CALIFORNIA ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Code Changes and Implications of Residential Low-Flow Hot Water Fixtures

Appendices A-I

September 2021 | CEC-500-2021-043-APA-I

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APPENDIX A: Literature Review

The purpose of this literature review is to briefly introduce the supporting research for the hot water distribution project described in this document. What is presented here is based on our review of more than 100 documents (See Appendix B: Bibliography). The following section outlines the design issues within hot water distribution systems and approaches taken to combat them. Low-flow distribution system design is discussed to expand on the focus of this project. The additional concerns that have been researched on low-flow hot water fixtures are included. Finally, the supporting research on the feasibility concludes the literature review with available case studies on current domestic hot water systems.

Design Issues of Distribution System

DeOreo WB (Aquacraft, Inc. Water Engineering and Management, Boulder, CO). Analysis of water use in new single-family homes. Final report 21 Apr 11-20 Jul 11. Salt Lake City (UT): The Salt Lake City Corporation and the US EPA. One goal of this study was to document indoor water use (both hot and cold) in new water efficient homes and compare the results to "standard" new homes and older (pre-1995) homes. Much larger datasets were available for standard and pre-1995 homes (~9000), but only 25 homes were available that met the water efficient criteria (EPA WaterSense® New Home Specification). Ten homes were in Eugene, OR and 15 were in Roseville, CA. The homes were monitored using a method that allows disaggregating usage based on flow signatures. Flow trace analysis was used on 10-second interval data collected at the house water meter. The key results from the study showed that indoor water uses for the pre-1995 homes totaled 177 gal/household-day, as compared to 140 for the standard new homes, and 110 for the water efficient homes. Interestingly shower usage was fairly constant, while clothes washer and toilet showed the greatest reduction, followed by faucets.

Henderson HI, Wade J (ARIES Collaborative, The Levy Partnership, Inc., New York, New York). Disaggregating Hot Water Use and Predicting Hot Water Waste in Five Test Homes. Golden (CO): U.S. Department of Energy; April 2014. NREL Contract No.: DE-AC36-08GO28308. Subcontract No.: KNDJ-0-40347-03. This next study seeks to quantify the magnitude of hot water waste in existing Northeastern homes. Monitoring of 5 homes near Syracuse, NY were selected for this study and divided into 3 groups. Group-1 had 2 control sites acting as baseline. Group-2 had one site where a conventional hot water tank was changed to tankless system. Group-3 had 2 sites where the water heater and distribution system were changed. Group2 and 3 were monitored both before and after the changes were implemented. Data was gathered in 15-minute intervals as well as 5-second intervals during each hot water draw. Each water draw was tied to a fixture using temperature sensors. Temperature sensors were also used to determine the portion of water that was deemed useful. At site 3 a new tankless water heater was installed to replace a conventional gas-fired tank. Site 1 had both a new heat pump water heater installed and distribution system improvements. The hot water supply line was shortened by 177". A recirculation pump was installed that included an internal time clock as well as an internal thermostat. Site 2 had a new condensing water heater installed with a Taco SmartPlus recirculation pump. The pump was set to operate in the smart mode where it anticipates hot water use based on the previous 7-day operating pattern

California Field Survey of Residential Hot Water Distribution Systems, Davis Energy Group, Inc. Amaro Construction. 2012. The key results from this study are as follows: Temperature sensors were able to detect only half the water draws but 95% of hot water volume in each home. Average number of hot water draw events ranged from 26 to 180 per day. Average hot water use ranged from 34 to 115 gal per day. The amount of hot water deemed useful ranged from a low of 75% ±5% at site 4 to a high of 91% ±2% at site 5, implying 9-25% waste among the 5 sites. The amount of hot water waste was found to be higher for bathroom and kitchen sinks and lowest for showers and washing machines draws. PEX piping was thought to be a reason for the lower useful percentage in site 4 as it can result a slower thermal response. Overall probable error in determination of usefulness was estimated to be ±2% for sites 1,2, 3 and 5 and ±5% for site 4. At site 3 (tankless retrofit), the number of hot water draws were cut in half but the volume of hot water use stayed the same. The overall percentage of useful hot water delivered to fixtures decreased from ~90% to 84-86%. The change was mostly explained by the 40-second startup delay in the tankless unit from a cold start. At site 1, on average, the pump ran about 3 minutes/day to prime the hot water lines during periods when hot water usage was expected to be high. The useful portion of hot water delivered increased from 82% before the retrofit to 91% after. The largest improvement was in the kitchen area. More modest improvements for other fixtures (not served by the pump) were also noted due to the shorter supply trunk (i.e., 28%–35% for the master sink and 49%–66% for the bath 2 sink). At site 2 the pump was observed to operate about 200 minutes/day, or about 14% of the time. This runtime resulted in significant thermal losses. While this water heater unit was observed to have an effective energy factor of 0.85 in the laboratory, it operated at 40%–70% efficiency at this site, varying based on daily hot water usage. The poor field performance of this system was linked to increased thermal standby losses of 15–16 kBtu/day due to pump operation and added pipe heat loss

The primary goal of another study was to characterize the configuration of the hot water distribution system (HWDS) in new CA homes by measuring and documenting:

- Piping installation (layout, pipe material type and diameter, insulation)
- Location of hot water piping (garage, underground, crawlspace, basement, exposed to attic air, buried in attic insulation, between floors, interior or exterior wall cavities)
- Location of hot water fixtures relative to the water heater(s)

The approach to the research consisted primarily of gathering information and documenting practices in the field

This study was done from late 2009 through late 2011 in California and looked at 97 houses statewide. Detail site surveys were done to collect relevant data. Data was gathered from sites from a broad geographic area and from as many plumbers as possible. Installations from 20 plumbing contractors were surveyed. In addition, extra efforts were made to find sites that fell into the four HWDS types (recirc, trunk and brunch, manifold, and hybrid systems). For sites without basic floor plan information, the researchers had to hand draw the plans, as well as the plumbing layout

The key element of the survey process involved measuring every section of installed hot water piping in the home with a tape measure. Additional data collected included pipe material type, diameter, location, and the presence of thermal insulation. The location of major components such as the water heater, trunks, manifolds, etc. were sketched on the floor plan. Pictures were also taken to document site observations including installation quality, hot water use points, under slab plumbing, pipe locations, and bundling of tubing. This study built on prior similar work completed in 2006 (60 home CA study).

The primary plastic piping material in California is cross-linked polyethylene piping (PEX), although CPVC pipe was found to have a very small market presence in recent field plumbing surveys. Plastic pipe has been found to have higher heat loss than copper pipe. The primary explanation for this is due to radiant heat transfer. PEX has effectively replaced copper piping as the material of choice. This is largely cost driven. It is not clear if CPVC will make inroads in the California market. The key findings are the following:

1. Average entrained pipe volumes were fairly consistent with the 2006 survey. For a typical 2,000 ft2 house, the average entrained volume (to any fixture use point) is close to one gallon of water. There is clear room for improvement in this regard.
2. Home run systems are much less common than in 2006. Again, this appears to be driven by cost. Mini-manifold "hybrid" systems are now the predominant system type.
3. Installation issues lead to significant variability in the installed HWDS. There are many instances when much more direct path can be followed, but for whatever reason, the installer chose not to.
4. The need for plumbing industry training is critical.
5. Builders need to recognize that there is value in good design. Good design begins with the architectural design and water heater location. Locating the water heater as centrally as possible is the first step in minimizing the energy and water waste inefficiencies of the HWDS. Efficient installation of the layout is also important.
6. Residential plumbing designs should be required.

Hoeschele M, Weitzel E (Alliance for Residential Building Innovation, Davis Energy Group, Davis, CA). Hot water distribution system model enhancements. Golden (CO): US Department of Energy; November 2012. Contract No.: DE-AC36-08GO28308. NREL Subcontract No.: KNDJ-0-40340-00. The next project involves enhancement of the HWSIM distribution system model to more accurately model pipe heat transfer. An analytical methodology for integrating radiant heat transfer was implemented with HWSIM. Standard horizontal pipe heat transfer calculation utilizing fluid velocity was implemented for determining the interior pipe heat transfer coefficient. Laboratory test data collected in another project was then used to validate the model for a variety of uninsulated and insulated pipe cases (copper, PEX, and CPVC). The results appeared favorable, with typical deviations from lab results less than 8%. Some level of uncertainty lies in specifying the mean radiant temperature condition, both in the lab environment, and more significantly, in many real-world piping applications such as attics and garages. In addition, copper surface emissivity, which will vary over time due to oxidation, is difficult to determine

Lutz JD, Renaldi, Lekov A, Qin Y, Melody M. Hot Water Draw Patterns in Single-Family Houses: Findings from Field Studies. Berkeley (CA): Lawrence Berkeley National Laboratory (US); May 2011. DOE Contract No.: DE-AC02-05CH11231. CEC Contract No.: 500-08-060. The purpose of the project described here was to develop a database of hot water draw patterns in single-family houses based on a range of field data. The database of field data on hot water use to date encompasses:

- 10 studies
- 142 monitored houses
- 200 monitored configurations of water heaters and hot water end uses
- 27,956 days of monitoring
- 23,994 good days (days providing acceptable data
- 1,547,144 hot water draws
- 4,582,960 records of hot water use

Data regarding hot water draw patterns that Lawrence Berkeley National Laboratory obtained from 10 different studies was used for this analysis. Software scripts written in Perl, a multipurpose programming language were used, to automate the process. Two studies recorded data when hot water was flowing and once every 15 minutes even if water was not flowing. Some of the studies recorded data only when water was flowing. Using draw and interval data from good days only, we summarized the hot water usage for every house.

Based on the hot water draw patterns for the 23,994 good days from the 200 configurations of water heaters and hot water end uses in houses (from 142 monitored homes), the daily volume of hot water use and the daily number of draws were determined. One distinctive feature of daily hot water use is its variability. A simple, unweighted calculation of the average hot water use for all households and all days in our database gives 58.7 gallons per day (GPD), with a standard deviation of 38.8 GPD. Another striking feature of the data is that the distributions of daily hot water use are not symmetrical normal distribution. The average daily median volume of hot water use among our sample of houses was 50.6 gallons. The average daily median number of hot water draws among the sample households was found to be 61.6. Information from this study is relevant to low-flow distribution system designs and is presented in the next section.

Low-Flow Distribution System Designs

Lutz JD, Renaldi, Lekov A, Qin Y, Melody M. Hot Water Draw Patterns in Single-Family Houses: Findings from Field Studies. Berkeley (CA): Lawrence Berkeley National Laboratory (US); May 2011. DOE Contract No.: DE-AC02-05CH11231. CEC Contract No.: 500-08-060. The study focused on typical hot water draw pattern in single-family residences in North America. Data were collected from 12 separate studies and compared with condition and draw pattern established in the then-current US Department of Energy test procedure for residential water heaters. After preparing the data, the complete data set was used to analyze inlet and outlet water temperatures. ASHRAE SPC 118.2 had identified the need to separately evaluate at least three, and perhaps as many as five, different water heater capacities. So, data were divided into three clusters reflecting house configurations that demonstrated small, medium, or large median daily hot water use. Daily hot water use data within each cluster in terms of volume and number of hot water draws was analyzed. The daily draw patterns in each cluster were characterized using distributions for volume of draws, duration of draws, time since previous draw, and flow rates.

There is significant variation in hot water use and draw patterns among households. The field data show more, shorter, smaller draws at lower flow rates clustered closer together in time than the then-current DOE test procedure. Using at least three different draw patterns for water heaters having different capacities, rated volume and/or rate maximum flow rate, could better reflect the wide range of hot water use seen in field data. The study found a higher-than-expected number of draws per day. This result indicates a need to reconsider the the start-up losses for tankless water heaters and the losses in hot water distribution systems caused by numerous short draws.

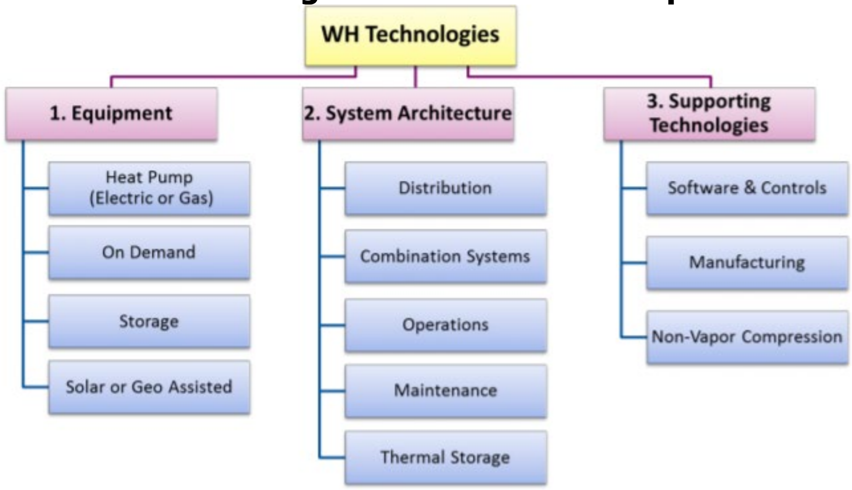
Henderson HI, Bogucz E, Wade J (Syracuse Center of Excellence in Environmental and Energy Systems, Syracuse, NY, and CDH Energy Corp., Cazenovia, NY). Evaluating Domestic Water Heater Performance for NY Homes. Albany, NY: New York State Energy Research and Development Authority; April 2015. Draft Report. Contract No.: 15606. This study compared the performance of a wide variety of water heating systems. It also looked at the impact of water use profiles on the Domestic Hot Water (DHW) system's efficiency. Laboratory testing was monitored to compare the performance of different systems. Field data were also collected from 18 homes in New York for water use patterns and for the quantity of distribution related water waste. The field study of 18 homes showed that median hot water use was 45 gal/day (average 2.7 occupants), resulting in 16.7 gpd-person average. The median 2-person household used 39 gallons per day and median 4-person household used 66 gallons per day. Water waste was measured at 5 homes by measuring pipe surface temperature close to the fixtures and counting waste as any flow with a temp < 90F. Waste in the 5 houses ranged from 9-25% Two homes were retrofitted with "smart" recirc pump systems. The systems reduced hot water waste but increased thermal losses relative to the base case. Authors concluded that that in the Northeast ".... recirculation pumps do not seem to be justified."

Improvement Strategies for Distribution System

Goetzler W, Gurnsey M, and Droesch M (Navigant Consulting, Inc., Burlington MA). Research & development roadmap for emerging water heating technologies. Washington (DC): US Department of Energy; September 2014. Summarized below, this roadmap laid out a strategy for the U.S. DOE Buildings Technologies Program Water Heating Research and Development (R&D) program to help DOE meet near- and long-term goals for energy use and carbon emissions reductions (Figure A-1). Developing this roadmap was a multistep process that included identifying and evaluating potential areas of research, a stakeholder workshop to discuss potential research areas, gather ideas, and understand stakeholder priorities, and additional evaluation of potential research areas against DOE priorities. The roadmap is organized around three main areas of focus:

1. Equipment, including water heaters and ancillary devices
2. System design, including hot water distribution systems and design tools
3. Policy and markets, including codes/standards and test methods, market encouragement and facilitation activities, etc.

Figure A-1: Department of Energy Roadmap for Water Heating Research and Development



Source: Gary Klein and Associates

Lutz JD. Feasibility study and roadmap to improve residential hot water distribution systems. Berkeley (CA): Lawrence Berkeley National Laboratory (US); 2004. Report No.: LBNL54841. The feasibility section of this study reviews water loss estimates from a previous residential hot water study by the same author. The road map section of this study outlines recommendations for improving distribution systems for residential hot water. Lutz assessed residential water end uses from data collected by the 1999 Residential End Uses Water Study (REUWS) using an independent method of estimation developed by Lutz. The parameters included in the estimation of hot water waste were peak flow, event water volume, mode flow, and the duration of events. Shower, faucet, and dishwasher events were analyzed for three types of loss: water loss while waiting for the desired temperature, energy loss from heating unused hot water, and energy loss from reheating water. Long sink faucet draws (at least 60 seconds) and short draws (at most 20 seconds) were considered. Water and energy losses from pipes and fittings were not included, as the underlying study did not collect data on these aspects of construction. The study estimated average water loss of 6.35 gallons per day, hot water waste of 10.9 gallons per day, and average daily hot water waste of approximately 20 percent of average total residential hot water use

Road Map

Considerations for single-family homes:

1. Extent of water, energy, sewer, and environmental issues
2. Extent of system from the water heater, through the piping, and to the fixtures
3. Health and safety, including risk of scalding

Recommendations

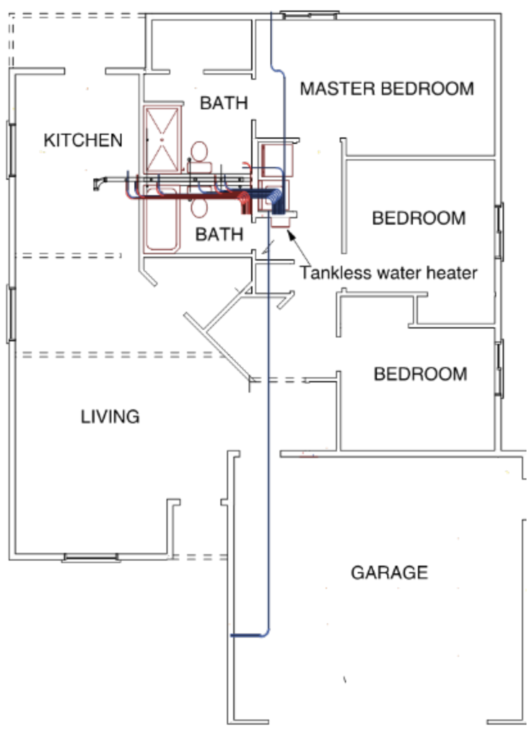
1. Conduct surveys to determine current designs and efficiencies
2. Conduct field measurements in existing homes to determine hot water use and waste
3. Develop distribution model for hot water systems and compare with existing models
4. Conduct laboratory experiments to determine parameters and calibrate models

Goals

1. Determine installation guidelines for hot water distribution systems optimized for both water and energy efficiency
2. Develop and implement useful tools for industry
3. Develop incentive programs
4. Update building and plumbing codes

The Habitat for Humanity house in San Joaquin County is a Zero Net Energy Demonstration Home. The low energy design groups all points of hot water use in a central location. The longest pipe is 12 feet away from the water heater, much shorter than the 50-foot maximum allowed by the EPA WaterSense® New Home Specifications. These short distances save water, energy, material and reduce the time spent waiting for hot water. The ZNE package reduced construction costs from the baseline by $3,000 and achieved energy savings of 41%. (Habitat for Humanity of San Joaquin County, 2017) The included the floorplan highlights the location of the water heating distribution system (Figure A-2).

Figure A-2: Floor Plan of Habitat for Humanity ZNE Demonstration House (Habitat for Humanity of San Joaquin County, 2017)



Source: Gary Klein and Associates

Evaluation of Residential Recirculation Pumps, Mary Nones, Jorge Gutierrez. 2015. The performance of a residential recirculation pump in saving water and energy is the focus of the next study. Five homes in LA with 3-8 people were selected and baseline data was collected measuring water consumption and gas use at the water heater. Then recirc pumps were installed in four homes and the difference in usage was recorded. Five different recirc systems (two from the same manufacturer) were tested in the homes. One phase of the testing allowed homeowners to select a new water heater and a recirculation pump. Performance data of each system was recorded. All hot water piping (base and recirc mode) was uninsulated. The following are the key results:

- One of the four pump systems reduced hot water usage at all sites.
- One of the four pump systems reduced hot water usage at 3 of 4 sites.
- One of the four pump systems reduced hot water usage at 2 of 5 sites.
- One of the four pump systems reduced hot water usage at 3 of 5 sites.
- Numerically averaging the hot water savings, the 4 technologies saved 5-15 percent of hot water.
- In terms of gas water heater consumption, only one pump technology reduced gas consumption at a majority of the sites (3 of the 4 sites). Average gas consumption was reduced by 1 percent (best case) and increased by as much 31%, relative to the non-recirc case.

With both a new water heater and recirculation pump, the majority of home owners saved 11-25 percent on water and 11-19 percent on gas.

Weitzel E, Hoeschele M (Alliance for Residential Building Innovation, Davis Energy Group, Davis, CA). Evaluating domestic hot water distribution system options with validated analysis models. Golden (CO): US Department of Energy; September 2014. Contract No.: DE-AC36-08GO28308. NREL Subcontract No.: KDNJ-0-40340-04. This study builds upon previous distribution model work to evaluate differing distribution systems and the sensitivities of water heating energy and water use efficiency to variations of climate, load, distribution type, insulation, and compact plumbing practices. Overall 124 different TRNSYS models were developed to compare various distribution system types in different climates. The base case, an uninsulated trunk and branch system distribution system, is best improved in terms of annual energy consumption by insulating and by locating the water heater central to the use points. Demand recirculation systems are not projected to provide significant energy savings relative to the base case, and in some cases would increase system energy consumption. Water use is most efficient with demand recirculation systems, followed by the insulated trunk and branch system with a centrally located water heater. Compact plumbing practices and insulation levels have the most impact on energy consumption (energy savings of 2–6 percent for insulation and 3–4 percent per gallon of enclosed volume reduced). Of the configurations evaluated, distribution losses account for 13–29 percent of the total water heating energy use, with compact, insulated low-load systems having the least distribution losses. Water use efficiency ranged from 11–22 percent, with uninsulated home run systems and noncompact plumbing practices accounting for the most water waste.

Progress Report on Building America Residential Water Heating Research, Davis Energy Group, Inc. 2013. The focus of this study was to understand the four factors affecting the water heating energy use namely End Use, Distribution Losses, Recovery Loss and Standby loss. Two locations were included in the study.

- Demand Recirculation System Monitoring: The first site was in Livermore, CA. Performance of hot water recirculation system was evaluated. Motion sensors were used to activate the recirculation pump in this project. This single family home site with 2 adults had lower than average water heating loads.
- Distribution System Monitoring: The second site was a production home in Sacramento, CA. This site was focused on studying the end use pattern and hot water distribution system efficiency. This building had a "main and branch" system. The temperature

decay constant and U-value were calculated from the monitoring data for use in analytical models. This single-family home site with 2 adults had lower than average water heating loads

The Livermore project showed improvement in measured distribution efficiency of 45%, achieved by eliminating the false signals from the motion sensors. Extrapolation of this data indicated that losses from uncontrolled and timer-controlled systems are as such as 14 and 9 times higher respectively than found in prior studies. Preliminary monitoring results from the "main and branch" system at the Sacramento site determined an overall distribution system efficiency of 57%, or about 24% less than the expected 75% efficiency (determined from modeling). The lower efficiency was partly due to lower than average hot water loads. Preliminary site data yielded water heater efficiencies of 33.1%and 68.5% for the storage and instantaneous water heaters respectively. The poor performance of the storage water heater is affected by low daily hot water energy consumption (22 gallons per day) and relatively high standby energy use. Using monitored energy savings, a payback of 4 years was estimated for substituting instantaneous for storage water heater in homes.

RESNET. Justification and background. Oceanside (CA): BSR/RESNET 301-2014: Addendum A-201x PD-03; 2014. This study outlines the updated RESNET assumptions and calculations for hot water system modeling. The authors reviewed recent research on hot water use and distribution system effectiveness and leveraged the results to inform the new equations presented in this report. They conducted some climate normalization and regression on water use relative to the number of bedrooms, the basis for RESNET's home energy rating methodology. Hot water usage calculations used for RESNET were updated to account for structural and operational water waste and to account for various distribution system designs and fixture flow rates. Energy waste for standard and recirculation distribution systems with and without pipe insulation was calculated. To account for the benefits of drain water heat recovery systems, calculations that adjust the water temperature entering the water heater were developed

Zhang Y (Heschong Mahone Group, Inc., Gold River, CA). Multifamily central domestic hot water distribution systems. California Energy Commission; June 2013. Publication No.: CEC-500-2013-011. This PIER study surveyed recirculation system designs and conducted field performance monitoring of recirculation system controls in 30 multi-family buildings in California. The study developed an energy flow analysis method to assess the energy impact of distribution system design and controls. The research team also developed a model to predict energy performance of central recirculation systems. The model was validated using data collected from field performance monitoring. The performance model considered the dynamic temperature change along the recirculation loop due to both recirculation flow and hot water use flows. The model was developed in a way that can be adapted to the Title 24 performance modeling method for central recirculation systems. Recirculation loop pipe heat loss represents about 30% of the total energy consumption in central DHW system. Overall system efficiency depends on recirculation loop plumbing design and hot water use patterns. Demand control and temperature modulation can reduce pipe heat loss and their impact on overall system energy use depends on recirculation loop plumbing design and hot water use patterns.

