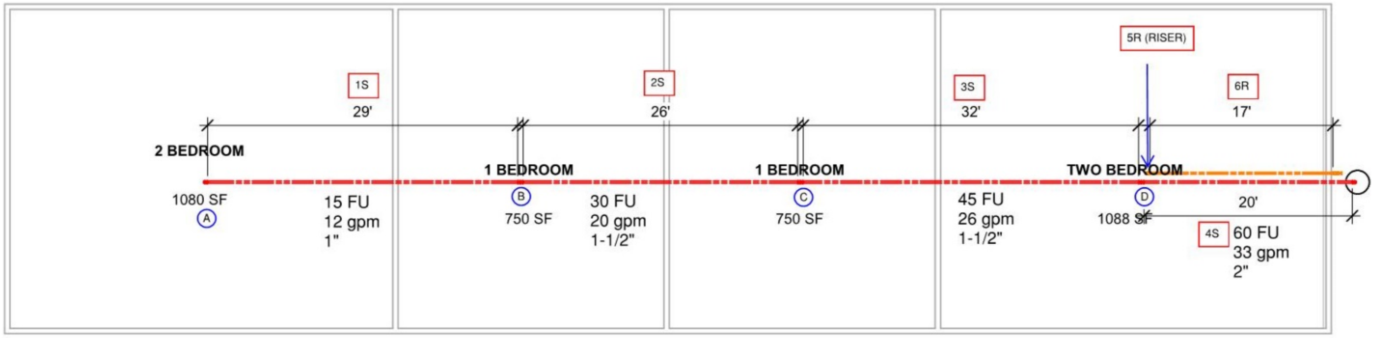

Figure 6 - Low-Rise Garden Style Baseline Distribution Piping

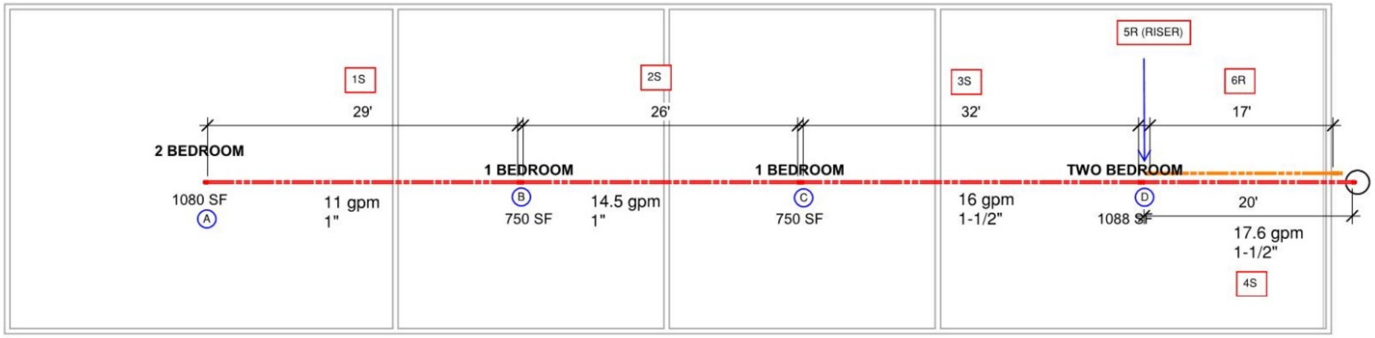

Figure 7 - Low-Rise Garden Style Proposed Distribution Piping

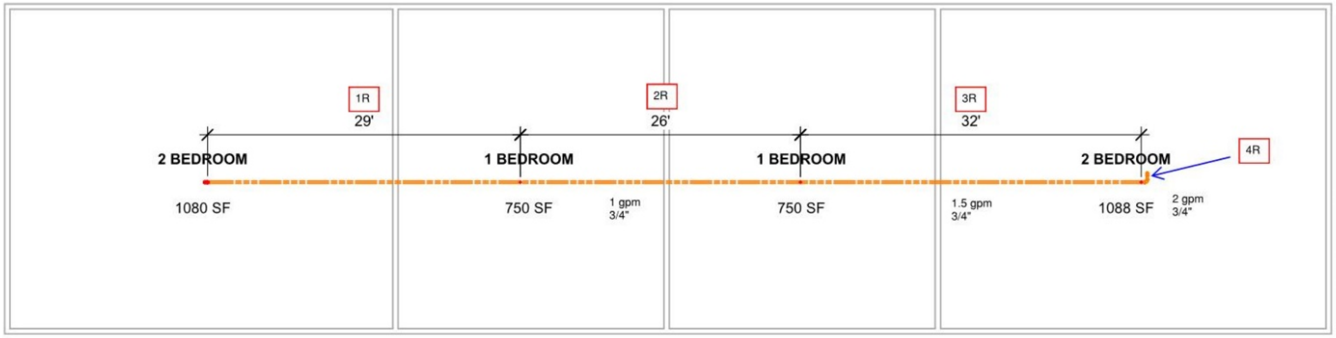

Figure 8 - Low-Rise Garden Style Recirculation Piping

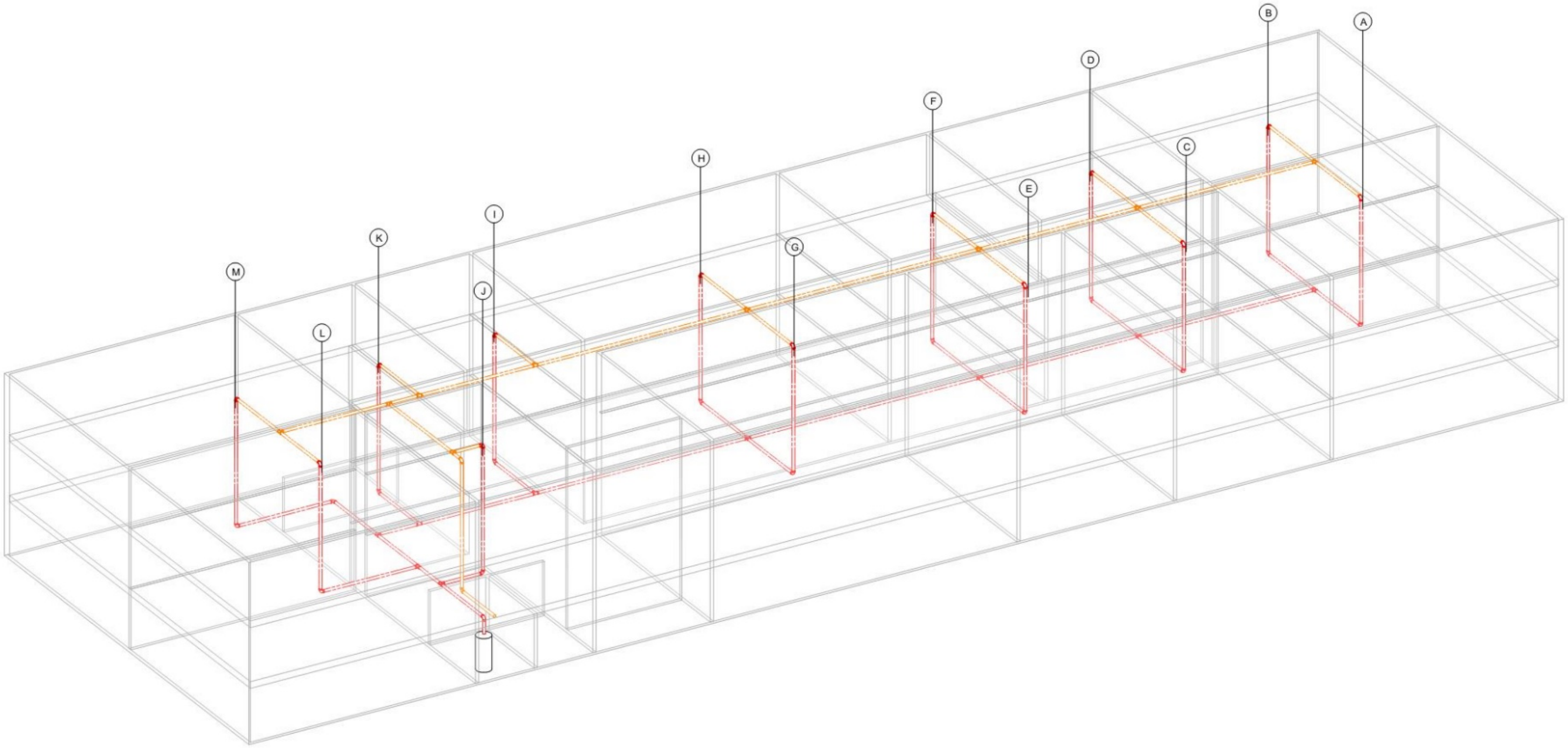