Hot Water Delivery Performance

Lutz JD. Estimating energy and water losses in residential hot water distribution systems. Berkeley (CA): Lawrence Berkeley National Laboratory (US); 2005. Report No.: LBNL57199. This study estimated water and energy losses from showers, faucets, and sinks in residential single-family buildings. Lutz assessed residential water end use from data collected from the 1999 Residential End Uses of Water Study (REUWS) using an independent method of estimation developed by Lutz. The parameters included in the estimation of hot water waste were peak flow, event water volume, mode flow, and the duration of events. Shower, faucet, and dishwasher events were analyzed for three types of loss: water loss while waiting for desired temperature, energy loss from heating unused hot water, and energy loss from reheating water. Sink faucet long draws (at least 60 seconds) and short draws (at most 20 seconds) were considered. Water and energy losses from pipes and fittings were not included.

Three types of loss considered were wasted water (water wasted while waiting for desired temperature), wasted heat (heat lost from unused water while stored in piping system), and energy (extra energy required to reheat water stored in piping system). The total amount of shower water waste estimated was 5.21 gallons per day per household. Water waste from sinks of 1.14 and 4.0 gallons per day per household was estimated for long and short draws, respectively. The average hot water waste estimated from dishwashers was 0.56 gallons per day per household. The study estimated average water loss (the amount of water not used by the consumer) of 6.35 gallons per day, hot water waste (the amount of hot water not used by the consumer) of 10.9 gallons per day, and average daily hot water waste of approximately 20 percent of average total residential hot water use.

Liao A, Lanzisera S, Lutz J, Fitting C, Kloss M, Stiles C. Performance monitoring of residential hot water distribution systems. Presented at the 2014 ACEEE Summer Study on Energy Efficiency in Buildings; California. Berkeley (CA): Lawrence Berkeley National Laboratory (US). The purpose of this study was to determine water and energy use and waste in hot water distribution systems in California residences. A wireless sensor network for large-scale, long time-series monitoring of residential water end uses was developed. This system consisted of flow meters connected to wireless motes transmitting data to a central "manager" mote, which in turn posted data to the server via the internet. Meters were installed in the water heater and at every end use point in 20 homes. Flow and temperature data was collected at one-second intervals over an 8-month period. Preliminary analysis of a few of the data sets demonstrated that the delivery efficiency of dishwashers were 47.4 percent, suggesting dishwasher hot-water draws were inefficient and would require water heating at the end use. This study also suggests future research be conducted to determine the efficiency of plumbing dishwashers to cold-water lines and using localized heating at the dishwasher.

Efficiency of Individual Hot Water Events

Maguire J, Krarti M (University of Colorado at Boulder, Boulder, CO), Fang X (National Renewable Energy Laboratory). An analysis model for domestic hot water distribution systems. International Conference on Energy Sustainability and Fuel Cells; 7-10 Aug 2011; Washington, DC. Golden (CO): Department of Energy. Conference Paper No.: NREL/CP-5500-51674. The purpose of this study was to understand the energy losses from prototypical domestic hot water (DHW) distribution systems for homes. A model was developed using the TRNSYS simulation software, allowing researchers and designers to better evaluate the performance of hot water distribution systems in homes. Modeling results were compared with past experimental study results and showed good agreement. The model was also compared with existing domestic hot water distribution system modeling software, HWSIM, for verification. The effects of adding insulation to a DHW in homes with either a gas water heater or a solar water heater were also examined.

The predictions of this model reasonably matched both data collected in the laboratory and predictions from other models. Some discrepancies occurred between lab testing and the model; those discrepancies can be attributed to flow phenomena too complex to properly model, possible underperformance of pipe insulation, and potentially moving air in the lab during testing. The impact of insulation was examined in detail and found to have a significant impact. Insulating the first few feet of the distribution system, particularly in homes with the water heater in unconditioned spaces, had significant energy savings, in some cases up to 30% of the savings that could be achieved by insulating the entire distribution system. The simple payback was examined for distribution system insulation and was found to be rather long for insulating the full distribution system, but more reasonable for just insulating the first few feet of the distribution system.

Pathogen Control, Including Legionella

Mader RP. Water conservation can have unintended consequences. Contractor; June 2014 [cited 10 Jul 2018]. Available from: http://www.contractormag.com/plumbing/water-conservation-can-have-unintended-consequences. This article references some effects of Legionella in drinking water and how water conservation may increase Legionella outbreaks from a previous study. Legionella causes 50 percent of illness outbreaks and 93 percent of deaths from waterborne diseases. Furthermore, drinking water containing Legionella can cause 20 to 40 percent of "common ailments."

Water use reduction causes water to take longer to get to buildings, remain in pipes longer, and generally results in warmer water*.* In one study, water took two months to travel from the point of entry of the building to a drinking fountain within the building. Water stored for months in cisterns in buildings contained high levels of Legionella even after ultraviolet light and secondary disinfectant treatments. Chloramine is widely used as a secondary treatment but effects are diminished within six hours of application. Chlorine dioxide is effective but corrodes PEX, HDPE, and stainless steel.

John Hopkins Medicine. Latest hands-free electronic water faucets found to be hindrance, not help, in hospital infection control [Internet]. Baltimore (MD): Johns Hopkins News and Publications 31 Mar 2011 [cited 10 Jul 2018]. Available from: https://www.hopkinsmedicine.org/news/media/releases/latest_hands_free_electronic_water_faucets_found_to_be_hindrance_not_help_in_hospital_infection_control. Another article discusses the results and recommendations from a study conducted at Johns Hopkins medical center focusing on the concentration of Legionella species in hands-free faucets. The presence and concentration of Legionella was tested with samples drawn from 20 electronic, hands-free faucets and 20 manual faucets within in-patient care units. The frequency of use and volume of water used from faucets were measured and compared. Four electronic faucets were disassembled and tested with swab cultures for bacteria, including

Legionella. Two of the four faucets were tested before, and two after the water was treated using standard hospital water treatment methods. The presence of Legionella was found in 50 percent of the electronic-eye faucets and 15 percent of manual faucets. The concentration of Legionella found in the manual faucet sample cultures was half the concentration of the sample cultures from the electronic-eye faucets. The volume of water from the electronic faucets was about one quarter of the volume of water from the manual faucets. The standard hospital water treatment methods were found inadequate for suppressing Legionella growth in the electronic faucets. The increased surface area of the complicated components in the electronic faucets may have caused this growth.

Keane T. ANSI/AHRAE standard creates multiple benefits in Legionella prevention: the domino effect of ASHRAE Standard 188 [Internet]. Troy (MI): PM Engineer Magazine; 21 Jan 2016 [cited 2018 Jul 10]. Available from: https://www.pmengineer.com/articles/92279-ansiashrae-standard-creates-multiple-benefits-in-legionella-prevention. This article presents the benefits of the ASHRAE Standard 188 "Legionellosis: Risk Management for Building Water Systems." Experts in engineering, plumbing, equipment design, microbiology, and public health developed the ASHRAE Standard 188 by methodologies not presented in this article. ASHRAE Standard 188 benefits include: dismissing harmful myths about Legionella, decrease costs, increase industry awareness, correct outdated plumbing codes, decrease outbreaks in the healthcare industry, and improve the Environmental Protection Agency's (EPA) Safe Drinking Water Act (SDWA).

Legionella was once believed to be found in the environment at pathogenic levels and could not be controlled. However, Legionella in natural environments is rarely found at pathogenic levels and is typically only found at these levels in building water systems with habitats conducive to its growth. This standard requires and presents a cost-efficient risk management plan to reduce public health risks from Legionella outbreaks for public health officials. Another benefit of this standard is increased industry awareness leading to product designs reducing Legionella outbreak risks. Outdated plumbing codes encouraging oversized pipes with low velocities and excess water retention, and temperatures conducive to Legionella growth may change. The increased awareness provided by the ASHRAE Standard 188 is expected to reduce the risk of outbreaks within the healthcare industry, which accounts for 67 percent of all outbreaks. The SDWA may also change to allow cost-efficient and safe disinfection to occur in building water systems.

Information to Support the Feasibility and Performance Analysis

Wiehagen J, Sikora JL (NAHB Research Center, Inc., Upper Marlboro, MD). Domestic hot water system modeling for the design of energy efficient systems. Golden (CO): US Department of Energy; 2 Apr 2002. This report evaluated the use of electric on-demand water heating equipment in conjunction with various hot water piping configurations. Specific performance issues, such as hot water delivery temperatures at the outlet, were used as a basis for understanding the adequacy of the system as well as comparing delivered outlet energy relative to the electric energy required to supply the outlet energy. The on-demand water heating equipment was evaluated as an alternative to a standard tank with a trunk and branch delivery system. Four different domestic hot water heating systems were evaluated for incremental performance changes. Using one-minute hot water flow data, variable interior air temperatures, and monthly variable cold-water inlet temperatures, the performance of a hypothetical domestic hot water system was simulated for both high and low hot water consumption profiles.

Maximum energy savings resulted from using a combination of a centrally located on-demand water heater with a parallel piping system supplying individual outlets. For the high-consumption home, savings were 17 percent or 920 kWh annually; savings were 35 percent or 817 kWh for the low-use home. Savings included an adjustment to the input electric energy if the delivery temperature fell below the set point and an adjustment to water heater system efficiency for higher-than-necessary delivery temperatures. For the on-demand water heating equipment, hot water delivery temperatures showed degradation at the outlets during periods of high flow rates. This performance issue appeared problematic in the high use home but not in the low use home. Performance gains such as higher than necessary delivered outlet temperatures were assumed to be an efficiency gain that results in a decrease of water heating energy.

Backman C, Hoeschele M (Alliance for Residential Building Innovation, Davis Energy Group, Davis, CA). Validation of a hot water distribution model using laboratory and field data. Golden (CO): U.S. Department of Energy; July 2013. NREL Contract No.: DE-AC36-08GO28308. Subcontract No.: KNDJ-0-40340-03. The aim of the project was to valid the TRNSYS Type 604 pipe model against laboratory pipe heat loss test data and detailed field monitoring data from a prior National Renewable Energy Laboratory (NREL) research project. Using measured data and an as-built distribution model of the NREL Solar Row field-monitoring project; modeled hot water distribution losses were compared to monitored data over the 4-month period when field data was available. The validated model was extended to a prototypical distribution system configuration in different climates. The model results were found to be within 2% of the measured data over the four-month period, indicating a high degree of confidence in the model. Distribution losses were found to represent about 26%–27% of the annual water heater recovery load at the site (2-person household), with an associated energy use impact of 534–892 kWh/yr. Insulating the full distribution system with ¾ in. pipe insulation reduced the distribution loss by a projected 111–170 kWh/yr.

Sherman T. Disaggregating residential shower warm-up waste: an understanding and quantification of behavioral waste based on data from Lawrence Berkeley National Labs. Scottsdale (AZ): Evolve Technologies LLC; 11 Aug 2014. The aim of the next study was to disaggregate and quantify the behavioral waste component of shower warm-ups based on primary field research. Applying the fundamentals of a method development by Lutz, Evolve technologies was able to analyze the shower events captured by the LBNL monitoring system from December 1-December 31, 2013. The method consisted of plotting the time, temperature and flow rate data collected by the LBNL monitoring system at each showerhead and then determining the point at which the user actually entered the shower (referred to as the 'entry point'). The entry point was indicated by a rapid reduction and subsequent stabilization of the shower's temperature after the shower's peak temperature has been achieved. The rapid drop in temperature is caused by the typical user behavior of turning the shower to full hot to speed the shower's warm up and then adjusting it to a comfortable bathing temperature upon entering the shower. Of the 19 homes monitored in California, 11 produced shower data applicable to the previously described analytical method. In total, 283 unique shower events were analyzed. The total occupancy of 11 homes was 34. There were 18 unique bathrooms with 8 dedicated showers and 10 tub / shower combos.

The average bathroom total warm-up waste was found to be 1.83 gal, with 0.7 gal assigned to structural waste (time to get water to temperature) and 1.13 gal assigned as behavioral waste. "The December 2013 data reveals that behavioral waste varies widely. .... some bathrooms/individuals consistently produce little or no behavioral waste, while others consistently generate a lot-- almost no one is "average". The author found "no correlation between consistently fast hot water delivery and reduced behavioral waste."

Froehlich J, Larson E, Saba E, Campbell T, Atlas L, Fogarty J, Patel S. A longitudinal study of pressure sensing to infer real-world water usage events in the home. Seattle (WA): University of Washington; 2011. This report focused on testing the accuracy of pressure sensor technology to estimate the water usage in homes. In order to study the pressure-based approach, a sensor network was deployed for five weeks in three homes and two apartments that directly monitored valve-level water usage by fixtures and appliances. This data was used to, first, demonstrate the practical challenges in constructing water usage activity inference algorithms and, second, to inform the design of a new probabilistic-based classification approach. It was found that with a single pressure sensor, the probabilistic algorithm was able to classify real-world water usage at the specific fixture level with 90% accuracy and at the fixture category (i.e. shower, sink, appliance) level with 96% accuracy. With two pressure sensors, these accuracies increase to 94% and 98% respectively.

Hendron R, Burch J. Development of standardized domestic hot water event schedules for residential buildings. Presented at Energy Sustainability 2007; 27-30 Jun 2007; Long Beach (CA). Golden (CO): National Renewable Energy Laboratory; August 2008. Conference Paper No.: NREL/CP-550-40874. The focus of this report was to generate a standard domestic hot water event schedule for residential buildings. High-level constraints on mains temperature and average daily hot water use were used to generate hot water events over one year for houses of different sizes in various locations. Detailed event characteristics derived from past research and a software tool developed by Kassel University in Germany were also used. The events were established in 6-minute increments for showers, baths, sinks, clothes washers, and dishwashers. Flow rates and times of occurrence were varied randomly based on specified probability distributions. The daily average hot water use for the Benchmark was established as a linear function of the number bedrooms, which served as a surrogate variable for number of occupants. The relationship between bedrooms and occupants was based on the DOE’s 2001 Residential Energy Consumption Survey (RECS). The final event schedules reflected the same daily variability as an actual household, thereby providing more realism to energy simulations involving advanced water heating systems.

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APPENDIX C: Primer on Plumbing

This appendix discusses issues related to the design and installation of hot water distribution systems. While the primary focus is on California, the principles apply in other places – after all, the physics is the same. The reason for this overview is that it is likely that many of the people reading this are not as familiar with plumbing issues as they are with other energy-related systems.

Hot Water Distribution Designs

All piping systems contain trunks and fixture branches (aka twigs). Some systems contain branches too. A fixture branch serves one plumbing fixture or appliance either hot or cold water; a branch serves two or more; a trunk serves branches and fixture branches; a main line serves the building.

In hot water distribution systems the first user clears out the trunk line to the branch, then the branch and then the fixture branch serving the fixture they are using. Research has shown that it takes roughly twice as much water as in the pipe before hot water comes out the other end. Subsequent users within 15-45 minutes of the completion of the first use can take advantage of the fact that at least some portion of the trunk line is hot, and will get hot water more quickly.[1]

Trunk and Branch: This is the most common system. A relatively large diameter trunk serves branches and fixture branches, which are usually smaller diameters. In residential applications, it is common to have 0.75 or 1.00 inch diameter trunk lines with 0.5 inch branches and fixture branches. In general, the trunk line is relatively long compared to the fixture branches. The layout of most trunk and branch systems does not make any attempt to optimize the delivery of hot water. In particular, one often sees the trunk running down the center of the building with long branches and fixture branches serves the fixtures and appliances on either side.

Circulation systems: In many ways, a circulation (aka: recirculation) system is a modified one-zone trunk and branch system. It is most often found in larger buildings where the distance from the water heater to the furthest fixtures is great than 100 feet of pipe. The distance is long, so are the volume and time-to-tap; the loop is installed to reduce this time. Usually a pump is installed to fill the supply portion (trunk) of the circulation loop with hot water before users need it. While it is possible to add a return pipe to the end of the trunk in a trunk and branch system, this does not reduce the delivery time of hot water for anyone except the first user. It is advisable to route the supply piping relatively close to the hot water

[1] Hiller, Carl. "Hot Water Distribution System Research–Phase I Final Report." California Energy Commission, November 2005. http://www.energy.ca.gov/2005publications/CEC-500-2005-161/CEC-500-2005-161.PDF; Hiller, Carl. Hot Water Distribution System Piping Heat Loss Factors--Phase I: Test Results." ASHRAE Transactions 112, no. 1 (2006); Hiller, Carl C. "Hot Water Distribution System Piping Heat Loss Factors, Both In Air and Buried-Phase II Test Results." ASHRAE Transactions 114, no. 2 (2008); and Hiller, Carl C. "Hot-Water Distribution System Piping Heat Loss Factors--Phase III: Test Results." ASHRAE Transactions 117, no. 1 (2011).

fixtures and appliances so that the branches and fixture branches will contain only a small volume and hot water delivery will be quick. It is often possible to have very similar and small volumes in each branch resulting in similar and short times-to-tap.

There are six control strategies for hot water circulation loops. Demand activated controls are the most efficient, using less than 80 percent of the thermal energy needed to continuously maintain a hot loop while simultaneously reducing the pumping energy by more than 95%. Internal erosion and corrosion are commonly found in continuous circulation systems, so there are good reasons to reduce the run time. In addition, the energy costs of keeping the loop warm can be very large. In single-family applications a continuous loop can add roughly 300 therms per year to a hot water energy use of 200 therms per year. In multifamily applications it can be 25 to 40 percent of the annual hot water energy use.[2]

Even well insulated loops lose heat. Additional heat losses come from the branches connected to the trunk since they act as fins pulling heat away from the trunk line. Branches need to be well insulated too to minimize this effect. One unintended consequence of continuously keeping a loop hot is that at some distance along each branch the temperature will be maintained in the optimal conditions for pathogen growth for many hours each day.

Circulation loops should be as short as possible with the caveat that they must get very close to the plumbing fixtures and appliances to minimize the time-to-tap.

Electric heat trace systems: It is possible to install a self-regulating heating cable along the length of the pipe, insulate the pipe and maintain the temperature in the pipe at practically any desired temperature for as many hours a day as needed. The heat trace can be installed along the trunk line; this gives similar performance to a circulation loop. It can also be installed along branch lines to get very close to each plumbing fixture and appliance; this reduces time-to-tap significantly. Unlike circulation loops, the water isn't moving, minimizing the effects of internal erosion and corrosion. Depending on the configuration of the hot water distribution system electric heat trace can be very competitive with continuous circulation systems in terms of annual energy performance.

Central home run systems: There is a trunk line from the water heater to a manifold and then fixture branches from the manifold the plumbing fixtures and appliances. The manifold is really part of the trunk line and its volume needs to be included in calculations. Manufacturers generally recommend a fixture branch for each for each fixture and appliance, even though in many cases the plumbing code would allow more than one fixture to be connected to the same branch.

Valved manifolds provide shut-offs for everything, not just sinks and appliances so that you can work on a shower valve without shutting off the water to the whole house. However, these valves need to be accessible which limits where the manifold can be installed.

A bathroom with two sinks and a tub/shower combination will have three fixtures branches coming from the manifold. As with the trunk and branch system, the first user will pull hot water from the water heater, through the manifold and then through the fixture branch they are using. Once they are done, the next user will go to a different fixture; they need to clear

[2] Zhang Yanda (Heschong Mahone Group, Inc., Gold River, CA). *Multifamily central domestic hot water distribution systems*. California Energy Commission; June 2013. Publication No.: CEC-500-2013-011.

out that fixture branch and possibly some more of the manifold. For the same floor plan, the first user in a home run system will waste less water waiting for the hot water to arrive, but only if the volume in the piping is smaller than in the trunk and branch system. If there is any savings for the first user, it generally disappears by the second or third consecutive use where the trunk line is still hot. In these cases, and with current pipe sizing rules, trunk and branch systems are more water, energy and time efficient.

Hybrid systems: These have come about recently with the advent of mini-manifolds. Mini-manifolds are multiport tees. A common configuration is a 0.75 inch trunk with 0.5 inch branches. These manifolds can either have water pass through them or have a cap on one end so they can be the termination of a trunk or branch. Hybrid generally refers to trunk and branch systems where the trunk branch is brought close to the bathroom for example, a mini-manifold is installed and a fixture branch is run to each plumbing fixture. Mini manifolds reduce the number of joints that need to be completed on the job site by two for every tee that is part of the mini manifold. They are most commonly found in PEX trunk and branch systems, but they are available in copper and CPVC. The can be used in any of the systems we have described. The reduced pressure drop is particularly beneficial in PEX systems. However, using mini manifolds often results in increased length and therefore volume in the fixture branches.

Common Piping Materials

Before discussing the strategies to reduce the volume in the piping between the sources of hot water and the uses, it seems advisable to discuss the commonly used piping materials. There are more than a half dozen materials currently used for hot water distribution systems. The decision is often based on price. Galvanized steel was common up until about 1970. Copper was most common until about 2000. Cross-linked Polyethylene (PEX) has taken over from copper in residential new construction in many jurisdictions. Chlorinated Polyvinyl Chloride (CPVC) is common in others.

Advantages of PEX: fewer fittings, if one takes advantage of its flexibility; less susceptible to corrosion; tends to absorb shocks, such as water hammer better than more rigid piping, such as copper or CPVC; somewhat smoother water way, providing less resistance to flow; can take a higher flow rate than copper without causing internal erosion or corrosion; flameless joining technologies are safer during construction; much lower installation cost than copper systems; better resistance to corrosion than copper from aggressive water conditions.

Disadvantages of PEX: susceptibility to sunlight degradation so it must be installed concealed from direct sunlight; somewhat larger pressure drops than copper or CPVC due to somewhat smaller inner diameter of the tubing and through the insert fittings; requires more support than copper due to its flexibility; light hydrocarbons, directly applied to the tubing and held in a wetted condition before evaporating can pass through the side walls.

Advantages of Copper: well known how to install it; less pressure drop than PEX and CPVC due to slightly larger inner diameter of the tubing and through the full-flow external; less thermal expansion than plastic piping – need to make less allowance for its movement in long runs; does not allow chemicals to pass through the side-walls; known long life in areas with good quality water.

Disadvantages of Copper: not well suited to areas with acidic or aggressive water; soldering fittings has the potential to cause fire damage during construction; currently it is a relatively expensive material.

Advantages of CPVC: similar to PEX in cost of materials and installation; flameless joining technology; resistance to aggressive water and many chemicals; fewer supports than PEX; somewhat smoother water way than copper, providing less resistance to flow; can take a higher flow rate than copper without causing internal erosion or corrosion; less pressure drop through the external fittings than PEX

Disadvantages of CPVC: less well-known in California since it was only recently approved as a material in the CPC; can be softened or embrittled from certain common construction chemicals and solvents; slightly more pressure drop through the pipe and fittings than copper.

Table C-1 presents the ounces per foot contained within piping materials allowed for use in the California Plumbing Code). The nominal diameters range from 0.375 inch up to 2 inches. There are 13 materials in this table; all of them are suitable for use with hot water. CPVC and PEX have columns for piping in copper tube size (CTS). One of the key features of CTS is that the outside diameter is the same regardless of the pipe material, resulting in different internal volumes per foot.

Table C-1: Water Volume Per Foot of Pipe

OUNCES OF WATER PER FOOT LENGTH OF PIPING													
NOMINAL SIZE (inch)	COPPER M	COPPER L	COPPER K	CPVC CTS SDR 11	CPVC SCH 40	PEX-AL- PEX	PE-AL- PE	CPVC SCH 80	PEX CTS SDR 9	PE-RT SDR 9	PP SDR 6	PP SDR 7.3	PP SDR 11
⅜	1.06	0.97	0.84	NA	1.17	0.63	0.63	NA	0.64	0.64	0.91	1.09	1.24
½	1.69	1.55	1.45	1.25	1.89	1.31	1.31	1.46	1.18	1.18	1.41	1.68	2.12
¾	3.43	3.22	2.90	2.67	3.38	3.39	3.39	2.74	2.35	2.35	2.23	2.62	3.37
1	5.81	5.49	5.17	4.43	5.53	5.56	5.56	4.57	3.91	3.91	3.64	4.36	5.56
1¼	8.70	8.36	8.09	6.61	9.66	8.49	8.49	8.24	5.81	5.81	5.73	6.81	8.60
1½	12.18	11.83	11.45	9.22	13.20	13.88	13.88	11.38	8.09	8.09	9.03	10.61	13.47
2	21.08	20.58	20.04	15.79	21.88	21.48	21.48	19.11	13.86	13.86	14.28	16.98	21.39

For SI units: 1 ounce = 29.573 mL
* NA: Not Applicable

Source: 2016 California Plumbing Code, Table L 602.7, page 474.

Table C-2 presents the lengths of three most common piping materials that contain eight ounces or one cup. One cup is a small, well known quantity of water. If there only one cup of water in the piping between the source and the use, hot water would arrive very quickly. CTS stands for copper tube size. A particular feature of the CTS designation is that the outside diameters of these materials are the same.

Table C-2: Length of Pipe that Contains 8 Ounces of Water

Material	3/8" CTS feet/cup	½" CTS feet/cup	¾" CTS feet/cup	1" CTS feet/cup
"L" Copper	7.92	5.16	2.49	1.416
CPVC	N/A	6.41	3.00	1.81
PEX	12.09	6.62	3.34	2.02

Source: Gary Klein and Associates

Codes and Standards Relevant to Hot Water Distribution Systems in California

Appliance Standards for Faucets and Showers

The definitions of terms found in California Title 20, Article 4, Section 1602 for hot water-using plumbing fixtures and fittings are consistent with those within the ANSI national product standard ASME A112.18.1-2018/CSA B125.1-18.

However, CalGreen and Title 20 threshold maximums for water consumption differ from the Federal standard as shown in Table C-3.

Table C-3: Maximum Water Consumption for Faucets and Showerheads

Hot water-using plumbing fixtures and fixture fittings	Max H_2O Cons. Federal Standard	Max H_2O Cons. 2016 CalGreen, Part 11 (mandatory)[A]	Max H_2O Cons. Title 20, Article 4, Sections 1605.1 & 1605.3[B]
Lavatory faucet-private[C]	2.2 gpm	1.2 gpm	1.2 gpm
Lavatory faucet-public[D]	2.2 gpm	0.5 gpm	0.5 gpm
Metering faucet-residential	0.25 gpc	0.25 gpc	0.25 gpc
Metering faucet-nonresidential	0.25 gpc	0.20 gpc	0.25 gpc
Kitchen faucet[E]	2.2 gpm	1.8 gpm	1.8 gpm[F]
Showerheads	2.5 gpm	2.0 gpm	1.8 gpm

A: https://codes.iccsafe.org/public/public/chapter/content/2057/ and https://codes.iccsafe.org/public/public/chapter/content/2058/

B: https://govt.westlaw.com/calregs/Browse/Home/California/CaliforniaCodeofRegulations?guid=I8F8F3BC0D44E11DEA95CA4428EC25FA0&originationContext=documenttoc&transitionType=Default&contextData=(sc.Default)&bhcp=1

C: specifically applies to residential applications, but also includes lavatory faucets in non-residential uses (e.g., commercial applications) where public access is not provided. Defined in the 2016 California Plumbing Codes (CCR Title 24, Part 5) as follows: "Private or Private Use. Applies to plumbing fixtures in residences and apartments, to private bathrooms in hotels and hospitals, and to restrooms in commercial establishments where the fixtures are intended for the use of a family or an individual."

D: Defined in the 2016 California Plumbing Code (CCR Title 24, Part 5) as follows: "Public or Public Use. Applies to plumbing fixtures that are not defined as private or private use."

E: Title 20 provides no distinction between residential kitchen faucets and kitchen faucets used in restaurant food preparation or dish rooms.

F: CalGreen and Title 20 provide for an "optional temporary flow" of 2.2 gpm, but neither provides a definition of 'temporary' nor the mechanism by which the faucet would revert back to the default 1.8 gpm setting.

Source: Gary Klein and Associates

California Code of Regulations Title 24, Part 5 California Plumbing Code (CPC)

The California Plumbing Code (CPC) is based on the Uniform Plumbing Code (UPC) developed by the International Association of Plumbing and Mechanical Officials (IAPMO). In addition to many other provisions, it provides the requirements for, installing fixture fittings and appliances, hot and cold-water distribution piping, pipe insulation, material selection, and pipe sizing. The provisions are usually applicable to plumbing in all occupancies, although there are a few cases where the provisions are specific to an individual occupancy.

The following CPC sections are most relevant to this research project:

- Chapter 2 Definitions
- Chapter 4 Plumbing Fixtures and Fixture Fittings
- Chapter 6 Water Supply and Distribution
- Chapter 17 Referenced Standards
- Appendix A Recommended Rules for Sizing the Water Supply System
- Appendix C Alternate Plumbing Systems
- Appendix I Installation Standard for PEX Tubing Systems for Hot- and Cold- Water Distribution
- Appendix L Sustainable Practices
- Appendix M Peak Water Demand Calculator

CPC Chapter 4 governs the material and installation of plumbing fixtures, including faucets and fixture fittings, and the minimum number of plumbing fixtures based on occupancy.

CPC Chapter 6 governs the materials, design, and installation of water supply systems, including the methods and devices used for backflow prevention. This is the pipe sizing method used by the majority of practitioners.

- Section 609.11 requires the insulation of all domestic hot water piping. Section 610 describes how to size potable water piping.
- Table 610.3 identifies the water supply fixture units (WSFU) for individual plumbing fixtures and appliances and minimum fixture branch sizes. Except under special circumstances, the minimum branch size is 0.5 inch nominal.
- Table 610.4 contains a fixture unit table for determining water pipe and meter sizes.

CPC Appendix A provides a general procedure for sizing a water supply system. This is the pipe sizing method used by plumbing engineers, most often for larger, more complex plumbing installations. The sizing method is based on determining the residual pressure needed at the highest point in the building with the longest developed length of pipe. The equivalent lengths of fittings on the longest path are added to the developed length. The difference between the city pressure and the residual pressure provides the pressure available for pipe friction loss. This value is then used to determine the average permissible friction loss per 100 feet of pipe. Chart A 105.1 provide a method for estimating pipe size based on friction loss per 100 feet of pipe.

CPC Appendix C provides clarification of procedures for the design and approval of engineered plumbing systems, alternate materials, and equipment not specifically covered in other parts o the code. Table C303.2 presents water supply fixture units (WSFU) for bathroom groups.

CPC Appendix I contains the text of IAPMO Installation Standard IAPMO IS 31-2014. This standard specifies the requirements for the installation of SDR9 CTS cross-linked polyethylene (PEX) tubing and fittings, including cold-expansion, crimp, press, and mechanical compression fittings, intended for hot- and cold- water distribution systems within buildings. Table 2 presents tubing sizes, flows and friction losses for hot-water recirculation systems. Figures 3 and 4 provide a method for estimating pipe size based on pressure loss in PEX tubing for water temperatures of 60°F and 120°F water. The results from these figures are then used in the method described in CPC Appendix A.

CPC Appendix L provides a comprehensive set of technically sound provisions that encourage sustainable practices and works toward enhancing the design and construction of plumbing systems that result in a positive long-term environmental impact. Some pertinent sections:

- Section L 402.0 Water –Conserving Plumbing Fixtures and Fittings
- Section L 403.0 Appliances
- Section L 501.0 Water Heating Design, Equipment, and Installation
- Section L 502.0 Service Hot Water – Low-Rise Residential Buildings
- Section L 503.0 Service Hot Water – Other Than Low-Rise Residential Buildings
- Section L 506.0 Drain Water Heat Exchangers

CPC Appendix M provides a method for estimating the demand load for the building water supply and principal branches for single- and multi-family dwellings with water-conserving plumbing fixtures, fixture fittings and appliances. The appendix refers the reader to a water demand calculator provided by IAPMO to calculate the peak flow rate on trunks and branches based on current flow rates and probabilities of use during congested periods. CPC Appendix A takes the results of these calculations to determine the pipe size. In many cases, this results in a reduction of the pipe size. Based on current requirements found in Title 20 and CalGreen, the provisions of this appendix are applicable to all new dwellings in California.

California has not yet adopted CPC Appendix L and M for the entire state. However, local jurisdictions are able to adopt them for use in their territories.

California Code of Regulations Title 24, Part 6 California Energy Code (T-24)

California Energy Code (T-24) provides requirements on hot water distribution systems in both residential and commercial buildings.

Complying with the California Energy Code (T-24) for Domestic Water Heating Systems

The general compliance approach is to meet the mandatory measures and then follow either the performance approach or the prescriptive approach.

The prescriptive approach defines standard measures that if included in a building assure compliance with the California Energy Code.

The performance method compares the simulated energy use of the proposed design with simulated energy use of the standard design building. The standard design building is modeled as the proposed building including the mandatory requirements and to meet but not exceed the prescriptive requirements that would apply to the proposed building.

Four sets of documents, the California Energy Code, appendices to the Energy Code, Compliance manuals and the Alternative Calculation Method Reference Manual (ACM) comprise T-24. So far the Energy Code, the Appendices, and the Compliance Manuals have been adopted for the 2019 version. The ACM was adopted in January 2019. See Appendix D Hot Water Distribution System Provisions in the 2019 California Energy Code.

The ACM describes the calculations in the simulation model, California Building Energy Code Compliance-Residential Standards (CBECC-Res)[3] for the performance calculations. The major changes for hot water distribution systems from the 2016 version are revisions to the Compact Hot Water Distribution System credit.

The Mandatory Measures for water-heating systems are the water heater must be certified, any recirculation systems must be capable of automatically turning off, any heat trace must be capable of automatically turning off, and the hot water pipes must be insulated to certain levels. The insulation thickness must be at least as thick as the nominal pipe diameter, except in certain situations, where it must be 1 inch thick.

The prescriptive method requires certified water heaters that meet the minimum standards. The baseline water heater is a minimum efficiency gas-fired instantaneous (tankless) water heater. To meet the prescriptive method, other water heater types need to be packaged with additional energy saving measures elsewhere on the building.

The performance approach allows for the modeling of water heating system performance by taking into account building characteristics, climate, system type, efficiency, and fuel type. The standard design water-heating budget is defined by the corresponding prescriptive requirements. The performance method allows for modeling alternative water heater and distribution system combinations. Some of these options will offer compliance credits, and others will result in penalties. Chapter 5 of the 2019 Residential Compliance Manual goes through the details.

In the case of single dwelling units, any type or number of water heaters supported by the software can be installed. The calculated energy use of the proposed design is compared to the standard design energy budget based on either a single gas instantaneous water heater for gas water heaters with a standard distribution system, or a heat pump water heater (HPWH) with a compact distribution system and drain water heat recovery. Adding multiple water heaters to a single-family design will generally result in an energy penalty in the water-heating budget that must be offset elsewhere in the total energy budget.

[3] http://www.bwilcox.com/BEES/cbecc2019.html

Hot Water Consumption Modeling

The following discussion of the hot water consumption modeling in Title 24 is based on Appendix B, Water Heating Calculation Method in the 2016 Residential Alternative Calculation Method Reference Manual.[4]

The draw patterns are characterized in CBECC-Res by 365-day sets of fixture water draw events for dwelling units depending on the number of bedrooms. Each draw in the set is characterized by a start time, duration, flow rate, and end use. The flow rates given are the total flow at the point of use (fixture or appliance). See below for additional details on CBECC-Res.

The fixture flow events are converted to water heater (hot water) draws by 1) accounting for mixing at the point of use and 2) accounting for waste, distribution heat losses, and solar savings. These conversions are modeled as different draw volumes at the water heater compared to the draw volume at the point of use.

The waste due to distribution heat losses are accounted for by assuming the water supply temperature at the point of use prior to mixing is 115 °F.

The annual average value for Solar Savings Fraction (SSF) is provided from the results generated by the Energy Commission approved calculations approaches for the OG-100 and OG-300 test procedure. The SSF is applied to every draw individually.

The waste calculation is applied only to shower and sink draws. It includes a hot water waste factor and a *distribution loss multiplier*.

The hot water waste factor is 0.9 if any within dwelling unit pumped circulation system is used otherwise it is 1.0.

The *distribution loss multiplier* is set to 1.0 plus a *standard distribution loss multiplier*. The *standard distribution loss multiplier* is based on the dwelling unit floor area. The floor area is capped at 2500 ft^2 for that calculation.

A *distribution system multiplier* is applied only to the *standard distribution loss multiplier* for alternative distribution systems. A standard distribution system serving a single dwelling unit does not incorporate a pump for hot water recirculation and does not take credit for any additional DHW design features. Mandatory pipe insulation requirements must be met, including insulating all hot water pipes.

Table 5-9 in the 2019 Residential Compliance Manual (2019 RCM) lists all the recognized distribution systems that can be used in the performance approach with an assigned *distribution system multiplier*. (see Table C-4) The standard distribution system has a *distribution system multiplier* of 1.0. Distribution systems with a multiplier less than 1 represent an energy credit, while distribution systems with a multiplier greater than 1 are counted as an energy penalty. For example, Pipe Insulation with HERS Inspection Required

[4] Ferris, Todd, Larry Froess, PE, Jeff Miller, PE, Ken Nittler, Jennifer Roberts, Dee Anne Ross, Peter Strait, Danny Tam, Bruce Wilcox. 2015. 2016 Residential Alternative Calculation Method Reference Manual. California Energy Commission, Building Standards Office. CEC-400-2015-024-CMF-REV3 https://www.energy.ca.gov/2015publications/CEC-400-2015-024/CEC-400-2015-024-CMF-REV3.pdf.

has a multiplier of 0.8. That means that it is modeled as a 20 percent smaller *standard distribution loss multiplier* than the standard distribution system.

Table C-4: Applicability of Distribution Systems Options Within a Dwelling Unit (Table 5-9: 2019 RCM)

Distribution System Types	Assigned Distribution System Multiplier	Systems Serving a Single Dwelling Unit	Multifamily With Central Recirculation Systems
No HERS Inspection Required			
Trunk and Branch -Standard	1	Yes	Yes
Compact Design – Basic	0.7	Yes	--
Parallel Piping	1.1	Yes	--
Point of Use	0.3	Yes	--
Recirculation: Non-Demand Control Options	9.8	Yes	--
Recirculation with Manual Demand Control	1.75	Yes	Yes
Recirculation with Motion Sensor Demand Control	2.6	Yes	--
HERS Inspection Required			
Pipe Insulation	0.85	Yes	Yes
Parallel Piping with 5' maximum length	1	Yes	--
Compact Design - Expanded *	0.3 – 0.7	Yes	--
Recirculation with Manual Demand Control	1.6	Yes	--
Recirculation with Motion Sensor Demand Control	2.4	Yes	--

*** The multiplier for the Compact Design – Expanded credit varies depending on the home's floor plan and water heater location.**

Source: Gary Klein and Associates

CBECC-Res 2019

The hot water draw patterns found in CBECC-Res 2019, the California Energy Commission software for residential building energy code compliance form the basis of the analysis in this project. These representative hot water draw patterns result in more realistic conditions being applied to the water heating simulation models.[5]

[5] Kruis, Neal, PE Bruce Wilcox, Jim Lutz, and Chip Barnaby. "*Development of Realistic Water Draw Profiles for California Residential Water Heating Energy Estimation.*" In Proceedings of the 15th IBPSA Conference, 15:876–

These draw patterns were constructed from measured water draws from a collection of 730 single family California homes characterized in the *California Single-Family Water Use Efficiency Study*.[6] These measurements logged mains water flow volumes every 10 seconds over a period of two weeks. A pattern recognition algorithm was used to assign each draw to a specific water end use (e.g., toilet, irrigation, faucet, clothes washer, leak, etc). Of these end uses, five are considered to be hot water related: shower, faucet, bathtub, clothes washer and dishwasher. Draws from these end uses were used to create the hot water draw patterns in the compliance software.

The occupants of many of the measured homes were surveyed to collect information characterizing the number of bedrooms in the home and the number of occupants. Occupancy is binned into 6 levels: one person through five people, and six or more people (i.e., 1, 2, 3, 4, 5, and 6+).

A representative set 8 of daily (5 weekday, 2 weekends, and 1 holiday) hot water use profiles was generated for each occupancy level. Each day within the set comes directly from the field measurements. The set of 8 days is selected to best match the same hourly average number of draws and same daily end-use sub-total volumes as the overall data set for that level of occupancy.

The draw patterns represent the total (hot and cold) water flow at the fixture. The actual fraction of hot water is calculated by the software and depends on the inlet water temperature for the building site. Occupants are assumed to mix hot and cold water at showers, and baths to achieve a use temperature of 105 ^{o}F so the amount of hot water varies with the inlet cold-water temperature. Because of this, a shower or bath takes more hot water in the winter than in the summer and more hot water is used annually in a cool climate than a hot climate.

The California Building Energy Efficiency Standard compliance rules are based on the number of bedrooms in a housing unit, not the number of occupants. The actual number of occupants in a housing unit varies widely independent of the number of bedrooms. Rather than assigning a single occupancy level to each number of bedrooms, the annual simulation varies the number of occupants in the dwelling unit day-by-day. Annual hot water draw patterns consist of 365 selections from the set of 48 hot water use days chosen so that the distribution of the number of occupants over the year reflects the distribution in California of the number of occupants in dwelling units with the same number of bedrooms. The default prototype building for Title 24 is a 3-bedroom house. Figure C-1 shows the distribution of occupancy levels across the 365 hot water use days for the default prototype 3-bedroom house.

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84. San Francisco, CA: International Building Performance Simulation Association, 2017. http://www.ibpsa.org/proceedings/BS2017/BS2017_237.pdf.

[6] DeOreo, William B., Peter W. Mayer, Leslie Martien, Matthew Hayden, Andrew Funk, Michael Kramer-Duffield, Renee Davis, et al. "California Single Family Water Use Efficiency Study." Aquacraft, Inc. for California Department of Water Resources, June 1, 2011. http://www.irwd.com/images/pdf/save-water/CaSingleFamilyWaterUseEfficiencyStudyJune2011.pdf.

Figure C-1: Distribution of Occupants Over Year

Source: Gary Klein and Associates

Low-Flow and High-Efficiency Fixtures

Difference Between Low-Flow and High-Efficiency Fixtures

When the plumbing code was first adopted shortly after World War II, toilets flushed at 7.5 gallons per flush. The flow rate of faucets and showers were uncontrolled and you got whatever the available pressure could push through the orifice. There were many showers that gave more than 5 gpm.

Flush rates of toilets were reduced from the 1940s to the 1990s going down from 7.5 to 5.0 to 3.5 gallons per flush. In the early 1990s, the Federal Energy Policy Acts (EPAct) set maximum water consumption as follows: toilets to flush at 1.6 gallons per flush (gpf); urinals at 1.0 gpf; lavatory and kitchen faucets at 2.2 gallons per minute (gpm), and showerheads at 2.5 gpm.[7] For metering faucets, the volume was limited to 0.25 gallons per cycle (gpc), a metered event.

California has limited the flush volume of toilets to a maximum of 1.28 gallons per flush, private lavatory faucets to 1.2 gpm, kitchen faucets to 1.8 gpm (with a temporary bump up to 2.2 gpm[8]), and showerheads to 1.8 gpm. Public lavatory faucets remain at 0.5 gpf, consistent with the model plumbing codes and the ANSI product standard. The current Federally required maximum flow rates are designated as "low-flow", whereas the lower volumes adopted by

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[7] Subsequent to the passage of EPAct in 1992, the ANSI plumbing product standard was revised to incorporate a change to the maximum flow rate for "public" utilization faucets at 0.5 gpm. ANSI ASME A112.18.1/CSA B125.1 defines public lavatory fittings as "fixture fittings designed to be installed in nonresidential bathrooms that are exposed to walk-in traffic." The ANSI standard was incorporated by reference into the model plumbing codes for the U.S. and thus the 0.5 gpf maximum became the requirement in jurisdictions adopting those full codes.

[8] No definition of "temporary" is provided in the standard, relevant codes, or Title 20.

California and others are designated separately as "high-efficiency". This research project is not intended to recommend minimum flow rates for any given task. However, since the purpose of using hot water is to accomplish various tasks in the home and elsewhere, if the flow rate is too low to perform those tasks, then it is no longer useful. In addition, there are some unintended consequences of water use reductions that will be discussed in later sections.

Potential Issues for Using Low-Flow or High-Efficiency Hot Water Fixtures

As hot water flow rates in residential dwellings are lowered in order to achieve water use reductions, unintended consequences can result. These consequences fall largely into the category of threats to health and safety due, in part, to (1) longer water residence times, and (2) the inability of (some) plumbing system components to protect against scalding and thermal shock. A related consequence of these reductions is the hot water 'wait times' associated with lower flows, severely inconveniencing many resident users.

Longer Water Residence Times in Premise Plumbing can Lead to Pathogen Growth

Water conservation efforts over the past 25 years have led to large reductions in water and energy consumption in many US communities. These efforts have frequently achieved significantly decreased treated water consumption, in spite of increasing populations in the served communities. Achieving these lower rates of water consumption resulted, in part, from lower flow and flush rates in plumbing, which created longer water travel times throughout the water distribution and premise plumbing systems. Additionally, some studies have linked these lower flows to a number of problems affecting water quality and availability. A National Research Council (NRC) report[9] cited the impact of lower flows and lower temperatures (to address scalding and energy efficiency), on greater loss of residual disinfectants and increased formation of sediment and biofilms, creating more conducive environments for pathogens such as ***Legionella pneumophila*** and ***Mycobacteria*** species[10] as well as corrosion and deposition issues. At low velocities, sediment in suspension will more likely drop out of solution and form deposits in the piping. These deposits can create corrosion cells and provide greater media for bacteria growth.

Legionella bacteria, which exist in rivers and lakes, thrive in warm, stagnant water found in building plumbing systems, decorative fountains, hot water tanks, hot tubs, shower systems, and faucets. Legionnaires' disease kills about one in 10 people who are infected, but it is not contagious.

Virtually every water distribution system is prone to the formation of biofilms, regardless of the purity of the water, type of pipe material, or the presence of a disinfectant. Growth of bacteria on surfaces can occur in the public water distribution system and in household (premise)

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[9] National Research Council (NRC), 2005. *Public Water Supply Distribution Systems: Assessing and Reducing Risks: First Report*, http://nap.edu/11262

[10] https://www.epa.gov/research-grants/national-priorities-impacts-water-conservation-water-quality-premise-plumbing-and

plumbing. It is reasonably well documented that the suspended bacterial counts observed in distribution systems are the result of biofilm cell detachment rather than growth of organisms in the water. This phenomenon extends to autotrophic and heterotrophic organisms, coliforms, and opportunistic pathogens in premise plumbing (OPPPs). As a result of detachment, the biofilm can act as a continuous inoculum into finished water. The organisms can then be inhaled through bathing and showering or ingested.[11]

Premise plumbing is that portion of the water distribution system from the main ferrule or water meter to the consumer's tap in homes, schools, hospitals, and other buildings. Virtually every problem identified in potable water transmission systems can also occur in premise plumbing. However, due to premise plumbing's higher surface area to volume ratio, *longer stagnation times*, and warmer temperatures (especially in the hot water system), the potential *health threat can be magnified*. This is an important problem because it requires that individual homeowners be responsible for making decisions that will affect the safety of their drinking water. *(italics added)*

The problems of greatest concern within premise plumbing include microbial regrowth, leaching, permeation, infiltration, cross connections, leaks and the resulting indoor mold growth, scaling, and the high costs of failure. Regrowth problems are exacerbated in premise plumbing due to *very long stagnation times resulting in a loss of chlorine residual*, to the presence of numerous microclimates, and to nutrient release from some pipes.[12]. *(italics added)*

Leaching and permeation mechanisms within premise plumbing are the same as for public water supply transmission lines. However, the wide variety of materials used in building plumbing and associated treatment devices, the higher surface area to volume ratio, very long stagnation times, and lessened dilution increase the potential severity of the problem in premise plumbing.[13]

The premise plumbing issue also poses unique challenges because there is no obvious single party that could assume responsibility for the problem, which might be best addressed through changes in and enforcement of plumbing codes and third-party standards, as well as through improved public education.[14]

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[11] NRC 2005, Op.Cit.

[12] NRC 2005, Op.Cit.

[13] NRC 2005, Op.Cit.

[14] NRC 2005, Op.Cit.

Energy and water conservation, noble ideas on their own, can produce ideal conditions for bacterial growth. Less water flowing through pipes results in stagnant water, while turning down water heaters to save energy brings water temperatures within the comfort zone for the Legionella bacteria, which die when water is above 140 degrees Fahrenheit.[15] Common sources for these bacteria are cooling towers, whirlpool baths, hot tubs, aerated faucets, showers, pools, decorative fountains, misters, humidifiers, and any other source of water mist or aerosols of the building water systems.

Loss of protection against thermal shock and scalding

It is widely understood that exposure to hot water or a sudden unanticipated change in water temperature in the shower can present a hazard. **Thermal shock** is a sudden and unanticipated change in water temperature that can cause an abrupt physical reaction of a person, resulting in a serious injury from a slip, fall or scalding. The rapid temperature changes can be either toward colder or hotter water. These changes are caused by simultaneous usage of other fixtures on the same hot and cold-water distribution system such as a toilet, or an appliance such as a dishwasher or washing machine, that demands a large quantity of water, quickly. This creates a pressure imbalance between the hot and/or cold-water supply at the shower. The imbalance changes the ratio of hot and cold water, which leads to a change in outlet temperature. If the temperature change to hotter water is great enough, it can also result in **scalding.**[16]

Much of this problem has been dramatically reduced due to the introduction of pressure balanced shower valves in the 1980s. While these valves respond very quickly to pressure imbalances, they require a minimum operating pressure at the valve to operate properly. Most of the shower valves in the United States are designed to operate at a pressure of at least 20 psi. This means that from the water main, though the meter, through the backflow prevention devices, through the pipe and fittings, through the height to the shower and on the hot water side, through the water heater, the pressure remaining (residual) after all of these losses must be at least 20 psi. If the difference between the available pressure and the pressure losses is less than this residual pressure, the plumbing engineer generally increases the diameter of the piping since there is less pressure drop at the same velocity through larger diameter piping.