Figure 9 - Mid-Rise Loaded Corridor Isometric

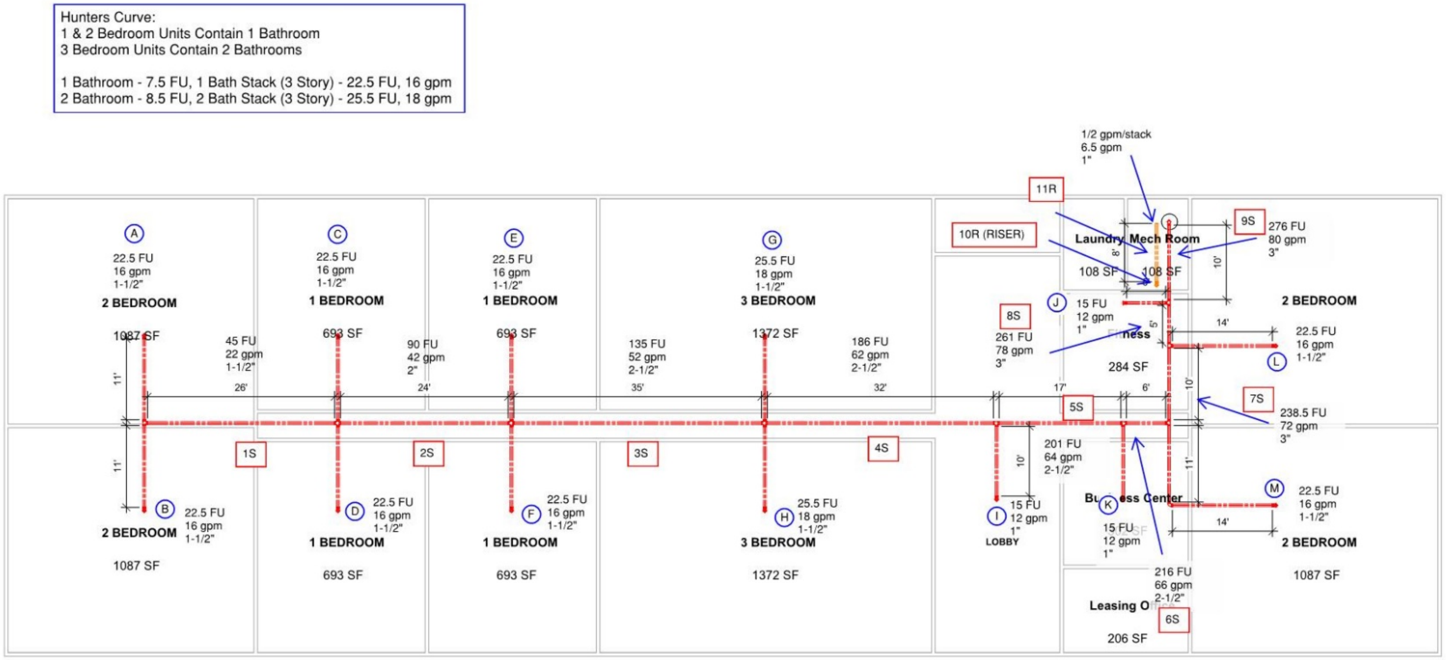

Figure 10 - Mid-Rise Loaded Corridor Baseline Distribution Piping

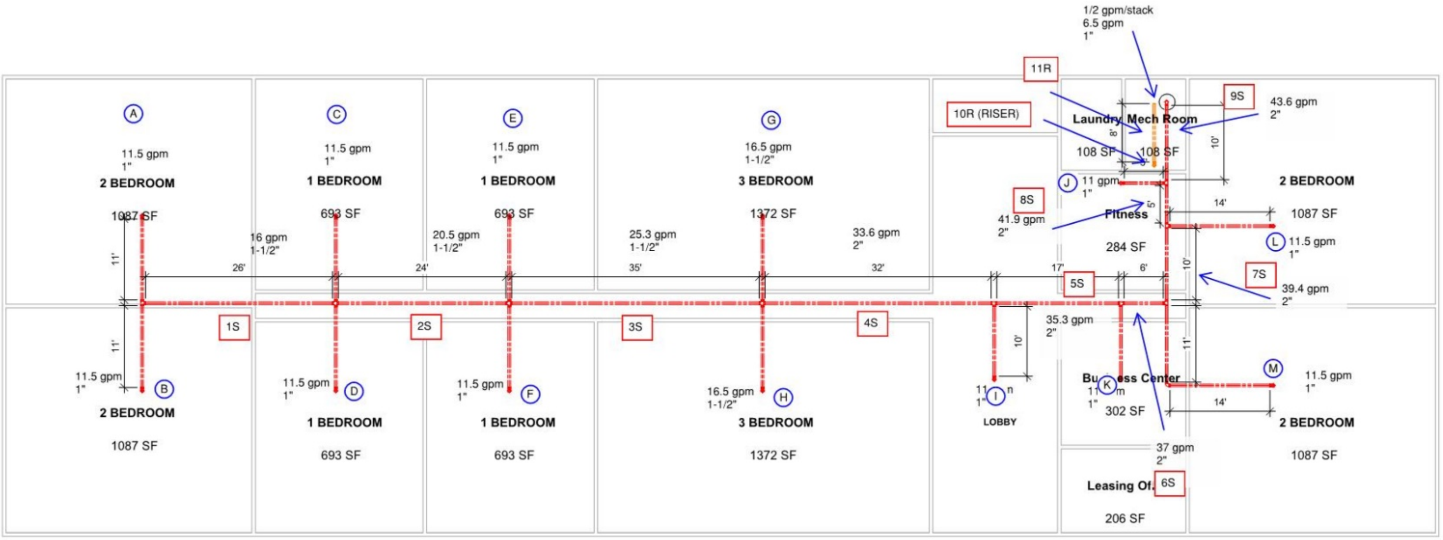

Figure 11 - Mid-Rise Loaded Corridor Proposed Distribution Piping

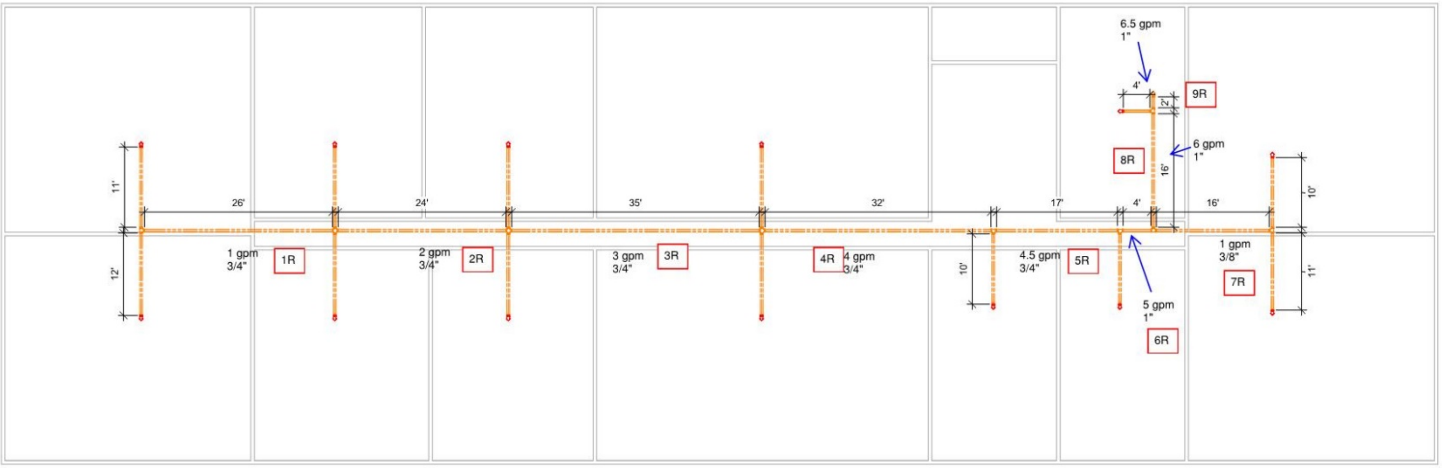

Figure 12 - Mid-Rise Loaded Corridor Recirculation Piping