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[15] There have been numerous websites, radio spots, print materials and well-intentioned people that discuss turning the water heater down to 120° F to save energy and minimizing scalding. These suggestions are wrong for many reasons. The thermostat on the water heater cannot accurately control the outlet temperature of the water heater. Low storage temperatures create a shortage of hot water. Low storage temperatures can allow condensing conditions in heaters that are not designed for condensing, which can lead to heat exchanger corrosion and create storage temperatures that are ideal for Legionella bacteria growth. Source: Ron George, 2013. Plumbing Engineer magazine, *A hot water system balancing act…Scald vs. Legionella prevention, Part 2.*

[16] Plumbing Manufacturers International, 2012. *Showerheads and Handheld Showers with Lower Flow Rates.* https://www.safeplumbing.org/pmi/position-papers/showerhead-and-handheld-showers-with-lower-flow-rates

In October 2010, the American Society of Sanitary Engineering (ASSE) released a white paper (revised in March 2012) to address scald hazards associated with low-flow showerheads and taps.[17] That paper noted the following related to burn issues:

BURN STATISTICS:

1. The majority of children ages 4 and younger who are hospitalized for burn-related injuries suffer from scald burns (65 percent) or contact burns (20 percent). However, this includes stovetop, microwave, steam iron, and other incidents *not* involving tap water from a shower or faucet.
2. Tap water burns are burns associated with sinks and showers, so they occur most often in the bathroom and kitchen. Stovetop and microwave burns exceed tap water burns in burn statistics.
3. In the 10 years from 2008 through 2017, there was a total of 69,510 reported scald injuries in the U.S.[18] Of these, 54,217 (85%) occurred in the home and 19,667 (1,967 per year on average) were of children ages 0 to 5 years old. Information was not available on the scald injuries resulting specifically from tap water from the shower or faucet
4. Overall, scalding is the most common burn injury in children under four years old, accounting for 200,000 injuries per year. A small part of these injuries are due to tap water burns.[19]

INCREASED RISK OF SCALDING TO THE ELDERLY

The National Burn Information Exchange states the elderly are at an increased risk of scalding because their reactions are slower and their skin is thinner. The American Burn Association annual report indicates that after the age of 60, the risk of a burn injury is greater than at any time since childhood and the average size of the burn is larger than any other age group. In the 10-year period from 2008 through 2017, reported scalding burns to this elderly group amounted to 6,914 cases, or about 10% of the total scald cases in the U.S.[20]

More specifically, a 2009 study by the Centers for Disease Control (CDC), Department of Health and Human Services, detailed the non-fatal hospital admissions of elderly individuals (age 65 and older) resulting from emergency room (ER) visits. The study gathered and evaluated data from ER visits during the period from 2001 through 2006 and found the

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[17] ASSE International, 2012. *Scald Hazards Associated with Low-Flow Showerheads*, http://www.asse-plumbing.org/ScaldHazards.pdf

[18] American Burn Association, 2017. *National Burn Repository, 2017 Update, Report of Data From 2008-2017.* http://ameriburn.org/wp-content/uploads/2018/04/2017_aba_nbr_annual_report_summary.pdf. Note: Data is aggregated from 101 participating burn centers in the U.S. out of a total of 134 burn centers nationally. As such, many burn injuries are not reported into the national database cited here, due to non-participating hospitals. As a result, it would be logical to extrapolate burn statistics to the entire U.S. by multiplying the data by approximately 133%.

[19] http://burninjuryguide.com/burn-statistics/

[20] http://www.burnsurvivor.com/burn_statistics.html and http://ameriburn.org/wp-content/uploads/2018/04/2017_aba_nbr_annual_report.pdf

following: There was an average of 8,620 initial ER visits annually for non-fatal scald burns. Of these 8,620 cases, only 220 were related to bathroom fixtures, or 2.55% of the total reported scald burns visits.[21]

Problems of scalding are associated closely with very low-flow (also known as 'high-efficiency') showerheads and faucets, particularly those with older non-automatic compensating-type shower and tub/shower valves; these valves do not compensate for sudden changes in incoming pressures and/or temperatures as described above. For showers, these are generally the traditional two and three-handle type shower and tub/shower valves with the cold-water handle to the right and the hot water handle to the left (some models of single-handle shower valves are also not of the automatic compensating type). The previously mentioned 2012 ASSE white paper was also intended to educate the public on the difference in types of shower and tub/shower valves and explain why there is an increased danger associated with installing a very low-flow showerhead on a non-automatic compensating type shower or tub/shower valve.

The white paper goes on to describe the most effective ways to minimize the risk of scalding and thermal shock by identifying the acceptable methods of controlling water temperatures when installing low-flow showerheads and hand held showers.

Both loss of protection against thermal shock and scalding and increased residence time in premise plumbing systems represent serious issues to be considered in developing new hot water distribution strategies within the boundaries of protecting human health and safety. While there is great concern about scalding in the plumbing industry, the research shows that the majority of scald cases are not due the premise plumbing system. Nonetheless, it is still important to pay attention to this risk as flow rates are further reduced at the terminal fittings (e.g., showerheads and faucets). The same is true for thermal shock concerns that may arise with older non-compensating valves on showers that may be affected by lower flow rates, smaller pipe sizes and potentially reduced pressures when the valves are operating.

Likewise, as flow rates and water usage drops, unless the plumbing within the building has been right-sized to account for the use of high-efficiency fixture fittings and appliances, the residence time of water in the building supply system will increase further, and the likelihood of the disinfection chemicals dissipating will be increased. This demands special attention to potential pathogen growth as new hot water distribution strategies are considered.

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[21] Centers for Disease Control, 2009. *Nonfatal Scald-Related Burns Among Adults Aged ≥65 Years --- United States, 2001-2006*, https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5836a1.htm

APPENDIX D: Hot Water Distribution System Provisions in the 2019 California Energy Code

The following relevant items have been extracted from the 2019 Revised Energy Code,[22] the 2019 Draft Residential Compliance Manuals,[23] and the 2019 Reference Appendices.[24] Table numbers reflect those in the original material.

Mandatory Provisions (Non-Residential & Residential)

Section 110.3 – Mandatory Requirements for Service Water-Heating Systems and Equipment

The water heater shall be certified and meet all efficiency requirements.

Controls for hot water distribution systems with circulating pumps or with electrical heat trace systems shall be capable of automatically turning off the system.

Section 120.3 – Requirements for Pipe Insulation (Non-Residential)

(a) General Requirements.

The piping conditions listed below for space-conditioning and service water-heating systems with fluid normal operating temperatures listed in TABLE 120.3-A, shall have at least the amount of insulation specified in Subsection (c):

3. Service water-heating systems.

   A. Recirculating system piping, including the supply and return piping to the water heater.

   B. The first 8 feet of hot and cold outlet piping, including piping between a storage tank and a heat trap, for a nonrecirculating storage system.

   C. Pipes that are externally heated.

[22] https://www.energy.ca.gov/title24/2019standards/rulemaking/documents/2018-05-09_hearing/2019_Revised_EnergyCode.php

[23] https://www.energy.ca.gov/title24/2019standards/post_adoption/2019_Draft_Compliance_Manuals/Residential_Manual_PDF/

[24] https://www.energy.ca.gov/title24/2019standards/rulemaking/documents/2018-05-09_hearing/2019_Reference_Appendices.php

(c) Insulation Thickness

1. For insulation with a conductivity in the range shown in TABLE 120.3-A for the applicable fluid temperature range, the insulation shall have the applicable minimum thickness or R-value shown in TABLE 120.3-A.

Table 120.3-A Pipe Insulation Thickness (for applicable pipe sizes only)

Fluid Operating Temperature Range (°F)	**Insulation Conductivity**			**Nominal Pipe Diameter (in inches)**		
	Conductivity (in Btu·in/h·ft2·°F)	Mean Rating Temperature (°F)		< 1	1 to <1.5	1.5 to < 4
Service Hot Water				Minimum Pipe Insulation Required (Thickness in inches or R-value)		
105-140	0.22-0.28	100	Inches	1	1.5	1.5
			R-value	R 7.7	R 12.5	R 11

Source: 2019 California Energy Code

Section 150.0 – Mandatory Features and Devices I Residential

(j) Insulation for Piping and Tanks

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 domestic hot water piping shall be insulated as specified in Section 609.11 of the California Plumbing Code.

California Plumbing Code Section 609.11 Pipe Insulation

609.11.1 Insulation Requirements. Domestic hot water piping shall be insulated.

609.11.2 Pipe Insulation Wall Thickness. Hot water pipe insulation shall have a minimum wall thickess of not less than the diameter of the pipe for pipe up to 2 inches in diameter.

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 hot and cold water pipes from the storage tank.

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

Prescriptive or Performance Measures

Section 140.0 – Performance and Prescriptive Compliance Approaches (Non-Residential)

Nonresidential, high-rise residential and hotel/motel buildings shall comply with all of the following:

(a) The requirements of Sections 100.0 through 110.102 applicable to the building project (mandatory measures for all buildings).

(b) The requirements of Sections 120.0 through 130.5 (mandatory measures for nonresidential, high-rise residential and hotel/motel buildings).

(c) Either the performance compliance approach (energy budgets) specified in Section 140.1 or the prescriptive compliance approach specified in Section 140.2 for the Climate Zone in which the building will be located. Climate zones are shown in FIGURE 100.1-A.

Section 140.1 – Performance Approach: Energy Budgets

A building complies with the performance approach if the energy budget calculated for the Proposed Design Building under Subsection (b) is no greater than the energy budget calculated for the Standard Design Building under Subsection (a).

(a) Energy Budget for the Standard Design Building.

The energy budget for the Standard Design Building is determined by applying the mandatory and prescriptive requirements to the Proposed Design Building. The energy budget is the sum of the TDV energy for space-conditioning, indoor lighting, mechanical ventilation, service water heating, and covered process loads.

(b) Energy Budget for the Proposed Design Building.

The energy budget for a Proposed Design Building is determined by calculating the TDV energy for the Proposed Design Building. The energy budget is the sum of the TDV energy for space-conditioning, indoor lighting, mechanical ventilation and service water heating and covered process loads.

(c) Calculation of Energy Budget.

The TDV energy for both the Standard Design Building and the Proposed Design Building shall be computed by Compliance Software certified for this use by the

Commission. The processes for Compliance Software approval by the Commission are documented in the ACM Approval Manual.

Section 140.5 – Prescriptive Requirements for Service Water Heating Systems

(b) High-Rise Residential and Hotel/Motel Occupancies.

A service water heating system installed in a high-rise residential or hotel/motel building complies with this section if it meets the requirements of Section 150.1(c)8.

Section 150.1 – Performance and Prescriptive Compliance Approaches for Low-Rise Residential Buildings (Residential)

(a) Basic Requirements.

Low-rise residential buildings shall meet all of the following:

1. The applicable requirements of Sections 110.0 through 110.10.

2. The applicable requirements of Section 150.0 (mandatory features).

3. Either the performance standards or the prescriptive standards set forth in this section for the Climate Zone in which the building is located. Climate zones are shown in Reference Joint Appendix JA2 – Weather/Climate Data.

(b) Performance Standards.

A building complies with the performance standards if the energy consumption calculated for the Proposed Design Building is no greater than the energy budget calculated for the Standard Design Building using Commission-certified compliance software as specified by the Alternative Calculation Methods Approval Manual.

1. Newly Constructed Buildings.

The Energy Budget for newly constructed buildings is expressed in terms of the Energy Design Rating, which is based on TDV energy. The Energy Design Rating (EDR) has two components, the Energy Efficiency Design Rating, and the Solar Electric Generation and Demand Flexibility Design Rating. The Solar Electric Generation and Demand Flexibility Design Rating shall be subtracted from the Energy Efficiency Design Rating to determine the Total Energy Design Rating. The Proposed Building shall separately comply with the Energy Efficiency Design Rating and the Total Energy Design Rating.

(c) Prescriptive Standards/Component Package.

Buildings that comply with the prescriptive standards shall be designed, constructed, and equipped to meet all of the requirements for the appropriate Climate Zone shown in TABLE 150.1-A or B.

from Table 150.1-A and Table 150.1-B

Water Heating, All Buildings, System Shall meet Section 150.1(c)8

Section 150.1(c)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 pumps 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.

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; or

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: 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.

Residential Appendix RA3 – Residential Field Verification and Diagnostic Test Protocols

RA3.6 Field Verification of Water Heating Systems

RA3.6.1 Purpose and Scope

Water Heating HERS field verification offers credits for improved performance in terms of "quality" pipe insulation installation, for the installation of field-verified hot water distribution systems that are more compact and therefore perform better than typical hot water distribution systems and for the installation of specific circulation strategies. The listed HERS measures can be completed on a sampling basis.

RA3.6.2 HERS-Verified Pipe Insulation Requirements for all Hot Water Distribution Systems

Unless otherwise stated, insulation must meet the requirements specified in §150.0(j). Pipe insulation shall fit tightly to the pipe and all elbows and tees shall be fully insulated. No piping should be visible due to insulation voids with the exception of the last segment of piping that penetrates walls and delivers hot water to the sink, appliance, etc. All 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:

(a) The first five feet of cold water piping from storage gas water heaters.

(b) All hot water piping with a nominal diameter between 3/4 inch (19 millimeter) and 1 inch.

(c) All hot water piping less than 3/4 inch in diameter that is associated with a domestic hot water recirculation system or leading to the kitchen fixtures.

(d) All underground hot water piping.

1. In addition, all piping below grade must be installed in a waterproof and non-crushable casing or sleeve that allows for installation, removal and replacement of the enclosed pipe and insulation. The internal cross-section or diameter of the casing or sleeve shall be large enough to allow for insulation of the hot water piping.

(e) Piping from the heating source to storage tank or between tanks.

Pipe insulation may be omitted where hot water distribution piping is buried within attic, crawlspace or wall insulation, as described below: In attics and crawlspaces the insulation shall completely surround the pipe with at least 1 inch of insulation and the pipe shall be completely covered with at least 4 inches of insulation further away from the conditioned space. In walls, the insulation must completely surround the pipe with at least 1 inch of insulation. If burial within the insulation does not meet these specifications, then this exception does not apply, and the section of pipe not meeting the specifications must be insulated as specified in §150.0(j).

RA3.6.3 HERS-Verified Pipe Insulation Credit (PIC-H)

The visual inspection shall verify that all hot water piping is insulated. This credit can only be taken for trunk and branch hot water distribution systems. Specific installation requirements include:

The HERS rater shall verify that all hot water piping is insulated in accordance with the provisions in RA3.6.2 HERS-Verified Pipe Insulation Requirements for all Hot Water Distribution Systems.

RA3.6.4 HERS-Verified Central Parallel Piping (PP-H)

This measure expands on the requirements for parallel piping systems that use one or more central manifolds with individual runs from the manifold to each point of use. Visual inspection shall verify that all supply lines of the parallel piping system meet the specific installation requirements listed below:

(a) The measured length of pipe from the water heater to each central manifold shall not exceed 5 feet (measured to the nearest half foot).

(b) The hot water distribution system piping from the manifold to the fixtures and appliances must take the most direct path. For example, in a house with more than 1-story and the water heater in the garage, this requirement would exclude running hot water supply piping from the manifold to the attic, and then running the line back down to a first floor point of use.

1. The hot water distribution piping must be separated by at least two inches from any other hot water supply piping, and at least six inches from any cold water supply piping.

(c) The HERS inspector shall also verify that other hot water piping is insulated and installed to meet the requirements of RA3.6.2.

RA3.6.5 HERS-Verified Compact Hot Water Distribution System Expanded Credit (CHWDS-H-EX)

To meet the Compact Hot Water Distribution System Expanded Credit eligibility requirements, the requirements in RA4.4.6 must be met. In addition, the following HERS field verifications are required:

(a) No hot water piping larger than 1 inch diameter is allowed,

(b) Length of 1 inch diameter piping is limited to 8 ft or less,

(c) Two and three story buildings cannot have hot water distribution piping in the attic, unless the water heater is also located in the attic, and

(d) Eligible recirculating systems must be HERS-Verified Demand Recirculation: Manual Control conforming to RA4.4.17.

RA3.6.6 HERS Verified Demand Recirculation; Manual Control (R-DRmc-H)

Demand controlled recirculation systems shall operate "on-demand", meaning that pump operation shall be initiated shortly prior to the hot water draw. The recirculation pump can be located external to the water heater or be integral to the water heater. The controls shall operate on the principal of shutting off the pump with a sensed rise in pipe temperature (Delta-T). For this HERS verification process, a manual switch is required.

Verification shall include:

(a) More than one circulation loop may be installed. Each loop shall have its own pump and controls.

(b) Verify that the pump, demand controls and thermo-sensor are present. Manual switches shall be located in the kitchen, all bathrooms, and any hot water fixture location that is at least 20 feet (measured along the hot water piping) from the water heater.

(c) Manual controlled systems may be activated by wired or wireless button mechanisms. Verify that manual controls have standby power of 1 watt or less.

(d) Verify that pump and control placement for the demand recirculation meets one of the following criteria:

1. When a dedicated return line has been installed the pump, controls and thermo-sensor are installed at the end of the supply portion of the recirculation loop (typically under a sink); or

2. The pump and controls are installed on the return line near the water heater and the thermosensor is installed in an accessible location as close to the end of the supply portion of the recirculation loop as possible (typically under a sink), or

3. When the cold water line is used as the return, the pump, demand controls and thermosensor shall be installed in an accessible location at the end of supply portion of the hot water distribution line (typically under a sink).

(e) Verify that a check valve is installed in the recirculation loop to prevent unintentional circulation of the water (thermo-siphoning) and back flow when the system is not operating. This check valve may be included with the pump.

(f)The HERS inspector shall also verify that the supply portion of each circulation loop, the first five feet of branches off the loop and the dedicated return line are insulated based on the conductivity range in TABLE 120.3-A, the insulation level shall be selected from the fluid temperature range based on the thickness requirements in TABLE 120.3-A and the insulation shall be installed in accordance with RA3.6.2. Other hot water piping shall meet the requirements of §150.0(j) and be installed in accordance with RA3.6.2. Insulation is not required on the cold water line when it is used as the return.

(g) The hot water distribution system piping from the water heater(s) to the fixtures and appliances must take the most direct path. For example, in a house with more than 1-story and the water heater in the garage, this requirement would exclude running hot water supply piping from the water heater to the attic, and then running the line back down to a first floor point of use.

(h) Verify that manual controls initiate pump operation by pressing one of the manual controls and observing that the pump turns on and then shuts off in accordance with one of the two methods listed:

1. After the pump has been activated, the controls shall allow the pump to operate until the water temperature at the thermo-sensor rises not more than 10°F (5.6 °C) above the initial temperature of the water in the pipe, or

2. The controls shall not allow the pump to operate when the temperature in the pipe exceeds 102°F (38.9 °C).

(i) Verify that the controls have a feature that limits pump operation to a maximum of 5 minutes following any activation. This is provided in the event that the normal means of shutting off the pump have failed.

(j) The manufacturer(s) of the recirculation pump and the controls shall provide installation and operation instructions that provide details of the operation of the pump and controls and such instructions shall be available at the jobsite for inspection.

RA3.6.7 HERS-Verified Demand Recirculation: Sensor Control (RDRsc-H)

Demand controlled recirculation systems shall operate "on-demand", meaning that pump operation shall be initiated shortly prior to the hot water draw. The recirculation pump can be located external to the water heater or be integral to the water heater. The controls shall operate on the principal of shutting off the pump with a sensed rise in pipe temperature (Delta-T). For this HERS verification process a sensor control is used to activate the pump rather than a manual control.

Verification shall include:

(a) More than one circulation loop may be installed. Each loop shall have its own pump and controls.

(b) Verify that the pump, demand controls and thermo-sensor are present. Sensor controls shall be located in the kitchen, bathrooms, and any hot water fixture location that is at least 20 feet

(measured along the hot water piping) from the water heater.

(c) Sensor controlled systems may be activated by wired or wireless mechanisms, including motion sensors, door switches and flow switches.

(d) Verify that sensors controls have standby power of 1 watt or less.

(e) Verify that pump and control placement for the demand recirculation meets one of the following criteria:

> 1. When a dedicated return line has been installed the pump, controls and thermo-sensor are installed at the end of the supply portion of the recirculation loop (typically under a sink); or
>
> 2. The pump and controls is installed on the return line near the water heater and the thermo-sensor is installed in an accessible location as close to the end of the supply portion of the recirculation loop as possible (typically under a sink), or
>
> 3. When the cold water line is used as the return, the pump, demand controls and thermosensor shall be installed in an accessible location at the end of supply portion of the hot water distribution line (typically under a sink).

(f) Verify that a check valve is installed in the recirculation loop to prevent unintentional circulation of the water (thermo-siphoning) and back flow when the system is not operating. This check valve may be included with the pump.

(g) The hot water distribution system piping from the water heater(s) to the fixtures and appliances must take the most direct path. For example, in a house with more than 1-story and the water heater in the garage, this requirement would exclude running hot water supply piping from the water heater to the attic, and then running the line back down to a first floor point of use.

(h) The HERS inspector shall also verify that the supply portion of each circulation loop, the first five feet of branches off the loop and the dedicated return line are insulated based on the conductivity range in TABLE 120.3-A , the insulation level shall be selected from the fluid temperature range based on the thickness requirements in TABLE 120.3-A and the insulation shall be installed in accordance with RA3.6.2. Other hot water piping shall meet the requirements of §150.0(j) and be installed in accordance with RA3.6.2. Insulation is not required on the cold water line when it is used as the return.

(i) Verify that sensor controls initiate pump operation by activating one of the sensor controls and observing that the pump turns on and then shuts off in accordance with one of the two methods listed.

> 1. After the pump has been activated, the controls shall allow the pump to operate until the water temperature at the thermosensor rises not more than 10^{o}F (5.6 ^{o}C) above the initial temperature of the water in the pipe, or
>
> 2. The controls shall not allow the pump to operate when the temperature in the pipe exceeds 102^{o}F (38.9 ^{o}C).

(j) Verify that the controls have a feature that limits pump operation to a maximum of 5 minutes following any activation. This is provided in the event that the normal means of shutting off the pump have failed.

(k) The manufacturer(s) of the recirculation pump and the controls shall provide installation and operation instructions that provide details of the operation of the pump and controls and such instructions shall be available at the jobsite for inspection.

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.

RA3.6.9 HERS-Verified Drain Water Heat Recovery System (DWHR-H)

A HERS inspection is required to obtain this credit. All DWHR unit(s) shall be certified to the Energy Commission according to the following requirements:

(a) Vertical DWHR unit(s) shall be compliant with CSA B55.2, and tested and labeled in accordance with CSA B55.1 or IAPMO IGC 346-2017. Sloped DWHR unit(s) shall be compliant with IAPMO PS 92, and tested and labeled with IAPMO IGC 346-2017.

(b) The DWHR unit(s) shall have a minimum rated effectiveness of 42 percent.

The HERS inspector shall verify that:

(a) The make, model, and CSA B55.1 or IAPMO IGC 346-2017 rated effectiveness of the DWHR unit(s) shall match the compliance documents. The DHWR unit(s) shall also be verified as a model certified to the Energy Commission as qualified for credit as a DWHR unit(s).

(b) The installation configuration (e.g. equal flow, unequal flow to the water heater, or unequal flow to the showers) and the percent of served shower fixtures shall match the compliance documents.

(c) For water heating system serving a single dwelling, the DWHR system shall, at the minimum, recover heat from the master bathroom shower and must at least transfer that heat either back to all the respective showers or the water heater.

(d) For central water heating system serving multiple dwellings, the DWHR system shall, at the

minimum, recover heat from half the showers located above the first floor and must at least transfer that heat either back to all the respective showers or the water heater.

(e) The DWHR unit(s) shall be installed within 1 degrees of the rated slope. Sloped DWHR shall have a minimum lengthwise slope of 1 degree. The lateral level tolerance shall be within plus or minus 1 degree.

(f) The installation shall comply with any applicable California Plumbing Code requirements.

RA4.4 Water Heating Measures

RA4.4.1 Proper Installation of Pipe Insulation

Unless otherwise stated, insulation must meet the requirements specified in §150.0(j). Pipe insulation shall fit tightly to the pipe and all elbows and tees shall be fully insulated. No piping should be visible due to insulation voids with the exception of the last segment of piping that penetrates walls and delivers hot water to the sink, appliance, etc. All 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:

(a) The first five feet of hot and cold water piping from storage gas water heaters.

(b) All hot water piping of 3/4" diameter or greater.

(c) All piping from the water heater to kitchen sinks and dishwasher.

(d) All underground hot water piping,

1. In addition, all piping below grade must be installed in a waterproof and non-crushable casing or sleeve that allows for installation, removal and replacement of the enclosed pipe and insulation. The internal cross-section or diameter of the casing or sleeve shall be large enough to allow for insulation of the hot water piping.

(e) Piping from the heating source to storage tank or between tanks.

Pipe insulation may be omitted where hot water distribution piping is buried within attic, crawlspace or wall insulation, as described below: In attics and crawlspaces the insulation shall completely surround the pipe with at least 1 inch of insulation and the pipe shall be completely covered with at least 4 inches of insulation further away from the conditioned space. In walls, the insulation must completely surround the pipe with at least 1 inch of insulation. If burial within the insulation does not meet these specifications, then this exception does not apply, and the section of pipe not meeting the specifications must be insulated as specified in §150.0(j).

RA4.4.2 The Standard Distribution System (STD)

The Standard Distribution System design requires that hot water distribution piping meets the requirements of Proper Installation of Pipe Insulation R4.4.1.

RA4.4.3 Reserved for future use

RA4.4.4 Central Parallel Piping (PP)

This hot water distribution system is comprised of one or more manifolds located relatively close to the water heater and pipes running from the manifold to individual fixtures and appliances. The manifolds may have valves for each pipe running from the manifold to individual fixtures and appliances. These valves must be readily accessible in accordance with the plumbing code. The measured length of pipe from the water heater each central manifold shall not exceed 15 feet (measured to the nearest half foot).

The hot water distribution system piping from the manifold to the fixtures and appliances must take the most direct path. For example, in a house with more than 1-story and the water heater in the garage, this requirement would exclude running hot water supply piping from the manifold to the attic, and then running the line back down to a first floor point of use.

The hot water distribution piping must be separated by at least two inches from any other hot water supply piping, and at least six inches from any cold water supply piping or the hot water supply piping must be insulated based on the conductivity range in TABLE 120.3-A and the insulation level shall be selected from the fluid temperature range based on the thickness requirements in TABLE 120.3-A.

Other hot water piping shall be insulated to a level that meets the requirements of §150.0(j) and be installed in accordance with Proper Installation of Pipe Insulation R4.4.1.

RA4.4.5 Point of Use (POU)

This measure requires that all hot water fixtures in the dwelling unit, with the exception of a stand-alone tub must use no more pipe per run than defined in Table 4.4.5. To meet this requirement most houses will require multiple water heaters.

Table 4.4.5

Size Nominal (Inch)	Length of Pipe (feet)
3/8″	15
1/2″	10
3/4″	5

Source: 2019 California Energy Code

(a) Measurements shall be made to the nearest half foot.

(b) If a combination of piping is used in a single run then one half the allowed length of each size is the maximum installed length.

(c) The hot water distribution system piping from the water heater(s) to the fixtures and appliances must take the most direct path. For example, in a house with more than 1-story and the water heater in the garage, this requirement would exclude running hot water supply piping from the manifold to the attic, and then running the line back down to a first floor point of use.

(d) Hot water piping shall be insulated to a level that meets the requirements of §150.0(j) and be installed in accordance with Proper Installation of Pipe Insulation R4.4.1.

RA4.4.6 Compact Hot Water Distribution System (CHWDS)

To receive the Compact Hot Water Distribution System credit (available for single family homes and multifamily dwellings served by individual water heaters), plan calculations must be completed that demonstrate that the water heater to fixture proximity is more compact than a threshold criteria that is defined based on the dwelling unit conditioned floor area and number of stories. Compactness is characterized by calculating the "Weighted Distance" from the water heater to key fixtures and the threshold criteria is identified by the "Qualification Distance". (The Qualification Distance is calculated directly by the ACM.) Determination of the Weighted Distance for a particular floor plan is dependent on whether it is a non-recirculating or a recirculating distribution system, with the recirculation option only available for single family homes.

Calculation of the Weighted Distance varies depending on the type of system being installed. The calculation is based on a equation with modifications based on the distribution system type. In each case the basis of the calculation is the plan-view, straight line distance from the water heater to the center of the further use point fixture in three locations of the dwelling unit, two of which are the master bathroom and the kitchen. It is calculated using the following equation:

Weighted_Distance = x * d_MasterBath + y * d_Kitchen + z * d_FurthestThird

Where:

x, y, and z = Weighted Distance coefficients (unitless), see Table 4.4.6-1.

d_MasterBath = The plan view, straight line distance from the water heater to the furthest fixture served by that water heater in the master bathroom (feet).

d_Kitchen = The plan view, straight line distance from the water heater to the furthest fixture served by that water heater in the kitchen (feet).

d_FurthestThird = The plan view, straight line distance from the water heater to the furthest fixture[25] served by that water heater in the furthest room in the dwelling unit (feet).

Table 4.4.6-1: Weighted Distance Coefficients

Distribution System	x	y	z
Non-Recirculating	0.4	0.4	0.2
Recirculating	0	0	1

Source: 2019 California Energy Code

Note that the calculations are only based on horizontal plan view distance measurements from the center of the water heater to the center of the use point in the designated location[26]. Vertical pipe run lengths (for example, the vertical distance from the first to second floor) is

[25] Because the Master Bath and Kitchen have unique separate terms, the d_FurthestThird fixture must located in neither of these rooms. The laundry room is excluded, and shall not be used as the furthest third fixture. In multifamily cases where there is not another qualifying use point, the d_FurthestThird term equals zero.

[26] For example, a shower/tub combination would take the measurement from the fixture supply outlet of the shower/tub, while a two sink lavatory in the master bath would take the measurement from the fixture supply outlet of the lavatory furthest from the water heater.

neglected in the calculations. Use points that are located on floors different than the water heater would have their location translated to the floor where the water heater is located.

In single family homes with multiple water heaters, the Weighted Distance “z term” calculation is performed for each water heater to arrive at a FurthestThird term averaged over each of the “n” water heaters installed. For a non-recirculating distribution system, the resulting Weighted Distance calculation would include the Master Bath, the Kitchen and an average of the FurthestThird term for each of the installed water heaters. (For recirculating systems, similarly the FurthestThird term would represent an average across the “n” water heaters.)

The Qualification Distance is a function of conditioned floor area (CFA), number of stories, and number of installed water heaters. The Qualification Distance for systems with multiple water heaters is identified by using the equation for the appropriate distribution system (recirculation or non-recirculation), and dividing by the number of water heaters installed as shown in the Equation below:

$$\text{Qualification Distance} = (a + b * CFA) / n$$

Where:

a, b = Qualification distance coefficients (unitless), see Table 4.4.6-2,

CFA = Conditioned floor area of the dwelling unit (ft^2), and

n = Number of water heaters in the dwelling unit (unitless).

Table 4.4.6-2: Coefficients for the Qualification Distance Calculation

Building Type	Coefficient a		Coefficient b	
	Non-Recirculating	Recirculating	Non-Recirculating	Recirculating
Single Family				
One story	10	22.7	0.0095	0.0099
Two story	15	11.5	0.0045	0.0095
Three story	10	0.5	0.0030	0.0140
Multifamily				
One story	7.5	n/a	0.008	n/a
Two or more story	7.5	n/a	0.005	n/a

Source: 2019 California Energy Code

RA4.4.7 Recirculation Systems

The supply portion of each circulation loop, the first five feet of branches off the loop and the dedicated return line are insulated based on the conductivity range in TABLE 120.3-A and the insulation level shall be selected from the fluid temperature range based on the thickness requirements in TABLE 120.3-A and the insulation shall be installed in accordance with Proper

Installation of Pipe Insulation. Other hot water piping shall meet the requirements of §150.0(j) and be installed in accordance with Proper Installation of Pipe Insulation R4.4.1.

A check valve shall be installed in the recirculation loop to prevent unintentional circulation of the water (thermo-siphoning) and back flow when the system is not operating. This check valve may be included with the pump.

The hot water distribution system piping from the water heater(s) to the fixtures and appliances must take the most direct path. For example, in a house with more than 1-story and the water heater in the garage, this requirement would exclude running hot water supply piping from the water heater to the attic, and then running the line back down to a first floor point of use.

The recirculation pump can be located external to the water heater or be integral to the water heater.

The manufacturer(s) of the recirculation pump and the controls shall provide installation and operation instructions that provide details of the operation of the pump and controls and such instructions shall be available at the jobsite for inspection.

RA4.4.8 Recirculation with non-demand controls (R-ND)

All recirculation controls with the exception of demand recirculation control systems fall under this category.

(a) More than one circulation loop may be installed. Each loop shall have its own pump and controls.

(b) The active control shall be either: timer, temperature, or time and temperature. Timers shall be set to less than 24 hours. The temperature sensor shall be connected to the piping and to the controls for the pump.

RA4.4.9 Demand Recirculation; Manual Control (R-DRmc)

Demand controlled recirculation systems shall operate "on-demand", meaning that pump operation shall be initiated shortly prior to the hot water draw. The controls shall operate on the principal of shutting off the pump with a sensed rise in pipe temperature (Delta-T). For this measure a manual switch is used to activate the pump.

(a) More than one circulation loop may be installed. Each loop shall have its own pump and controls.

(b) Manual controls shall be located in the kitchen, bathrooms, and any hot water fixture location that is at least 20 feet (measured along the hot water piping) from the water heater.

(c) Manual controlled systems may be activated by wired or wireless mechanisms, Manual controls shall have standby power of 1 watt or less.

(d) Pump and demand control placement meets one of the following criteria.

1. When a dedicated return line has been installed the pump, demand controls and thermo-sensor are installed at the end of the supply portion of the recirculation loop (typically under a sink); or

2. The pump and demand controls are installed on the return line near the water heater and the thermo-sensor is installed in an accessible location as close to the end of the supply portion of the recirculation loop as possible (typically under a sink), or

3. When the cold water line is used as the return, the pump, demand controls and thermo-sensor is installed in an accessible location at the end of supply portion of the hot water distribution line (typically under a sink).

(e) Insulation is not required on the cold water line when it is used as the return.

(f) Demand controls shall be able to shut off the pump in accordance with one of the following two methods:

1. After the pump has been activated, the controls shall allow the pump to operate until the water temperature at the thermo-sensor rises not more than 10^{o}F (5.6 ^{o}C) above the initial temperature of the water in the pipe, or

2. The controls shall not allow the pump to operate when the temperature in the pipe exceeds 102^{o}F (38.9 ^{o}C).

(g) The controls shall limit pump operation to a maximum of 5 minutes following any activation. This is provided in the event that the normal means of shutting off the pump have failed.

RA4.4.10 Demand Recirculation; Sensor Control (RDRsc)

Demand controlled recirculation systems shall operate "on-demand", meaning that pump operation shall be initiated shortly prior to the hot water draw. The controls shall operate on the principal of shutting off the pump with a sensed rise in pipe temperature (Delta-T). For this measure a sensor control is used to activate the pump rather than a manual control.

(a) More than one circulation loop may be installed. Each loop shall have its own pump and controls.

(b) Sensor controls shall be located in the kitchen, bathrooms, and any hot water fixture location that is at least 20 feet (measured along the hot water piping) from the water heater.

(c) Sensor controlled systems may be activated by wired or wireless mechanisms, including motion sensors, door switches and flow switches. Sensors controls shall have standby power of 1 watt or less.

(d) Pump and demand control placement meets one of the following criteria.

1. When a dedicated return line has been installed the pump, demand controls and thermo-sensor are installed at the end of the supply portion of the recirculation loop (typically under a sink); or

2. The pump and demand controls are installed on the return line near the water heater and the thermo-sensor is installed in an accessible location as close to the end of the supply portion of the recirculation loop as possible (typically under a sink), or

3. When the cold water line is used as the return, the pump, demand controls and thermo-sensor is installed in an accessible location at the end of supply portion of the hot water distribution line (typically under a sink).

(e) Insulation is not required on the cold water line when it is used as the return.

(f) Demand controls shall be able to shut off the pump in accordance with one of the following two methods:

1. After the pump has been activated, the controls shall allow the pump to operate until the water temperature at the thermo-sensor rises not more than 10°F (5.6 °C) above the initial temperature of the water in the pipe, or

2. The controls shall not allow the pump to operate when the temperature in the pipe exceeds 102°F (38.9 °C).

(g) The controls shall limit pump operation to a maximum of 5 minutes following any activation. This is provided in the event that the normal means of shutting off the pump have failed.

RA4.4.11 Multiple Dwelling Units: Recirculation Temperature Modulation Control

A recirculation temperature modulation control shall reduce the hot water supply temperature when hot water demand is determined to be low by the control system. The control system may use a fixed control schedule or dynamic control schedules based measurements of hot water demand. The daily hot water supply temperature reduction, which is defined as the sum of temperature reduction by the control in each hour within a 24-hour period, shall be more than 50 degrees Fahrenheit to qualify for the energy savings credit.

Recirculation systems shall also meet the requirements of §110.3.

RA4.4.12 Multiple Dwelling Units: Recirculation Continuous Monitoring Systems

Systems that qualify as a recirculation continuous monitoring systems for domestic hot water systems serving multiple dwelling units shall record no less frequently than hourly measurements of key system operation parameters, including hot water supply temperatures, hot water return temperatures, and status of gas valve relays of water heating equipment. The continuous monitoring system shall automatically alert building operators of abnormalities identified from monitoring results.

Recirculation systems shall also meet the requirements of §110.3.

RA4.4.13 Multiple Dwelling Units: Demand Recirculation

Demand controlled recirculation systems shall operate “on-demand”, meaning that pump operation shall be initiated shortly prior to, or by a hot water draw. The controls shall operate on the principal of shutting off the pump with a sensed rise in pipe temperature (Delta-T). For this measure sensor or manual controls may be used to activate the pump(s).

(a) Manual or sensor controls shall be installed and if powered, have standby power of 1 watt or less. Controls may be located in individual units or on the loop. Controls may be activated by wired or wireless mechanisms, including buttons, motion sensors, door switches and flow switches.

(b) Pump and control placement shall meet one of the following criteria:

1. When a dedicated return line has been installed the pump, controls and thermo-sensor are installed at the end of the supply portion of the recirculation loop; or

2. The pump and controls are installed on the dedicated return line near the water heater and the thermo-sensor is installed in an accessible location as close to the end of the supply portion of the recirculation loop as possible, or

3. When the cold water line is used as the return, the pump, demand controls and thermosensor shall be installed in an accessible location at the end of supply portion of the hot water distribution line (typically under a sink).

(c) Insulation is not required on the cold water line when it is used as the return.

(d) Demand controls shall be able to shut off the pump in accordance with these three methods:

1. After the pump has been activated, the controls shall allow the pump to operate until the water temperature at the thermo-sensor rises not more than 10 ^{o}F (5.6 ^{o}C) above the initial temperature of the water in the pipe, or

2. The controls shall not allow the pump to operate when the temperature in the pipe exceeds 102 ^{o}F (38.9 ^{o}C).

3. The controls shall limit pump operation to a maximum of 10 minutes following any activation.

This is provided in the event that the normal means of shutting off the pump have failed.

Recirculation systems shall also meet the requirements of §110.3.

RA4.4.14 HERS-Verified Pipe Insulation Credit (PIC-H)

Consistent with the requirements of RA4.4.1, this measure requires a HERS inspection to verify that all hot water piping is insulated correctly.

RA4.4.15 HERS-Verified Parallel Piping (PP-H)

Consistent with the requirements of RA4.4.4 this measure requires a HERS inspection to verify that the length of pipe between the water heater and each central manifold does not exceed 5 feet and to verify pipe insulation.

RA4.4.16 HERS-Verified Compact Hot Water Distribution System Expanded Credit (CHWDS-H-EX)

A HERS inspection is required in order to obtain this credit. To meet the Compact Hot Water Distribution System Expanded Credit eligibility requirements, the requirements in RA4.4.6 must be met. In addition, the following HERS field verifications are required:

(a) No hot water piping >1” diameter piping is allowed,

(b) Length of 1” diameter piping is limited to 8 ft or less,

(c) Two and three story buildings cannot have hot water distribution piping in the attic, unless the water heater is also located in the attic and,

(d) Eligible recirculating systems must be HERS-Verified Demand Recirculation: Manual Control conforming to RA4.4.17.

RA4.4.17 HERS-Verified Demand Recirculation: Manual Control (RDRmc-H)

Consistent with the requirement of RA4.4.7.3, this measure includes a visual HERS inspection to verify that the demand pump, manual controls and thermo-sensor are present and operating properly.

RA4.4.18 HERS-Verified Demand Recirculation: Sensor Control (RDRsc-H)

Consistent with the requirement of RA4.4.6.4 this measure includes a visual HERS inspection to verify that the demand pump, sensor controls and thermo-sensor are present and operating properly.

RA4.4.19 HERS-Verified Multiple Recirculation Loops for DHW Systems Serving Multiple Dwelling Units

Central DHW systems serving a building with more than eight dwelling units shall have at least two recirculation loops, each serving roughly the same number of dwelling units. 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. This credit may be taken in combination with recirculation system defined in RA 4.4.7.5 through RA 4.4.7.7.

RA4.4.20 Solar Water Heating Systems

Solar water-heating systems and/or collectors shall be certified and rated by the Solar Rating and Certification Corporation (SRCC), the International Association of Plumbing and Mechanical Officials, Research and Testing (IAPMO R&T), or by a listing agency that is approved by the Executive Director.

To use collectors with the SRCC OG-100 certification and rating, the installed system shall meet the following eligibility criteria:

(a) Include all of the features modeled and generated in the Commission approved solar savings fraction calculation.

(b) The collectors shall be installed according to manufacturer’s instructions.

(c) The collectors shall be located in a position that is not shaded by adjacent buildings or trees between 9:00 AM and 3:00 PM (solar time) on December 21.

To use a solar water-heating system with the SRCC OG-300 certification and rating, the installed system shall meet the following eligibility criteria:

(a) The collectors shall face within 35 degrees of south and be tilted at a slope of at least 3:12.

(b) The system shall be installed in the exact configuration for which it was rated. The system shall have the same collectors, pumps, controls, storage tank and backup water heater fuel type as the rated condition.

(c) The system shall be installed according to manufacturer's instructions.

(d) The collectors shall be located in a position that is not shaded by adjacent buildings or trees

between 9:00 AM and 3:00 PM (solar time) on December 21.

RA4.4.21 HERS-Verified Drain Water Heat Recovery System (DWHR-H)

A HERS inspection is required to obtain this credit. All DWHR unit(s) shall be certified to the Energy Commission according to the following requirements:

(a) Vertical DWHR unit(s) shall be compliant with CSA B55.2, and tested and labeled in

accordance with CSA B55.1 or IAPMO IGC 346-2017. Sloped DWHR unit(s) shall be compliant with IAPMO PS 92, and tested and labeled with IAPMO IGC 346-2017.

(b) The DWHR unit(s) shall have a minimum rated effectiveness of 42 percent.

The HERS inspector shall verify that:

(a) The make, model, and CSA B55.1 or IAPMO IGC 346-2017 rated effectiveness of the DWHR unit(s) shall match the compliance documents. The DHWR unit(s) shall also be verified as a model certified to the Energy Commission as qualified for credit as a DWHR unit(s).

(b) The installation configuration (e.g. equal flow, unequal flow to the water heater, or unequal flow to the showers) and the percent of served shower fixtures shall match the compliance documents.

(c) For water heating system serving a single dwelling, the DWHR system shall, at the minimum, recover heat from the master bathroom shower and must at least transfer that heat either back to all the respective showers or the water heater.

(d) For central water heating system serving multiple dwellings, the DWHR system shall, at thecminimum, recover heat from half the showers located above the first floor and must at least transfer that heat either back to all the respective showers or the water heater.

(e) The DWHR unit(s) shall be installed within 2 1 degrees of the rated slope. Sloped DWHR shall have a minimum lengthwise slope of 1 degree. The lateral level tolerance shall be within plus or minus 1 degree.

(f) The installation shall comply with any applicable California Plumbing Code requirements.

Alternative Calculation Methods Approval Manual.

Open source compliance software developed by the Energy Commission, called the Compliance Manager in this document, is made available at no cost to potential compliance software vendors, and is created and approved by the Energy Commission following the specifications of this Manual. The ACM tests submitted by the vendor either confirm and document that the Compliance Manager is successfully integrated into the vendor software, or demonstrate that the vendor software accurately achieves the same results as the Energy Commission's software.

Section 2 provides the specifications and requirements that apply to the Compliance Manager in establishing the standard design energy use of residential and nonresidential buildings. The Residential and Nonresidential ACM Reference Manuals required by Section 2.4 are documents that are developed and maintained by the Energy Commission to document in greater detail the specific building performance modeling calculations implemented in the Compliance Manager software and used to model building performance. These reference manuals are approved by the Energy Commission and updated as necessary to resolve issues identified during implementation.

2.1 Standard Design

The standard design building is a building simulated to establish the baseline energy budget for space heating, space cooling, indoor air quality ventilation, and water heating for a proposed building.

For newly constructed buildings, the standard design building shall be modeled as existing in the same location and having the same characteristics, including but not limited to floor area, volume, and configuration, as the proposed building, except that wall and fenestration areas shall be distributed equally between the four main compass points, North, East, South and West. For additions and alterations, the standard design shall be modeled as existing in the same location and having the same characteristics, and shall have the same wall and fenestration areas and orientations as the existing building.

Where the Energy Commission specifies that the standard design building includes a covered product subject to 42 USC 6295, or an appliance regulated by the Appliance Efficiency Regulations, the standard design building shall be modeled to meet but not exceed the efficiency level required by 42 USC 6295 for that covered product or applicable standards required by the Appliance Efficiency Regulations for that regulated appliance, respectively.

The standard design building shall be modeled to include the mandatory requirements of the 2019 Standards, and to meet but not exceed the prescriptive requirements that would apply to the proposed building.

The process of generating the standard design shall be performed automatically by the compliance manager software. The compliance manager shall perform this modeling based on the inputs that describe the proposed building, substituting the assumptions for wall and fenestration area distribution, required efficiency for the covered product subject to 42 USC 6295 that the Energy Commission specifies in the standard design, and the applicable standards for the appliance regulated by the Appliance Efficiency Regulation that the Energy Commission specifies in the standard design, and mandatory and prescriptive options applicable to the proposed building, thereby creating a standard design building against which the energy use of the proposed building can be evaluated.

The specific calculations used by the Compliance Manager to model the performance of the standard design building shall be documented in the Reference Manual described in Section 2.4.

2.4 Reference Manual

The Energy Commission shall publish a Reference Manual for the Compliance Manager software that specifies the standard design and documents the calculations and methods used by the Compliance Manager software to model building performance, calculate TDV energy, and determine compliance with the 2019 Standards.

APPENDIX E:
Hot Water System Area versus Total Floor Area

PowerPoint slide show illustrating hot water system area versus total floor area.

New Single-Family Homes Completed in 2017

Median Home Size in Western United States
-2,398 sq ft

Average Home Size in Western United States
-2,548 sq ft

6% under 1,400
15% 1,400 to 1,799
29% 1,800 to 2,399
25% 2,400 to 2,999
17% 3,000 to ,3,999
8% 4,000 or more

(Source: https://www.census.gov/construction/chars/pdf/squarefeet.pdf) 2

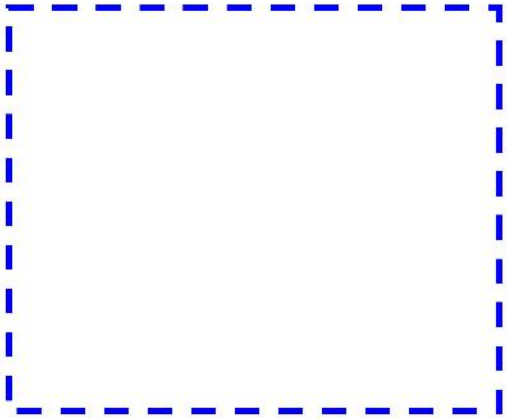
New Multi-Family Units Completed in 2017

Median Unit Size in Western United States
-1,045 sq ft

Average Unit Size in Western United States
-1,088 sq ft

42% under 1,000
31% 1,000 to 1,199
15% 1,200 to 1,399
9% 1,400 to 1,799
4% 1,800 or more

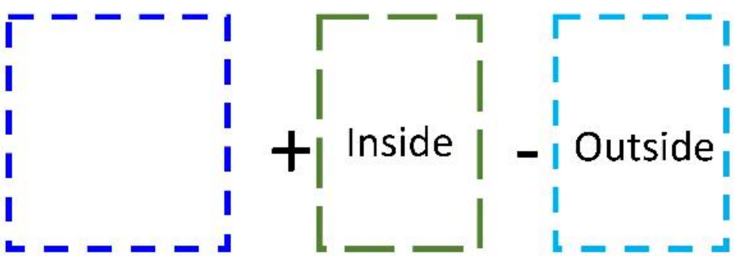
(Source: United States Census Bureau)



= Wet Room Rectangle

Ratio in Percent: Hot Water System Rectangle/Floor Area x 100%

Use the dimensions available on the floor plan when available. Otherwise, determine the areas based on the formula below. The dimensions come from the drawing program.