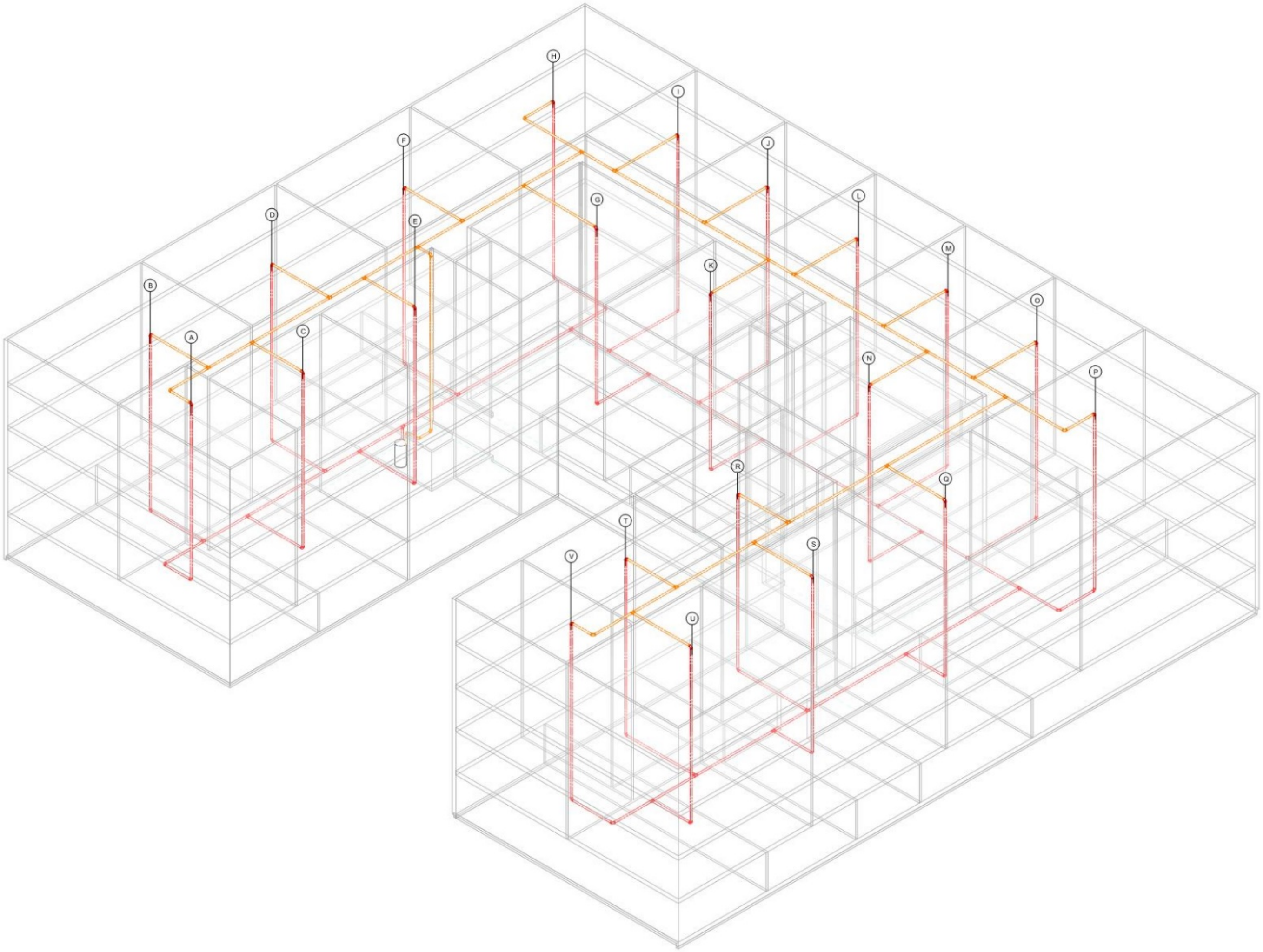

Figure 13 - Mid-Rise Mixed-Use Isometric

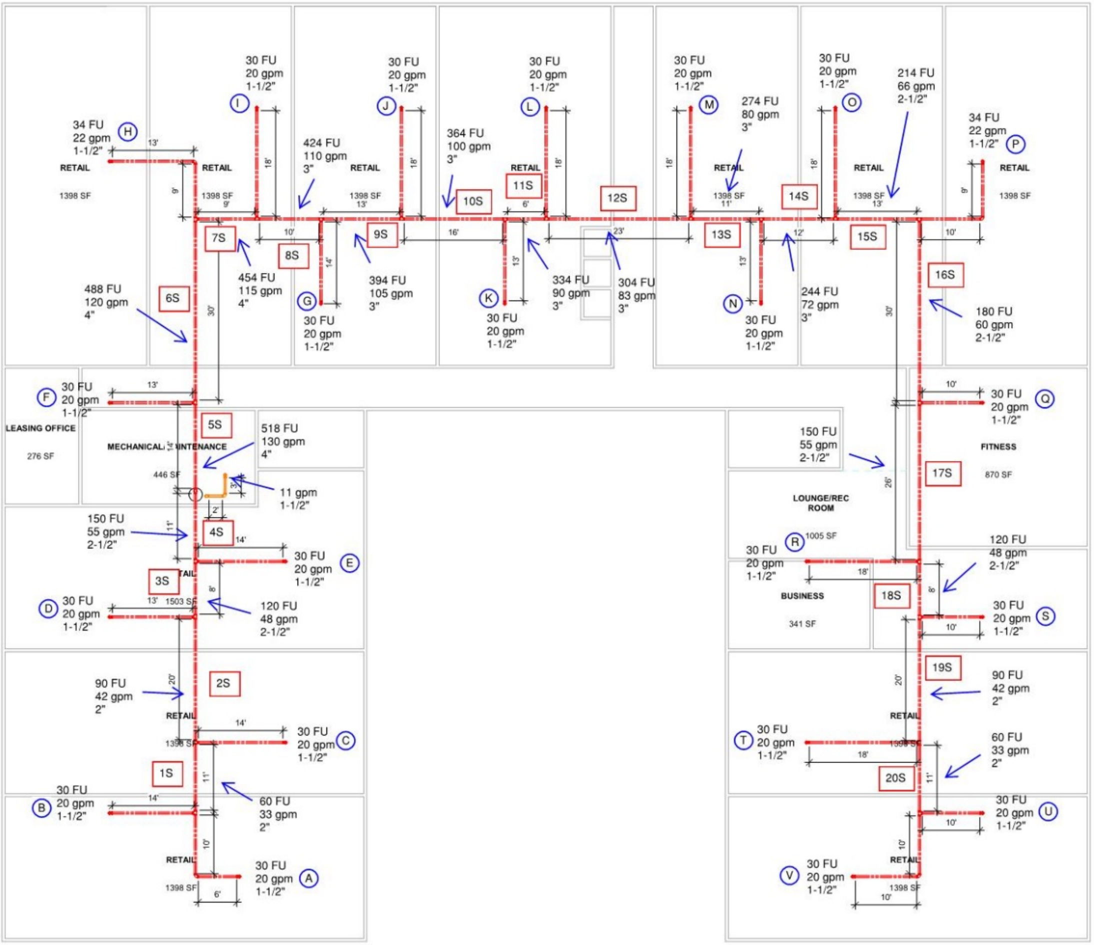

Figure 14 - Mid-Rise Mixed-Use Baseline Distribution Piping

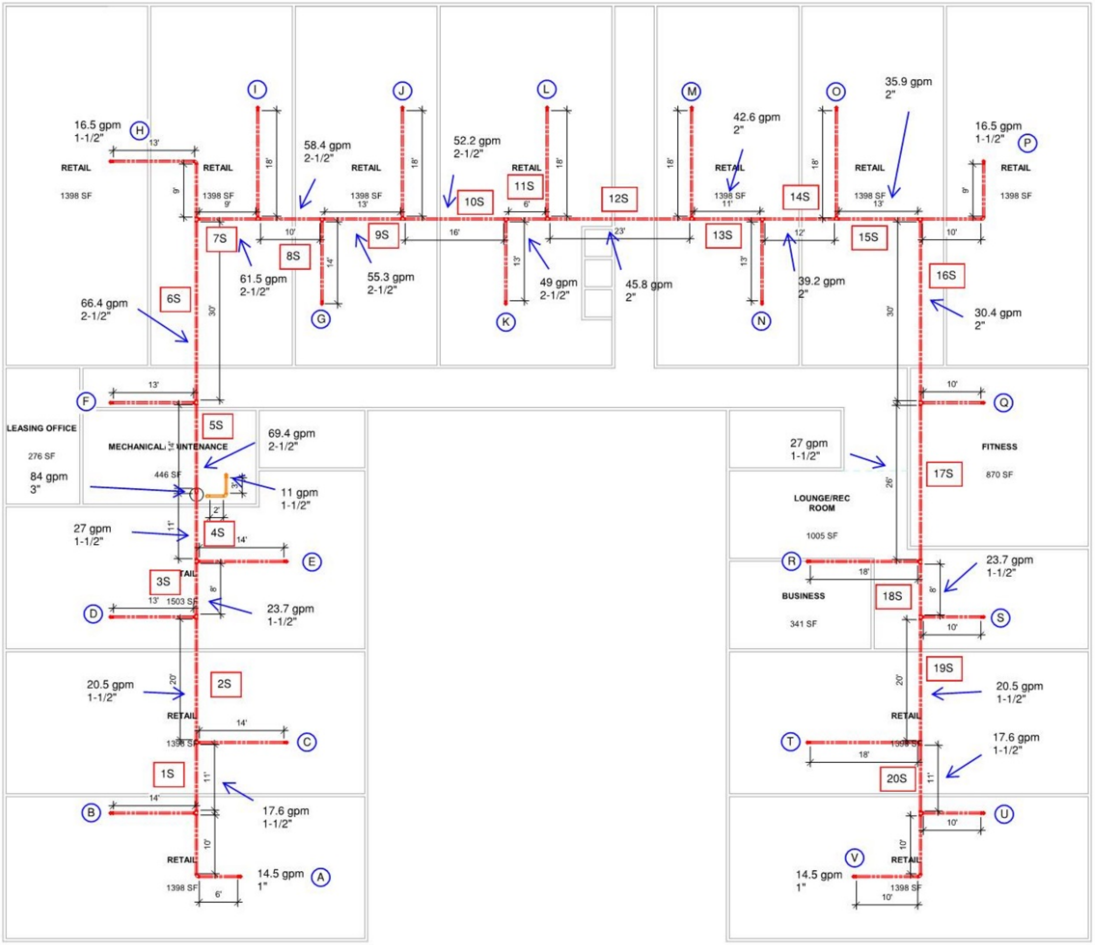

Figure 15 - Mid-Rise Mixed-Use Proposed Distribution Piping

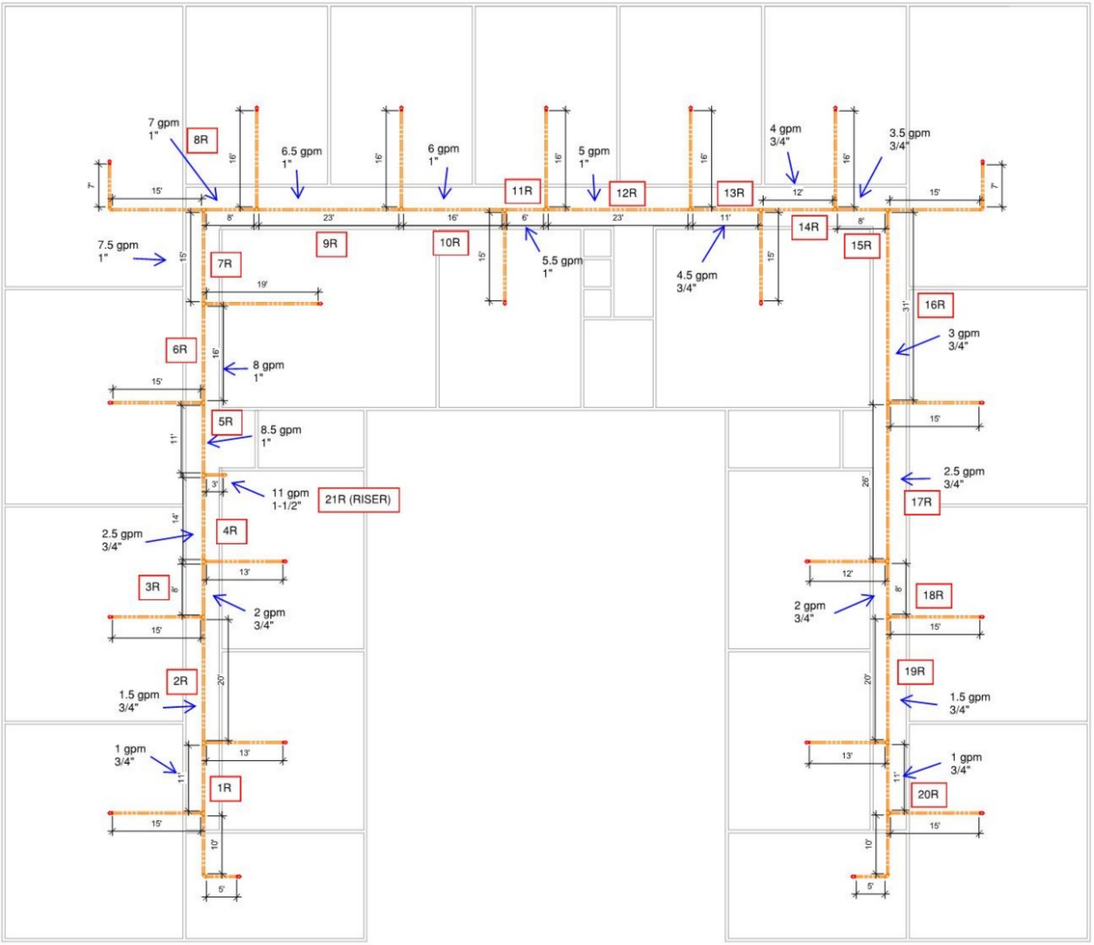