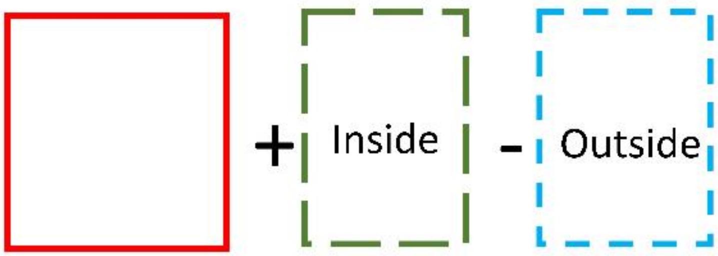


= Home Floor Area

= Hot Water System Rectangle

Ratio in Percent: Hot Water System Rectangle/Floor Area x 100%

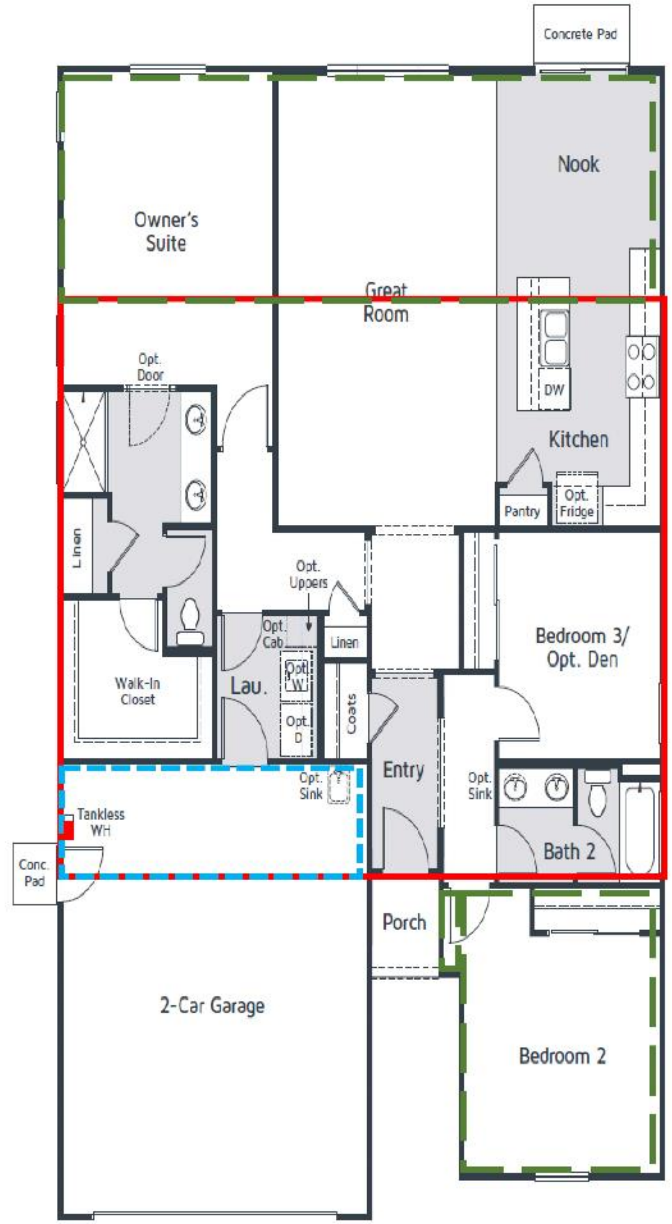
Use the dimensions available on the floor plan when available.
Otherwise, determine the areas based on the formula below.
The dimensions come from the drawing program.



= Home Floor Area

Example:

1 Story
3Br/2Ba
1,697 sq ft
Fresno, CA
~67% (1137 sq ft)



Relationship between the Hot Water System and the Floor Area – The Logical Worst Case

Number of Stories	Hot Water System/ Floor Area (%)
1-story	100%
2-story	50%
3-story	33.3%
4-story	25%
5-story	20%

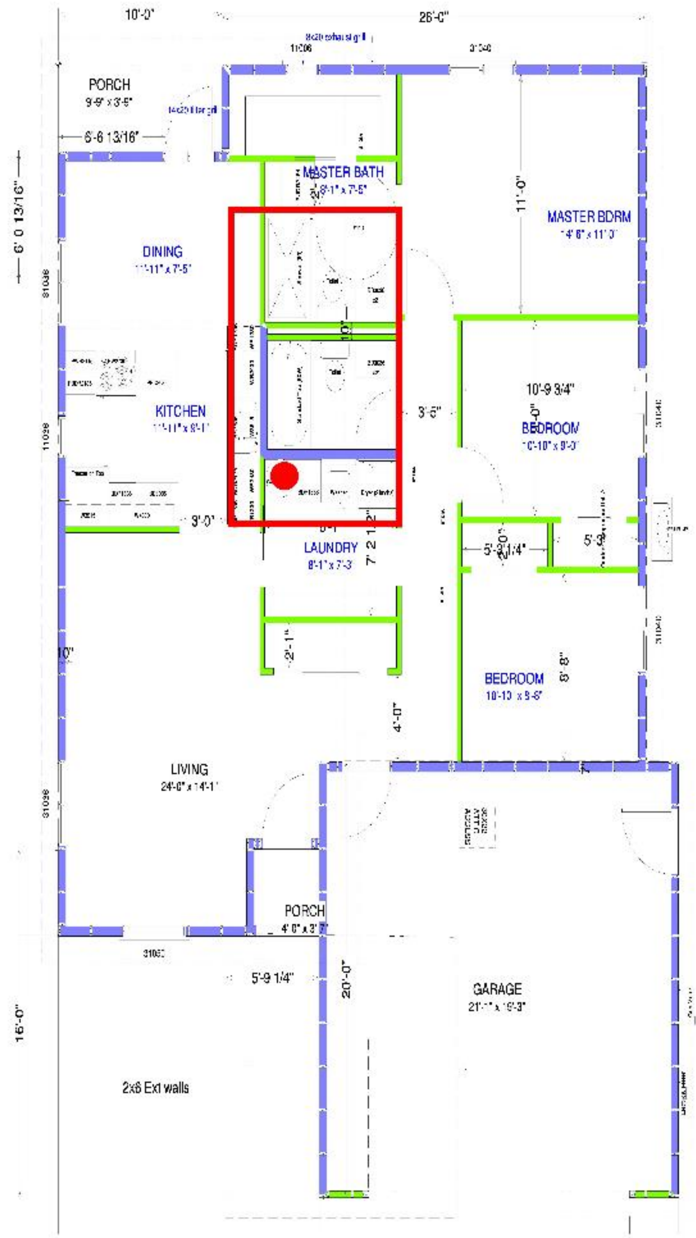
Basements count as stories if they contain wet rooms.

1-Story Floor Plans

- The wet room rectangle has the same area as the hot water system rectangle for all of the 1-story homes in this sample.

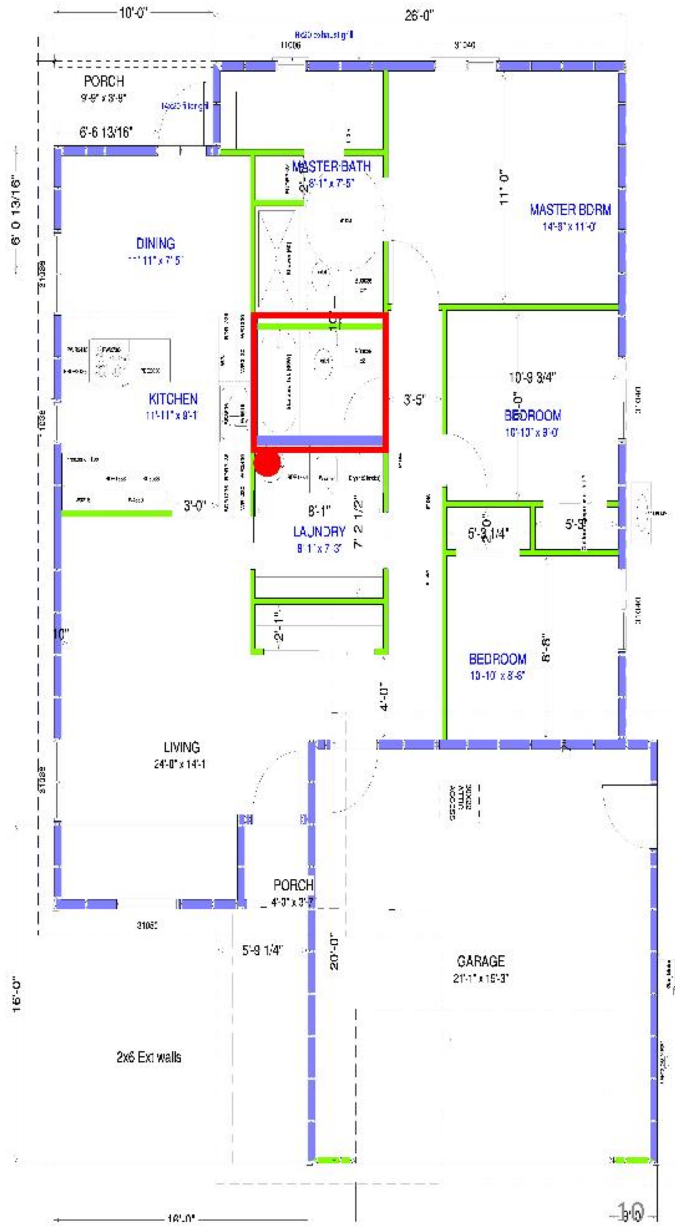
1 Story
3 Br/2 Ba
1,223 sq ft
Stockton, CA

~15%
(183 sq ft)
(when bounding the hot water plumbing fixtures and appliances)



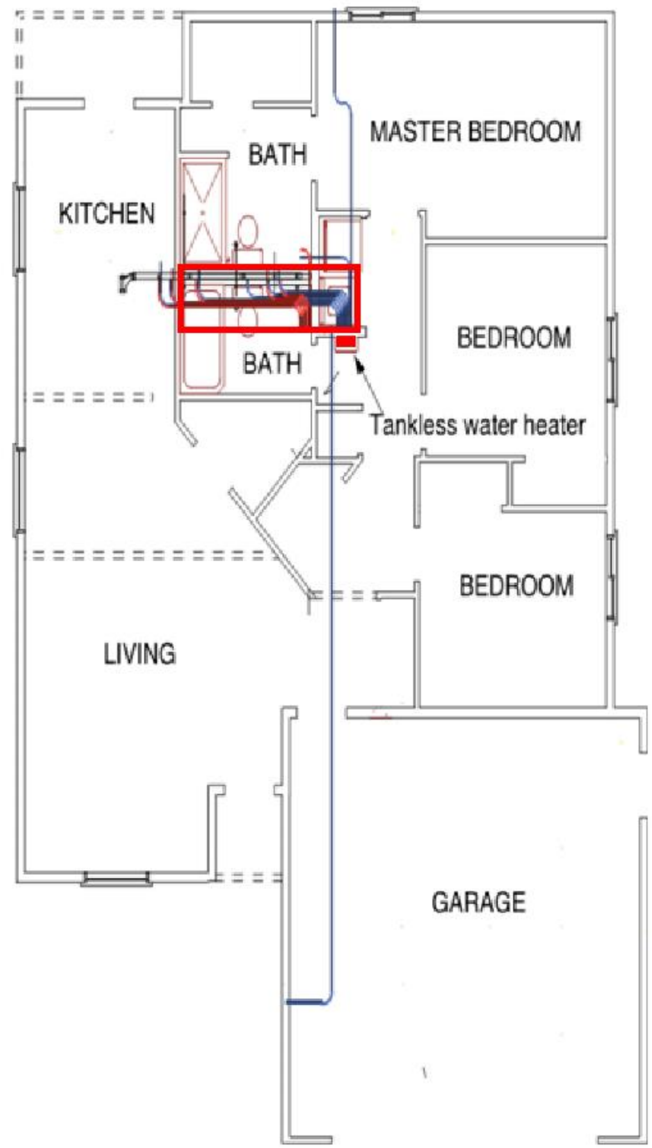
1 Story
3 Br/2 Ba
1,223 sq ft
Stockton, CA

~4%
(49 sq ft)
(when bounding the plumbing walls)



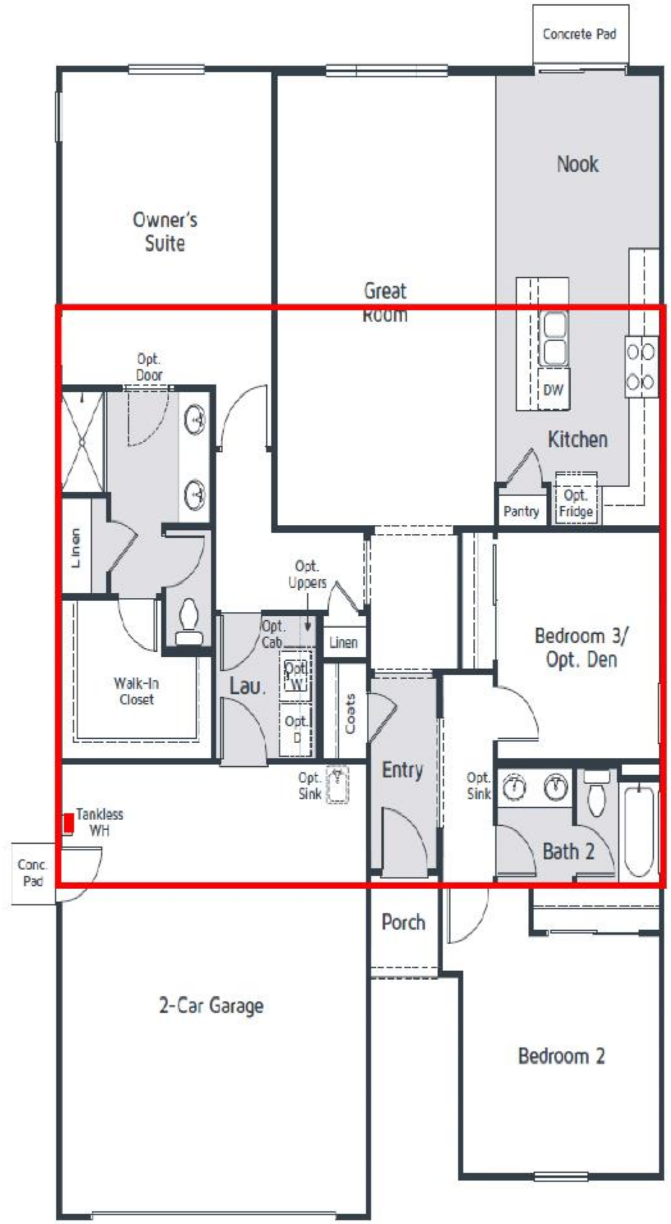
1 Story
3 Br/2 Ba
1,223 sq ft
Stockton, CA

~2.5%
(30 sq ft)
(when bounding the plumbing walls)



1 Story
3Br/2Ba
1,697 sq ft
Fresno, CA

~67%
(1,137 sq ft)



1 Story

3Br/2.5Ba

2,466 sq ft

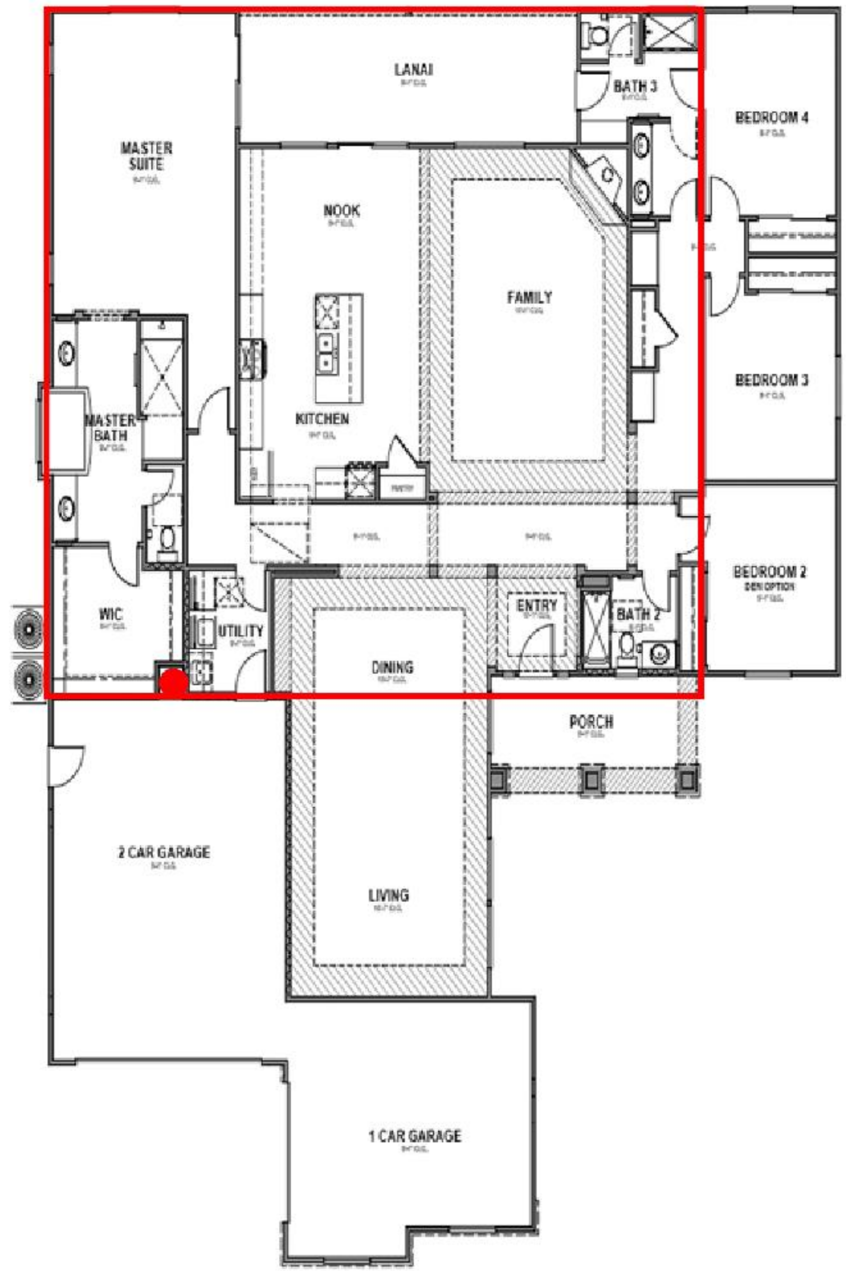
Roseville, CA

~75%

(1,835 sq ft)

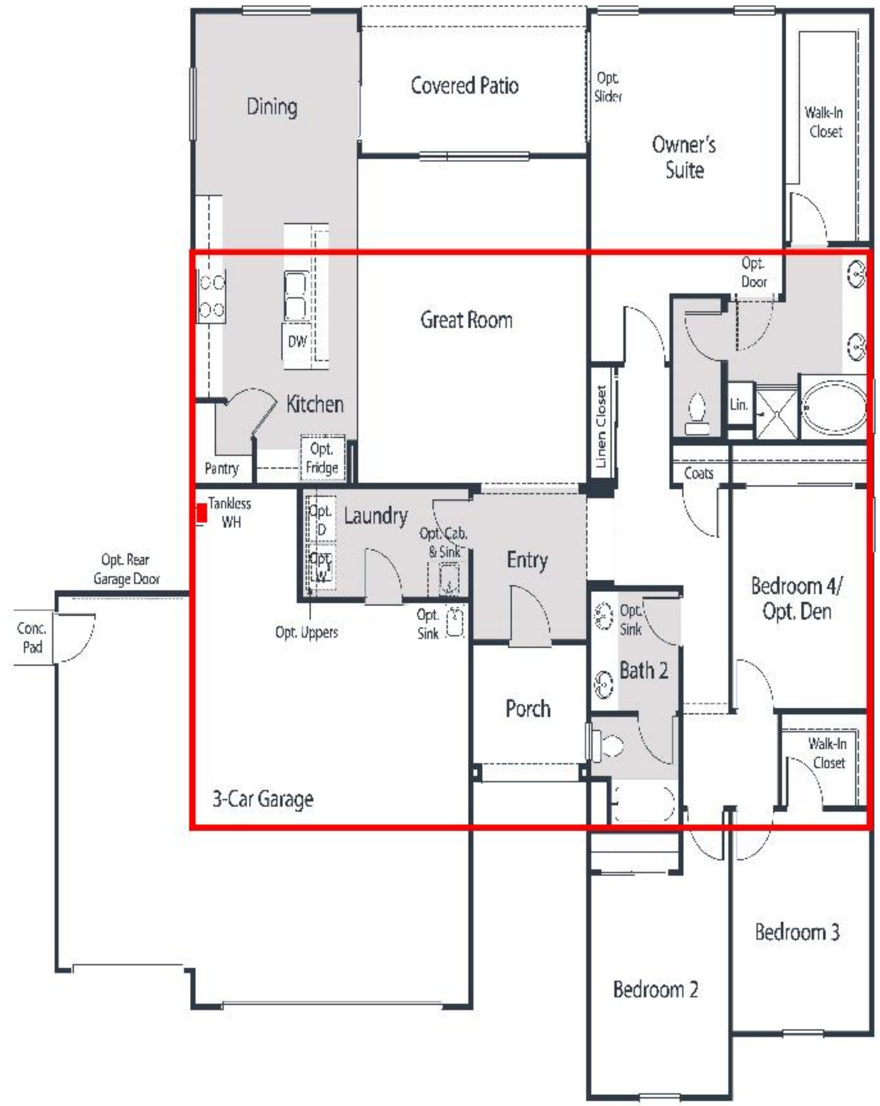
1 Story
4Br/3Ba
3,073 sq ft
Chico, CA

~80%
(2,459 sq ft)



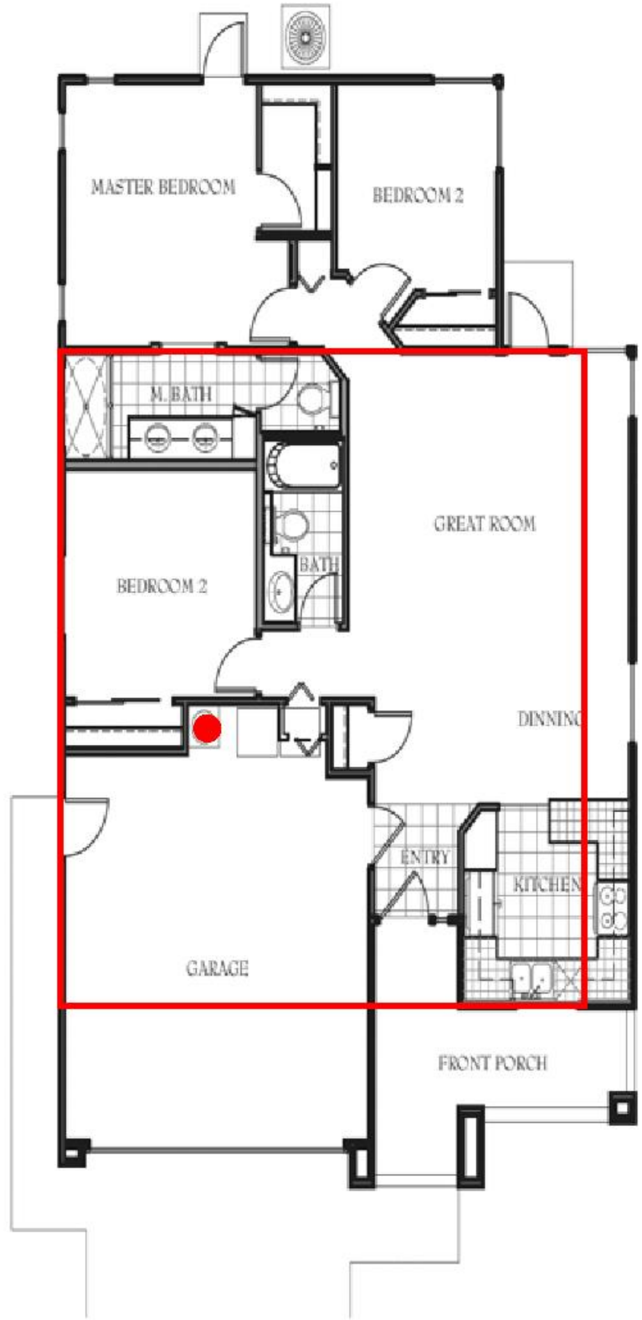
1 Story
4Br/2Ba
2,010 sq ft
Fresno, CA

~81%
(1,628 sq ft)