Figure 16 - Mid-Rise Mixed-Use Recirculation Piping

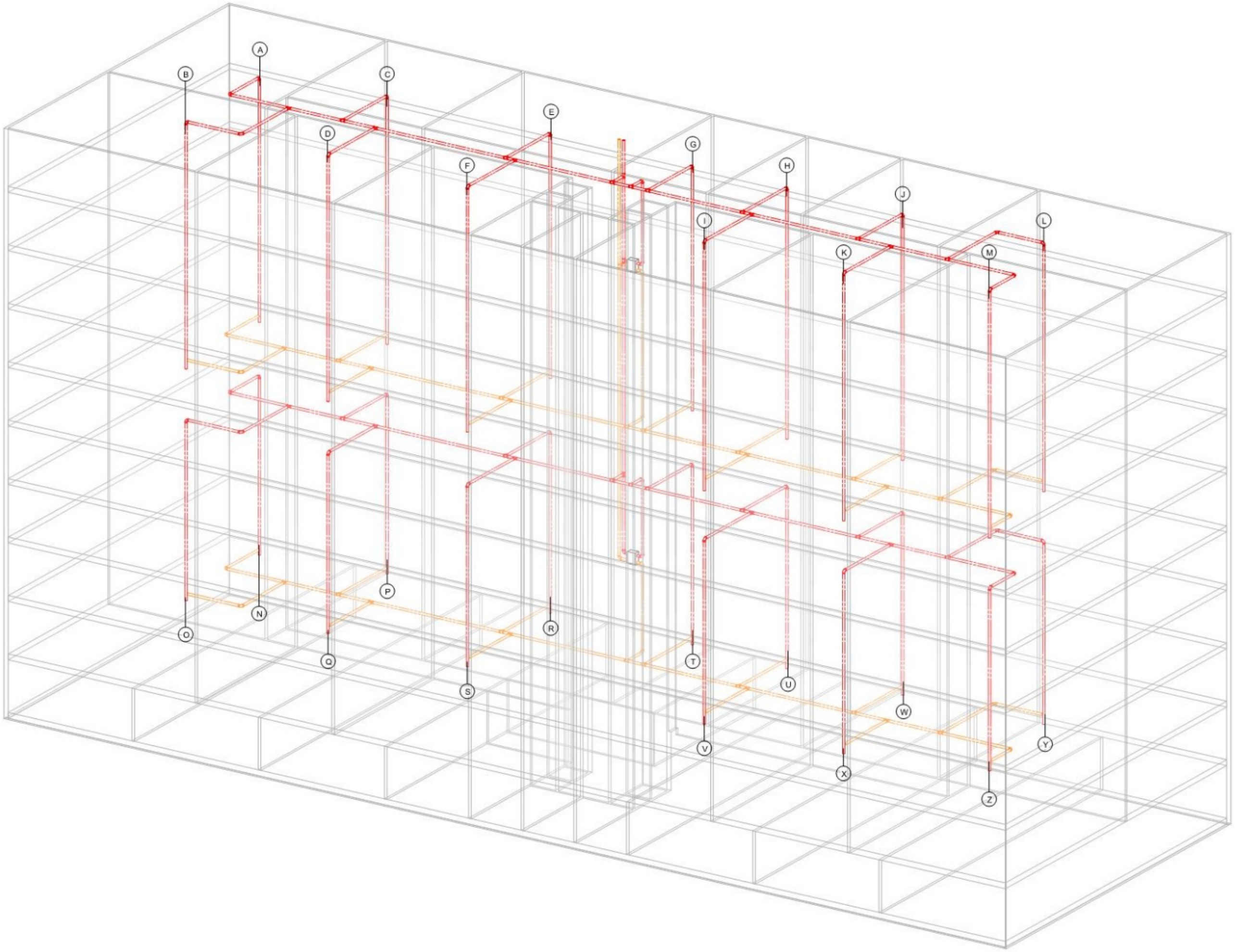

Figure 17 - High-Rise Mixed-Use Isometric

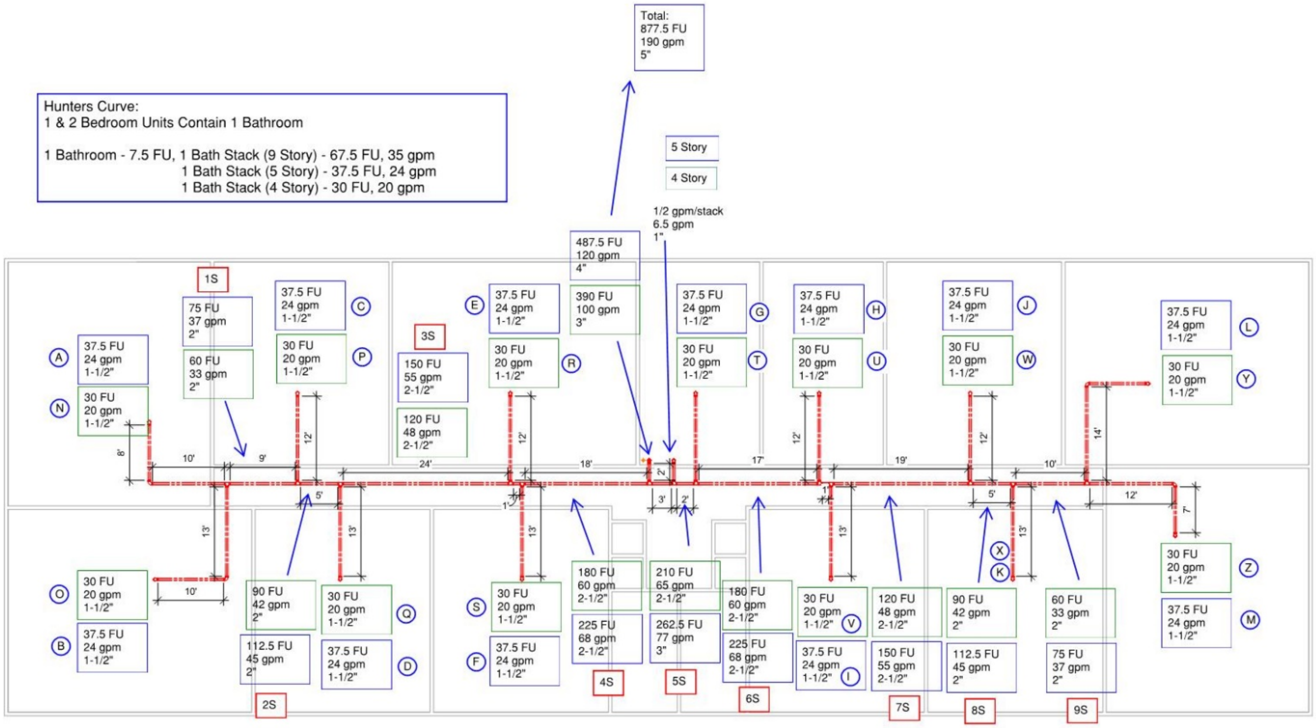

Figure 18 - High-Rise Mixed-Use Baseline Distribution Piping

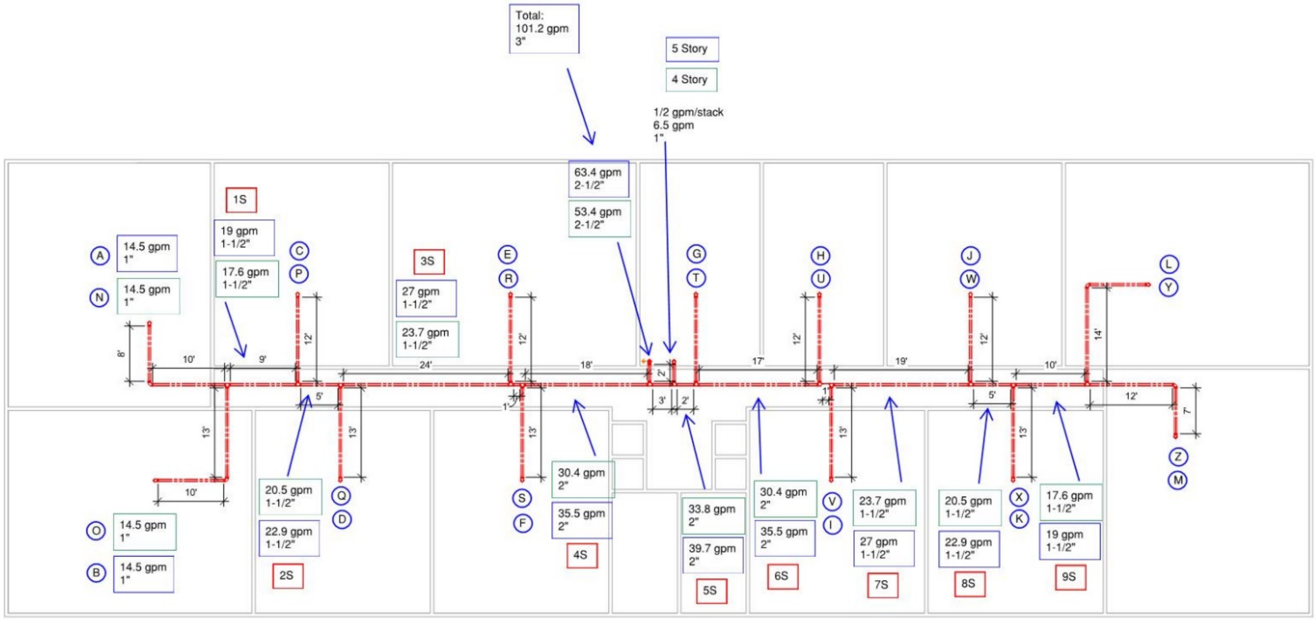

Figure 19 - High-Rise Mixed-Use Proposed Distribution Piping