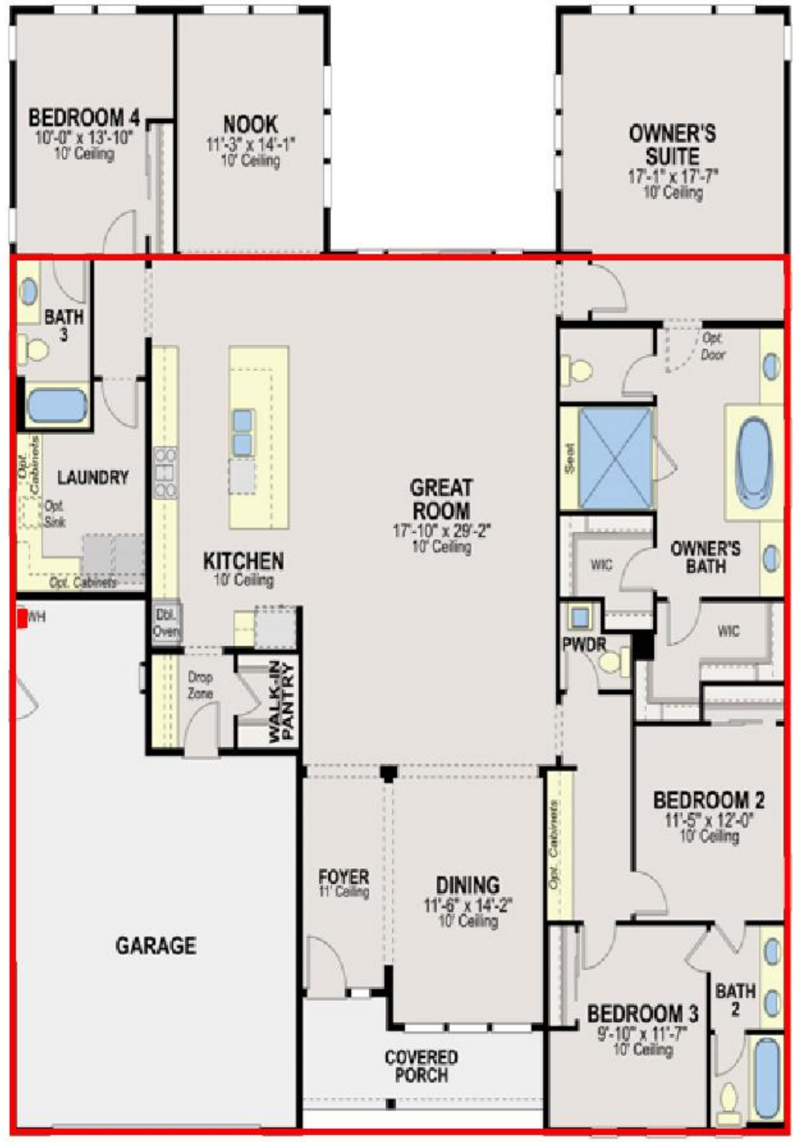
1 Story
2 Br/2 Ba
1,224 sq ft
Chico, CA

~88%
(1,077 sq ft)



1 Story
4Br/3.5Ba
2,952 sq ft
Morgan Hill, CA

~105%
(3,100 sq ft)



17

1 Story

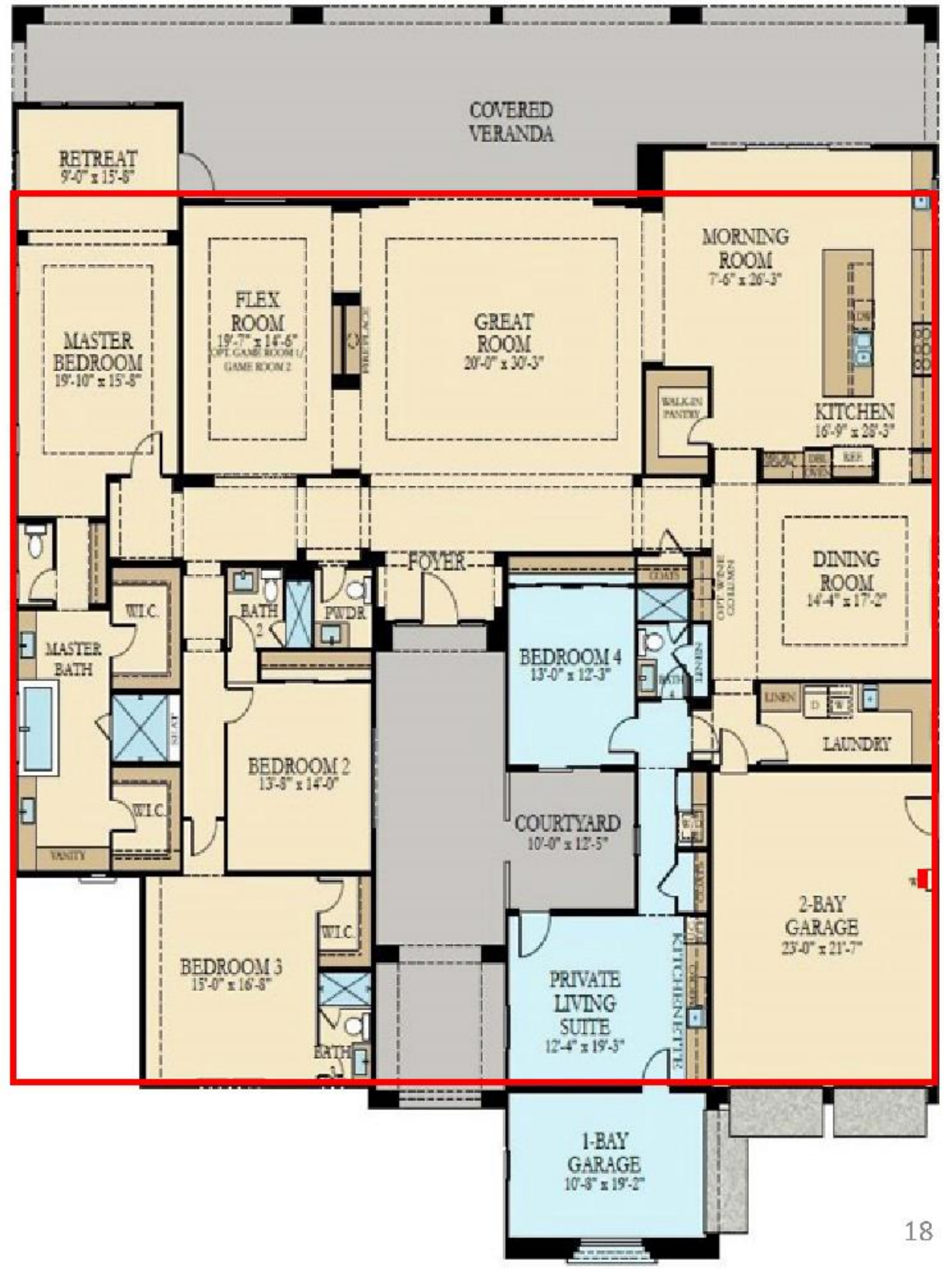
4 Br/4.5 Ba

4,820 sq ft

La Quinta, CA

~110%

(5,302 sq ft)



18

1 Story
5 Br/5.5Ba
4,467 sq ft
San Diego, CA

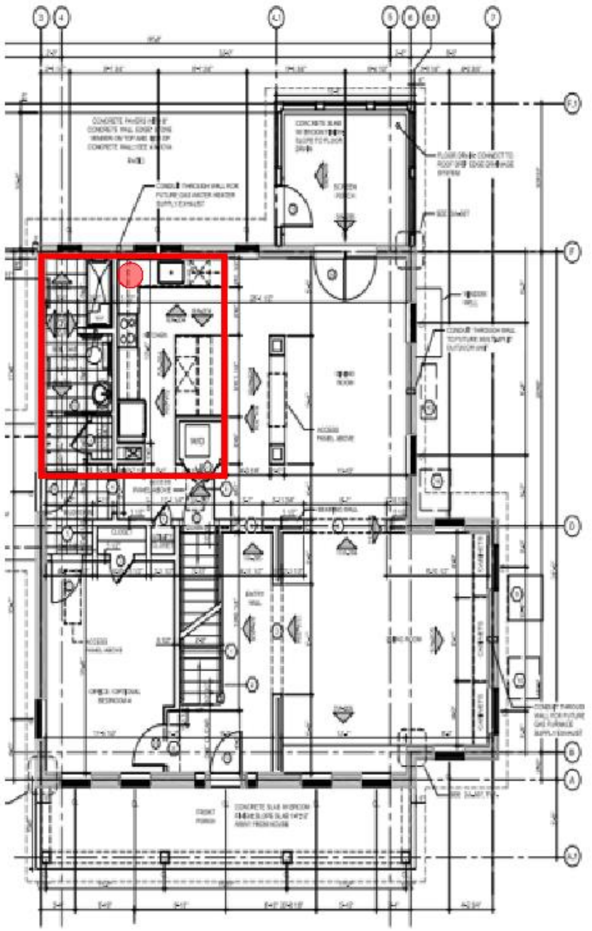
~155%
(6,924 sq ft)

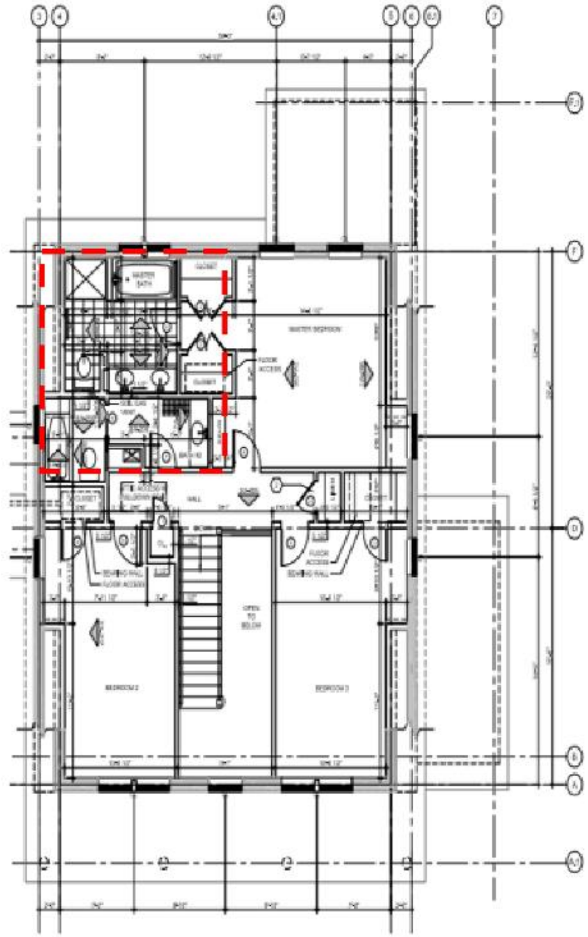
19

2-Story Floor Plans

The wet room rectangle has the same area as the hot water system rectangle for all of the 2-story homes in this sample.

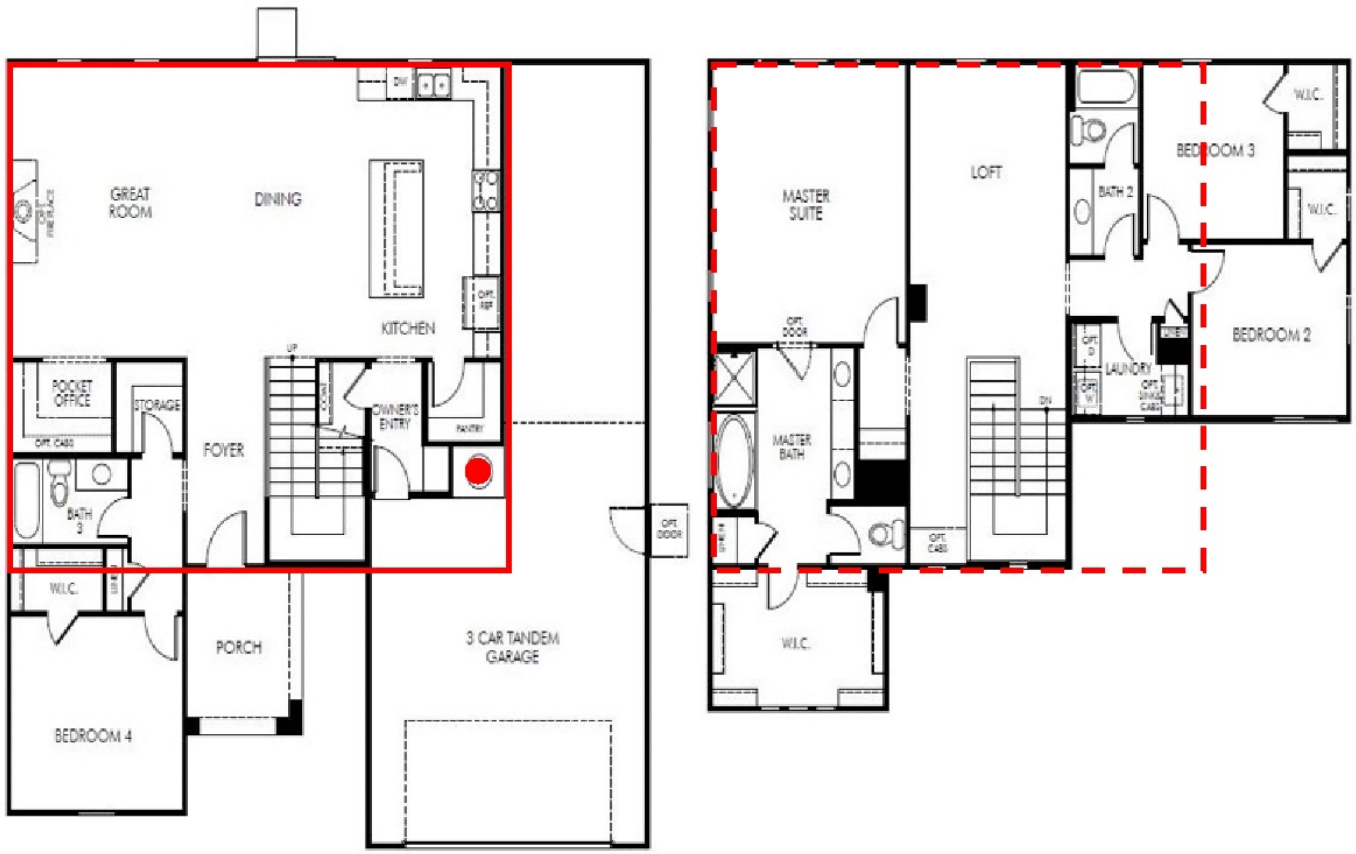
2 Story, 4Br / 3Ba, 2,709 sq ft
Gaithersburg, MD ~12% (325 sq ft)





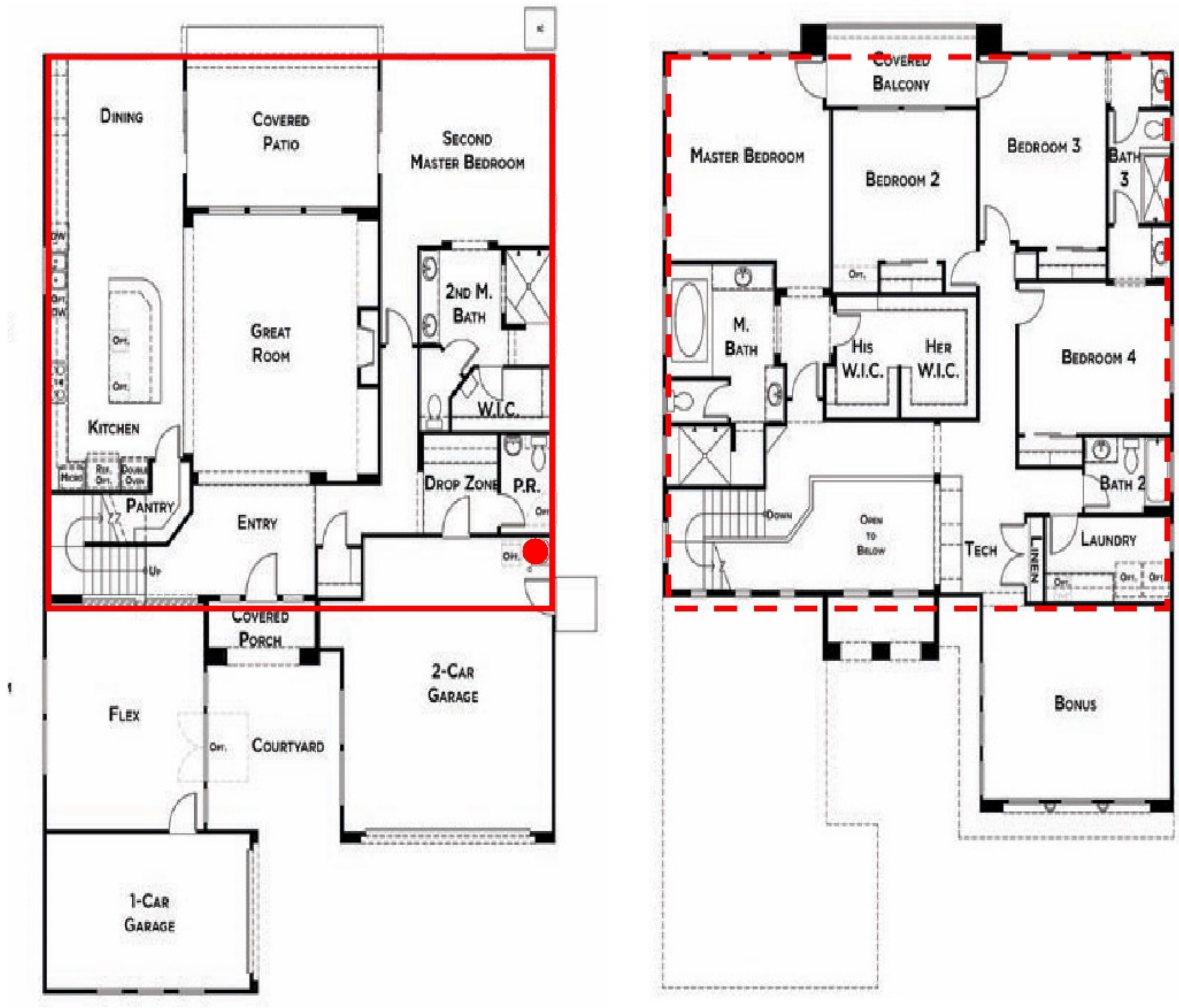
21

2 Story, 4 Br/3 Ba, 2,625 sq ft
Bakersfield, CA ~37% (962 sq ft)



2 Story, 3 Br/2.5 Ba, 1,837 sq ft
Salinas, CA ~48% (882 sq ft)

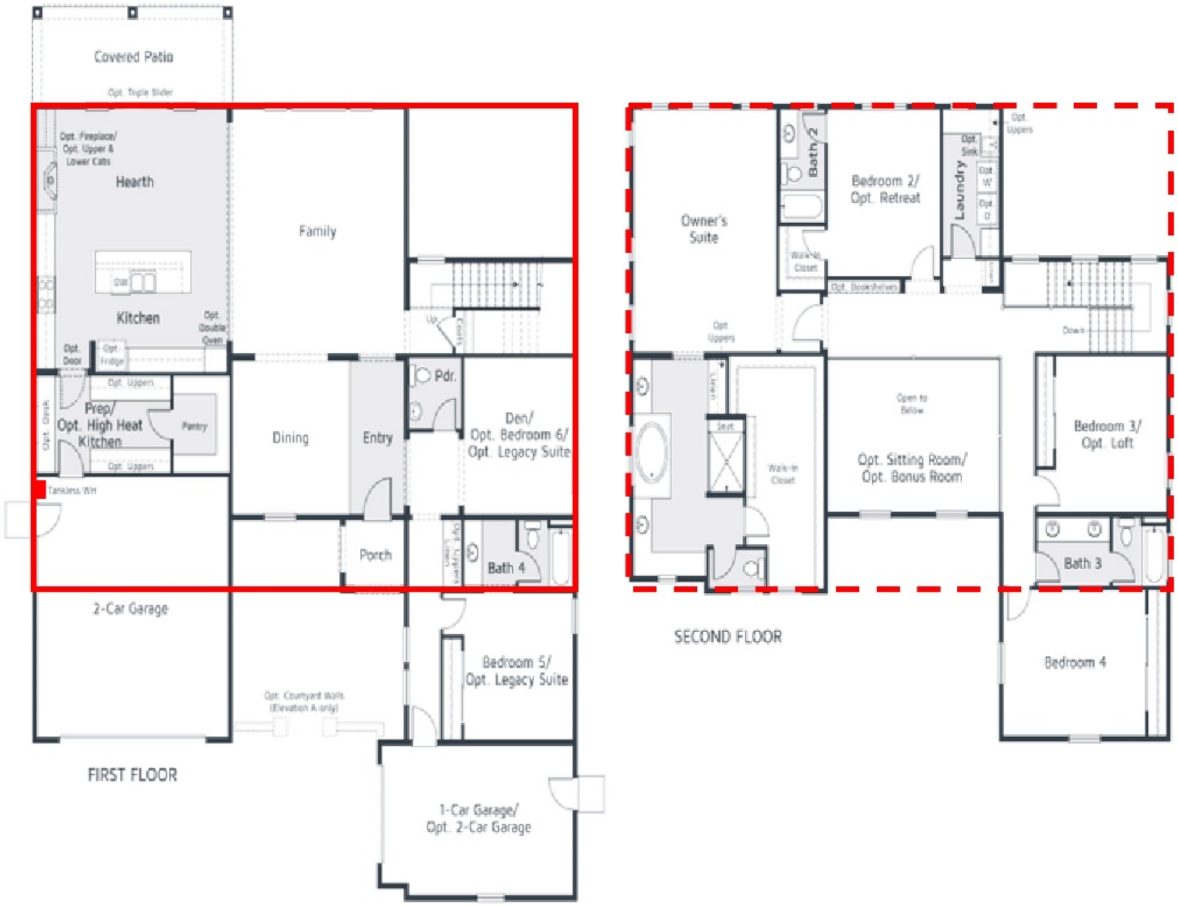
2 Story, 5 Br/4.5 Ba, 4,003 sq ft
Rocklin, CA ~51% (2,042 sq ft)



24

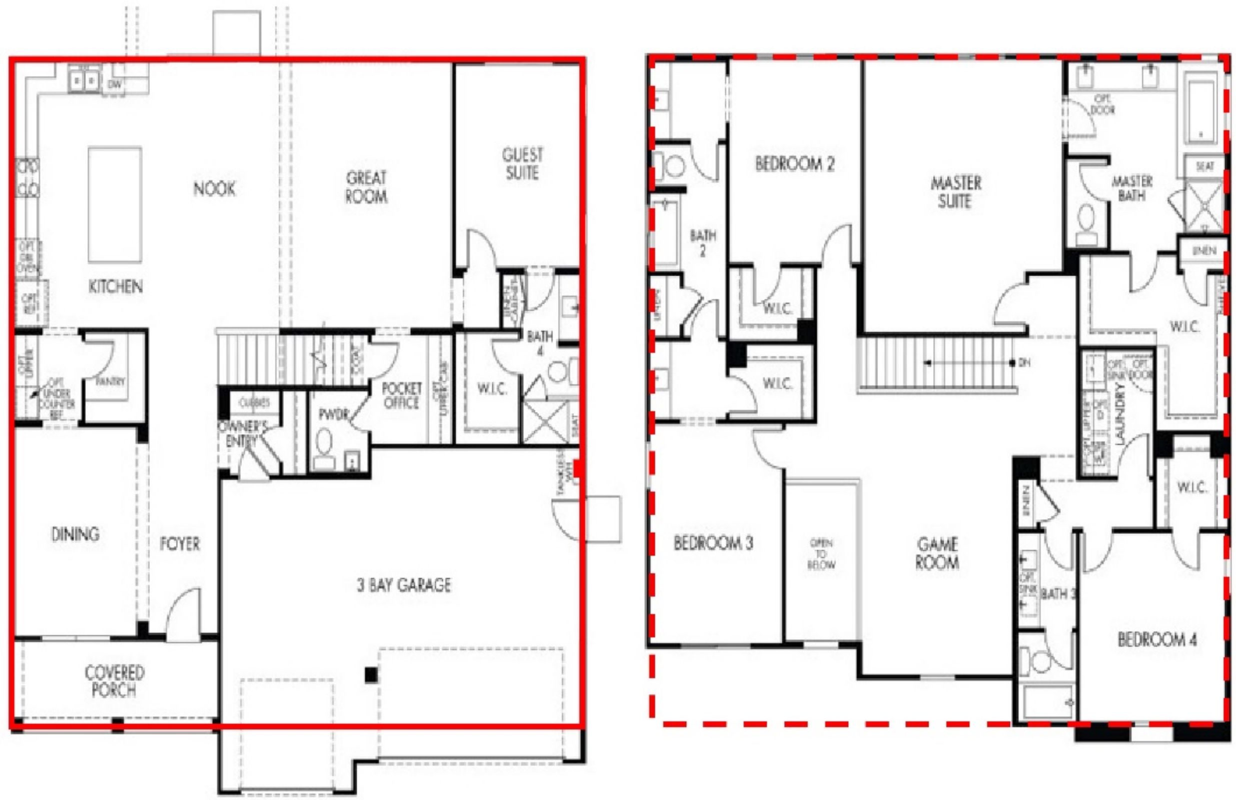
2 Story, 5 Br/5.5 Ba, 3,983 sq ft
Irvine, CA ~58% (2,310 sq ft)