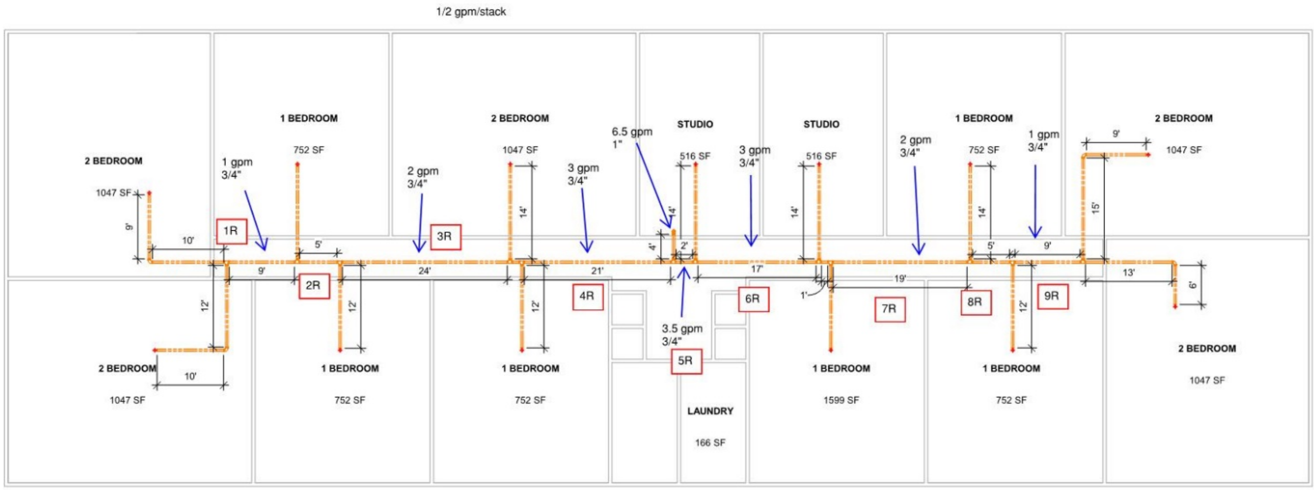

Figure 20 - High-Rise Mixed-Use Recirculation Piping

6. PIPING DISTRIBUTION CALCULATIONS

See the separate attached spreadsheet showing detailed calculations for all prototype plumbing distribution systems.

7. REFERENCES

Hunter, Roy B. 1940. "Methods of Estimating Loads in Plumbing Systems." *Building Materials and Structures* (National Bureau of Standards).

IAPMO. 2018. "Peak Water Demand Calculator." In *Uniform Plumbing Code*, Appendix M. International Association of Plumbing and Mechanical Officials.

TRC Advanced Energy. 2019. *Multifamily Prototypes.* Southern California Edison.

Appendix I: Nominal TDV Energy Cost Savings

Per-unit energy cost savings for newly constructed buildings that are realized over the 30-year period of analysis are presented in nominal dollars in Table 85 through Table 96

Submeasure A: Pipe Insulation Verification

Table 85 through Table 88 provide the 30-year TDV energy cost savings for pipe insulation verification.

Table 85: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction – Low-Rise Garden

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$0	$1,158	$1,158
2	$0	$1,061	$1,061
3	$0	$1,068	$1,068
4	$0	$1,050	$1,050
5	$0	$1,116	$1,116
6	$0	$1,036	$1,036
7	$0	$1,013	$1,013
8	$0	$1,008	$1,008
9	$0	$1,015	$1,015
10	$0	$1,023	$1,023
11	$0	$1,043	$1,043
12	$0	$1,042	$1,042
13	$0	$1,034	$1,034
14	$0	$1,039	$1,039
15	$0	$957	$957
16	$0	$1,073	$1,073

Table 86: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - Low-Rise Loaded Corridor

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$0	$812	$812
2	$0	$743	$743
3	$0	$749	$749
4	$0	$736	$736
5	$0	$782	$782
6	$0	$726	$726
7	$0	$710	$710
8	$0	$707	$707
9	$0	$711	$711
10	$0	$717	$717
11	$0	$731	$731
12	$0	$730	$730
13	$0	$725	$725
14	$0	$729	$729
15	$0	$671	$671
16	$0	$752	$752

Table 87: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - Mid-Rise Mixed Use

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$0	$678	$678
2	$0	$621	$621
3	$0	$625	$625
4	$0	$615	$615
5	$0	$653	$653
6	$0	$607	$607
7	$0	$593	$593
8	$0	$590	$590
9	$0	$596	$596
10	$0	$599	$599
11	$0	$611	$611

12	$0	$610	$610
13	$0	$605	$605
14	$0	$609	$609
15	$0	$560	$560
16	$0	$628	$628

Table 88: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - High-Rise Mixed Use

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$0	$578	$578
2	$0	$529	$529
3	$0	$533	$533
4	$0	$523	$523
5	$0	$557	$557
6	$0	$517	$517
7	$0	$505	$505
8	$0	$503	$503
9	$0	$508	$508
10	$0	$510	$510
11	$0	$520	$520
12	$0	$519	$519
13	$0	$516	$516
14	$0	$518	$518
15	$0	$477	$477
16	$0	$578	$578

Submeasure B: Increased Insulation

Table 43 through Table 92 provide the 30-year TDV energy cost savings for increased insulation.

Table 89: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction – Low-Rise Garden

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$0	$53	$53
2	$0	$49	$49
3	$0	$49	$49
4	$0	$48	$48
5	$0	$52	$52
6	$0	$48	$48
7	$0	$47	$47
8	$0	$47	$47
9	$0	$47	$47
10	$0	$47	$47
11	$0	$48	$48
12	$0	$48	$48
13	$0	$48	$48
14	$0	$48	$48
15	$0	$44	$44
16	$0	$50	$50

Table 90: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - Low-Rise Loaded Corridor

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$0	$98	$98
2	$0	$90	$90
3	$0	$91	$91
4	$0	$89	$89
5	$0	$95	$95
6	$0	$88	$88
7	$0	$86	$86
8	$0	$86	$86
9	$0	$86	$86
10	$0	$87	$87

11	$0	$89	$89
12	$0	$88	$88
13	$0	$88	$88
14	$0	$88	$88
15	$0	$81	$81
16	$0	$91	$91

Table 91: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - Mid-Rise Mixed Use

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$0	$67	$67
2	$0	$62	$62
3	$0	$62	$62
4	$0	$61	$61
5	$0	$65	$65
6	$0	$60	$60
7	$0	$59	$59
8	$0	$59	$59
9	$0	$59	$59
10	$0	$60	$60
11	$0	$61	$61
12	$0	$61	$61
13	$0	$60	$60
14	$0	$61	$61
15	$0	$56	$56
16	$0	$62	$62

Table 92: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - High-Rise Mixed Use

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$0	$59	$59
2	$0	$54	$54
3	$0	$54	$54

4	$0	$53	$53
5	$0	$57	$57
6	$0	$53	$53
7	$0	$52	$52
8	$0	$51	$51
9	$0	$52	$52
10	$0	$52	$52
11	$0	$53	$53
12	$0	$53	$53
13	$0	$53	$53
14	$0	$53	$53
15	$0	$49	$49
16	$0	$59	$59

Submeasure C: CPC Appendix M Pipe Sizing

Table 93 through Table 96 provide the 30-year TDV energy cost savings for increased insulation.

Table 93: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction – Low-Rise Garden

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$0	$143	$143
2	$0	$131	$131
3	$0	$132	$132
4	$0	$130	$130
5	$0	$138	$138
6	$0	$128	$128
7	$0	$125	$125
8	$0	$125	$125
9	$0	$126	$126
10	$0	$127	$127
11	$0	$129	$129
12	$0	$129	$129

13	$0	$128	$128
14	$0	$129	$129
15	$0	$118	$118
16	$0	$133	$133

Table 94: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - Low-Rise Loaded Corridor

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$0	$195	$195
2	$0	$179	$179
3	$0	$180	$180
4	$0	$177	$177
5	$0	$188	$188
6	$0	$175	$175
7	$0	$171	$171
8	$0	$170	$170
9	$0	$171	$171
10	$0	$173	$173
11	$0	$176	$176
12	$0	$176	$176
13	$0	$174	$174
14	$0	$175	$175
15	$0	$161	$161
16	$0	$181	$181

Table 95: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - Mid-Rise Mixed Use

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$0	$240	$240
2	$0	$220	$220
3	$0	$222	$222
4	$0	$218	$218
5	$0	$232	$232
6	$0	$215	$215
7	$0	$210	$210
8	$0	$209	$209
9	$0	$211	$211
10	$0	$212	$212
11	$0	$216	$216

12	$0	$216	$216
13	$0	$215	$215
14	$0	$216	$216
15	$0	$199	$199
16	$0	$223	$223

Table 96: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction - High-Rise Mixed Use

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$0	$265	$265
2	$0	$243	$243
3	$0	$244	$244
4	$0	$240	$240
5	$0	$255	$255
6	$0	$237	$237
7	$0	$232	$232
8	$0	$231	$231
9	$0	$233	$233
10	$0	$234	$234
11	$0	$239	$239
12	$0	$238	$238
13	$0	$237	$237
14	$0	$238	$238
15	$0	$219	$219
16	$0	$265	$265