2 Story, 5 Br/ 4.5 Ba, 4,301 sq ft
Rancho Cucamonga, CA ~62% (2,667 sq ft)



26

2 Story, 5 BR/4.5 Ba, 3,493 sq ft
Manteca, CA ~63% (3,493 sq ft)



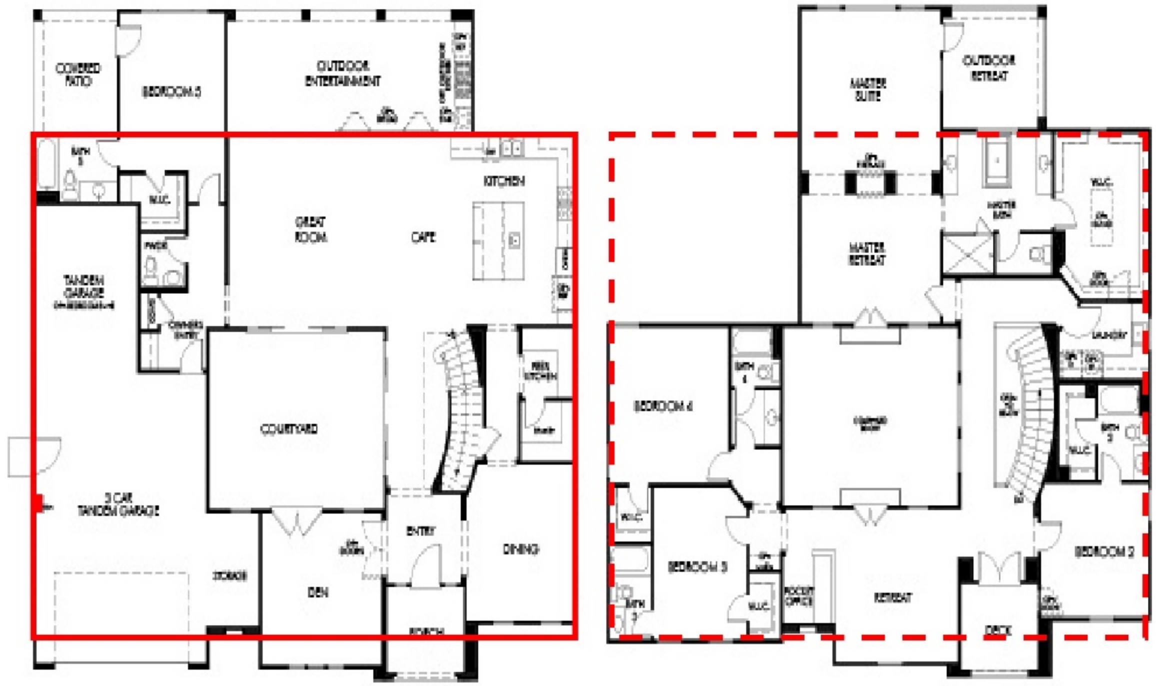
27

2 Story
4 Br/3.5 Ba
3,853 sq ft
Lincoln, CA

~71 %
(2,026 sq ft)

28

2 Story, 5 Br/5.5 Ba, 4,269 sq ft
La Verne, CA ~72% (3,074 sq ft)



Multi-Family Unit Floor Plans

The wet room rectangle has the same area as the hot water system rectangle for all of the 2-story homes in this sample.

1 Story
1Br/1Ba
720 sq ft
Chula Vista, CA

~29%
(209 sq ft)

31

2 Story
2Br/2Ba
908 sq ft
Richmond, CA

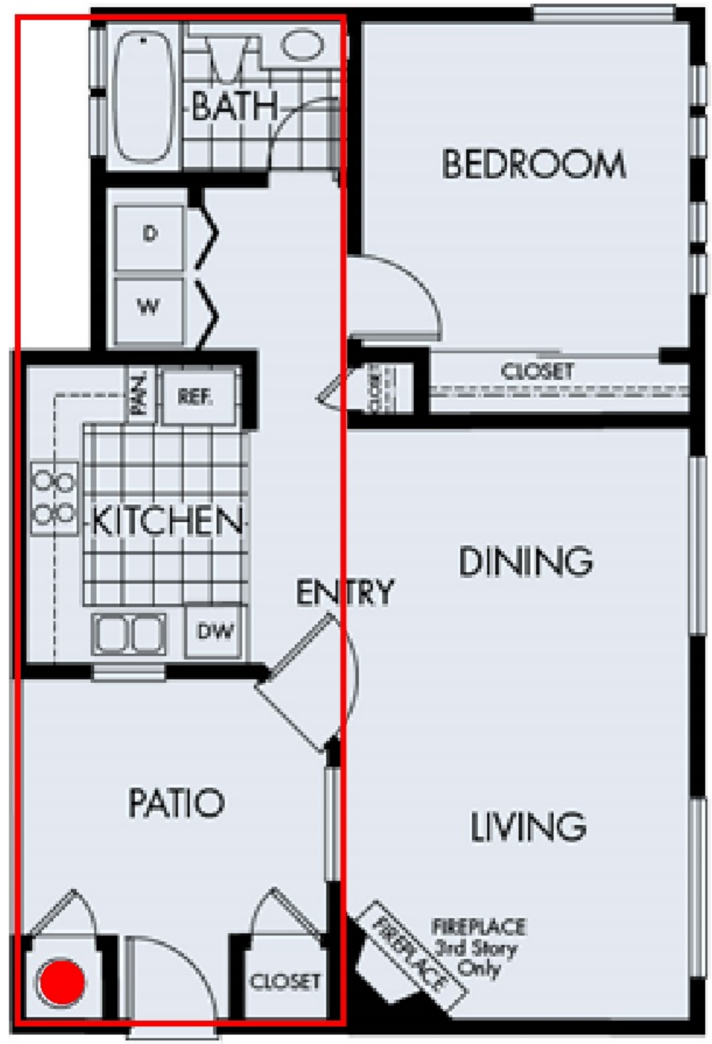
~33%
(300 sq ft)

2 Story, 2 Br/2.5 Ba, 1275 sq ft
Ventura, CA ~34% (434 sq ft)

33

1 Story
1Br/1Ba
665 sq ft
Newark, CA

~50%
(333 sq ft)



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1 Story, 3 Br/2 Ba, 1136 sq ft
Bakersfield, CA ~62% (699 sq ft)

1 Story, 4Br/2Ba, 1217 sq ft
Banning, CA ~67% (815 sq ft)

1 Story

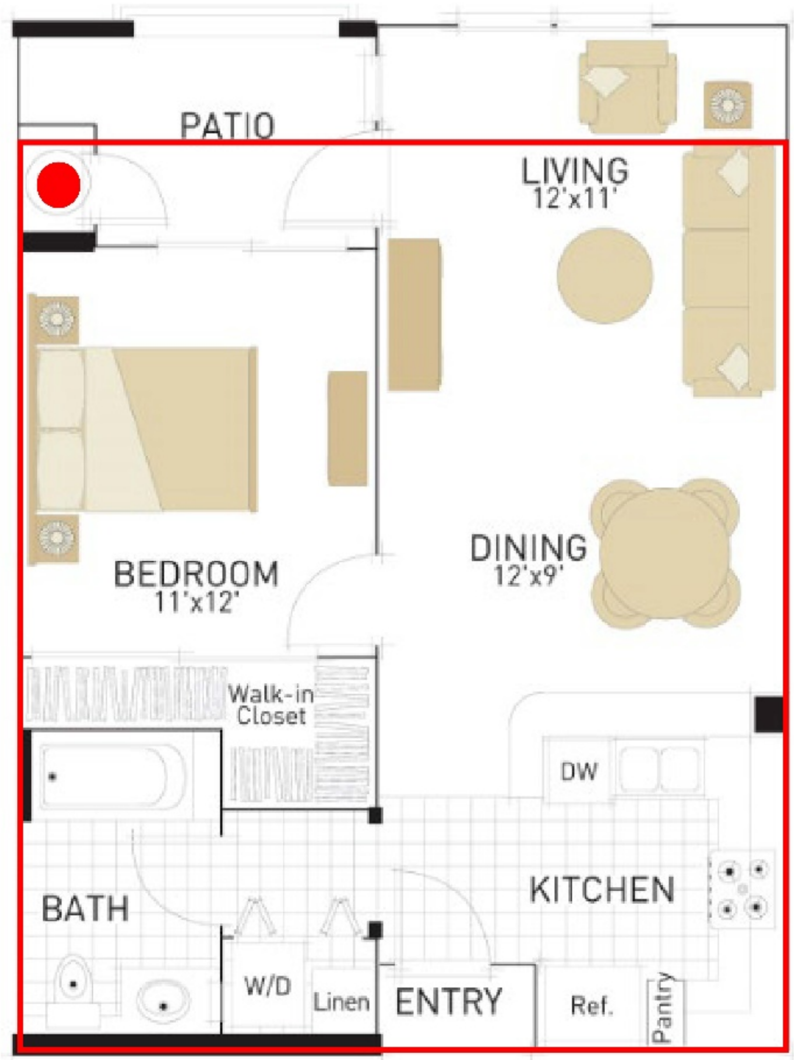
1Br/1Ba

670 sq ft

San Jose, CA

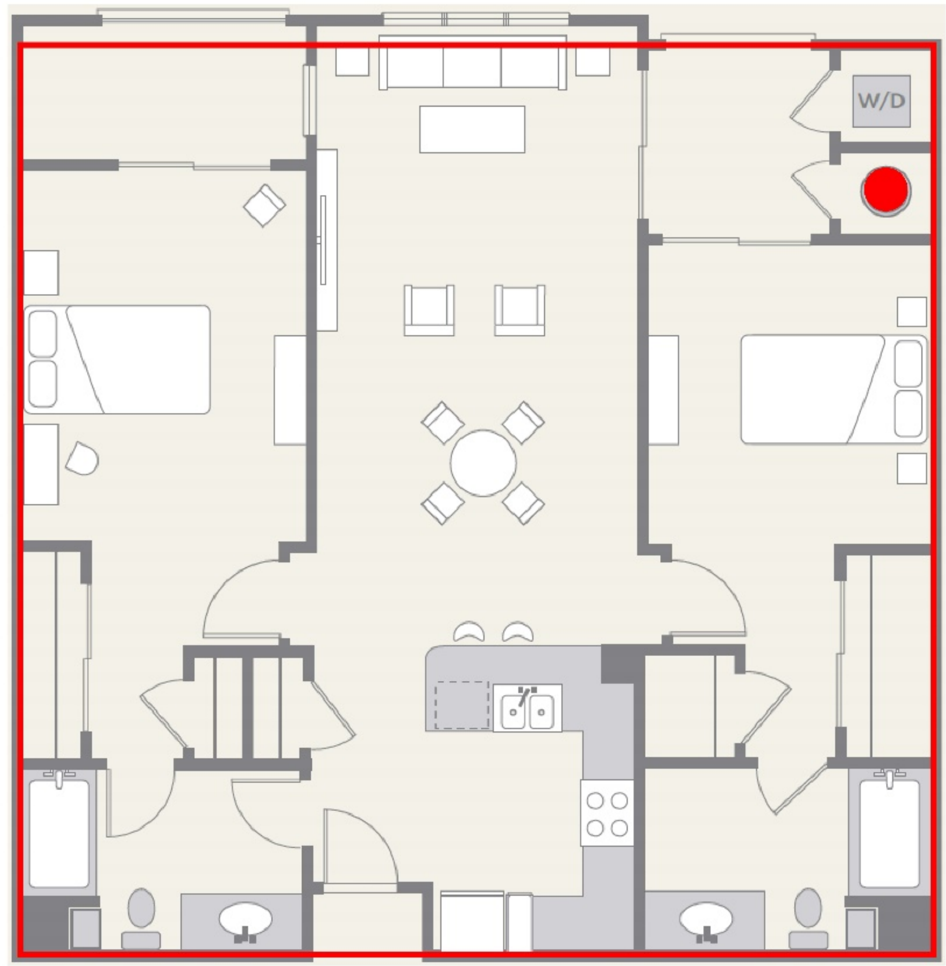
~90%

(603 sq ft)

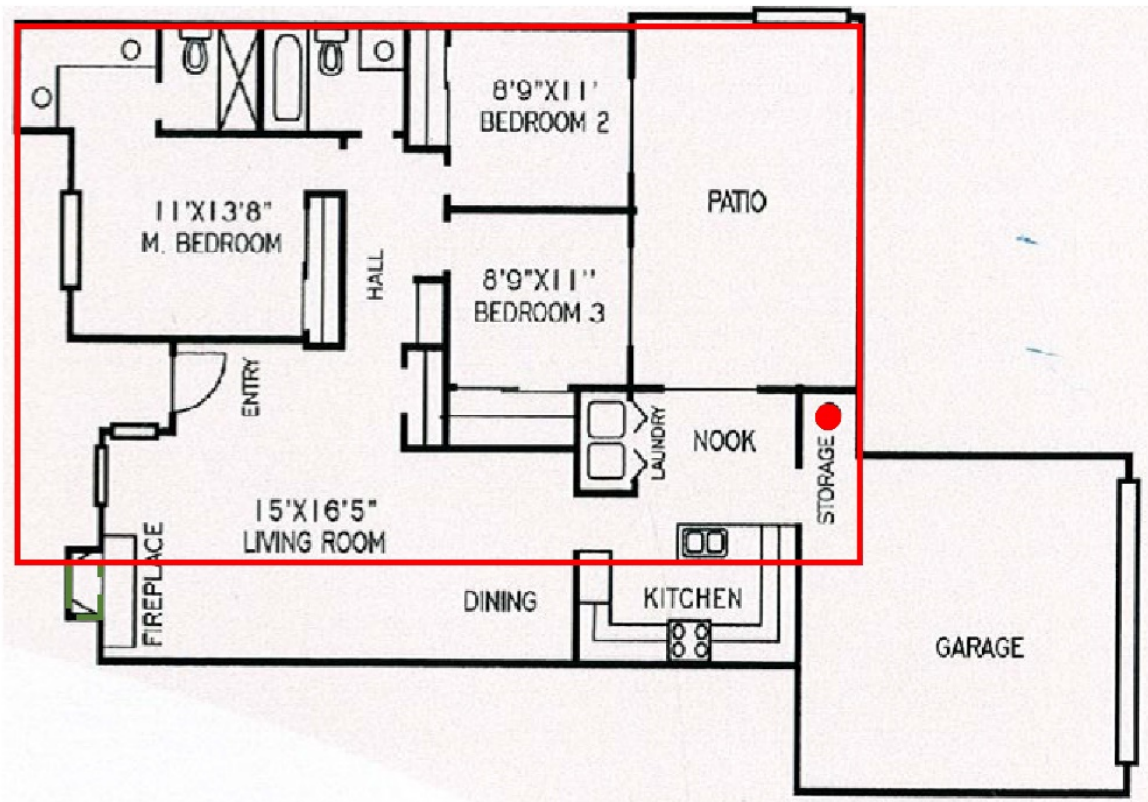


1 Story
2Br/2Ba
1232 sq ft
San Diego, CA

~99%
(1220 sq ft)



1 Story, 3Br/2Ba, 1360 sq ft
Fresno, CA ~115% (1564 sq ft)



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Scatter Plot of the Relationship between the Hot Water System and the Floor Area

Source: http://kiddywampus.blogspot.com

APPENDIX F: Hot Water Draw Schedule and Adjustments

Adjustments to CBECC-Res Draw Schedules

The hot water draw patterns from CBECC-Res 2019 only indicate type of fixture or appliance associated with each hot water draw, but not location of the fixture. For example, shower draws do not indicate in which bathroom the shower occurred. In order to model the system performance, every draw in those schedules was assigned to a specific fixture and appliance on the prototype floor plan based on project team's best judgment.

Hot water delivery efficiency and water waste are influenced by the draw patterns. Is the time between hot water events within the window in which hot water pipes will still be hot enough for the next event? Where do the hot water events occur in relationship to each other within the hot water distribution system? How much of the trunk line do they share? Are they on the same branch or fixture branch? The distribution performance model can address these questions by tracking pipe temperatures between hot water draws for all pipe sections.

Hot water delivery efficiency and water waste also depend on the type of end use. For example, showers are much more likely to trigger hot water waiting than faucet draws. Clothes washing machine draws do not involve any hot water waiting. The hot water draw patterns used in CBECC-Res 2019 were derived from information collected at the house water meter. Therefore, they indicate total amount of water consumed by each draw, not how much hot water was delivered to the end use and how much hot water was wasted during structural and behavioral waiting phases. The research team added hot water waiting specifications to each hot water draw event obtained from CBECC-Res 2019.

As indicated previously, CBECC-Res 2019 draw patterns total water use (mixture of cold and hot water) by fixtures. For hot water distribution performance assessment, the research team developed hot water use volume based on fixture characteristics.

Methods and assumptions used to develop waiting specifications and hot water use volumes for each end use type are explained in following sections.

Shower Draws

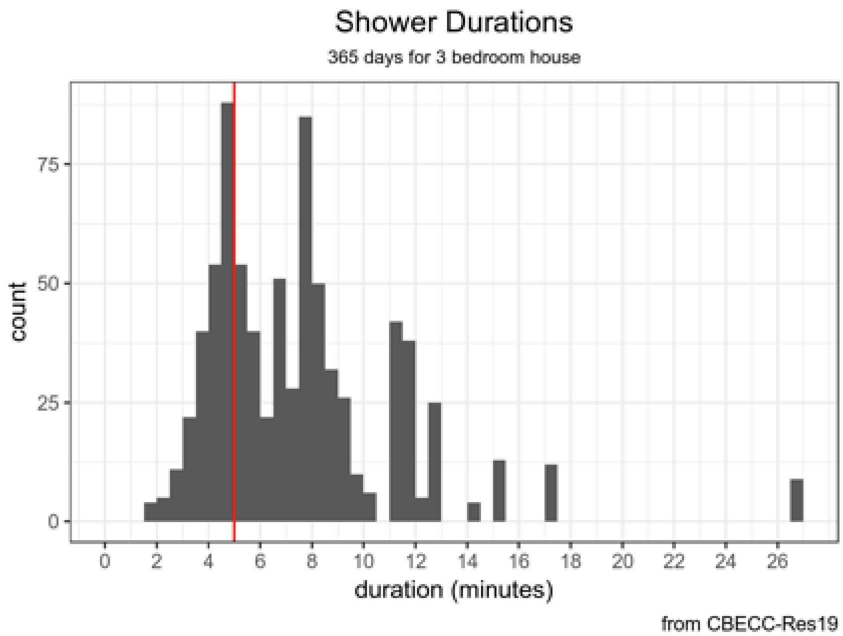
Showers are most likely to involve hot water waiting. A shower event can be considered as two separate draws. The first draw is a clearing draw, or a waiting phase, to get water delivered to the showerhead to a usably temperature. This is the primary water waste in shower events. The second draw is the portion of the event where the user is actually in the shower and showering.[27]

Figure F-1 shows the distribution of shower durations based on CBECC-Res 2019 draw patterns. This shower draw pattern includes the clearing phase so that the water use volume

[27] Jim Lutz, "*In Search of Missing Shower Head Water Savings*." presented at the 6th Biennial Emerging Water Technology Symposium, Ontario, California, May 15, 2018. http://www.iapmo.org/Documents/2018_EWTS/9%20-%20Lutz%20-%20Are%20There%20Savings%20in%20Lower%20GPM%20Showerheads.pdf.

and duration are more than those in the use phase. The team modified the shower data in the CBECC-Res 2019 draw patterns in order to represent only the use portion of the shower events. Showers in the CBECC-Res 2019 draw patterns that are less than 5 minutes long were considered not to include waiting phase and used in the model without modifications. In other words, the entire hot water draw was considered to represent only the use-portion of a shower. Showers in the CBECC-Res 2019 draw patterns with a duration of 5 minutes or greater were considered to include waiting phases. The exact waiting time of these draws are unknow. These draws were shortened by one minute to account for the unknown built-in clearing periods.

Figure F-1: Breakpoint Between Short and Long Showers



Source: CBECC-Res 19

The model calculates the clearing portion of the draw separately from the use. For stand-alone showers (in stalls without a bathtub) the team assumed the flow of only hot water at the showerhead during the clearing draw. Although the maximum showerhead flow rate is 1.8 GPM, the scald prevention valve that mixes hot and cold water requires the simultaneous flow of hot and cold water to properly protect the occupants. This means that there is never 100 percent hot water flowing through the mixing valve. According to conversations with manufacturers, roughly 70 percent of the rated flow rate passes through the valve as hot water. For this study, this means the flow rate during the clearing draw is 1.26 GPM. During the use period of the shower, when both hot and cold water are flowing, the flow rate reverts to 1.8 GPM.

In a tub-shower combination the team assumed that the flow of fully hot water through the tub spout is 4.5 GPM, after which the use portion of the shower begins. As with stand-alone showers, the flow rate during use is 1.8 GPM.

The use period of a shower draw is modeled as the mix of cold and hot water to achieve 105ºF for the duration of the shower. The proportions of hot and cold water depend on the set point of the water heater and the incoming cold-water temperature. The set point of the water heater is 125ºF. The temperature of the incoming cold water varies by climate zone throughout the year. This affects the amount of hot water used and the energy needed to heat it.

If the 105ºF water arrives within 15 seconds (structural waste), the use portion of the draw starts when the hot water arrives. The team has assumed that there is no additional behavioral waste when the structural wait is short. However, if hot water takes longer than 15 seconds to arrive, the clearing draw is extended an additional 45 seconds after the arrival of the hot water. This is to emulate behavioral waste.

Faucet Draws

CBECC-Res 2019 assumes that all faucet draws are half hot water and half cold water. Some faucet draws, for example hand washing dishes at a kitchen sink, will likely contain some clearing draw as described above for showers. However, it is often the case that people will not wait for the hot water to arrive and will use whatever temperature water comes out of the faucet.

The research team assumed that if the faucet draw was longer than 60 seconds and the flow rate was greater than 0.25 GPM, the user actually waited for hot water. In these cases, event duration was shortened by 60 seconds to account for hot water waiting and the remaining portion of the draw was considered as use phase. It was also assumed that faucet draws do not involve behavioral waiting.

Clothes Washer Draws

CBECC-Res 2019 assumes that all clothes washer draws are 22% hot water and the remainder is cold water. This is a simplification of the actual hot water use of modern clothes washers. Only some of the draws use hot water. Other draws, such as some of the rinse draws, are likely to use only cold water. It was assumed that faucet draws do not involve any waiting.

Dishwasher Draws

Dishwashers are plumbed only to hot water so 100% of the use is hot water. Dishwasher draws do not have wait phases.

Bathtub Draws

The amount of total water drawn for baths in the CBECC-Res 2019 is based a final water temperature of 105ºF. The bath draws are modeled as the mix of cold and hot water to achieve 105ºF at the average flow rate reported in the draw pattern.

However, cold water comes out of the hot water piping until hot water arrives. To model this effect, bath draws are separated into two parts, a clearing draw and a filling draw, similar to the manner shower events are treated. The clearing draw is only water from the hot water pipe until the average temperature of all the water drawn in the clearing draw is 105 ºF. At that point the mix of hot and cold water is adjusted to continue delivering 105 ºF until the total bath draw volume is reached. The flow rate for both the clearing draw and the filling draw will be constant at the average flow rate reported in the draw pattern.

There are actually two types of bathtub draws: one for stand-alone bathtubs and the other for combination tub/shower valves. Stand-alone bathtubs generally have separate valves for the hot and the cold water. The rated flow rate for each of these valves is often 5-10 gpm. However, since these valves are fixed orifice devices, the actual flow rate is dependent on the available pressure. Combination tub/shower valves are thermally protected in the same manner as stand-alone shower valves. The rated flow rate of the tub spout portion of the device is often 4-6 gpm. However, since the tub spout is a fixed orifice device the actual flow rate is dependent on the available pressure. In addition, due to the protection features in the valve, the hot only flow rate is roughly 70 percent of the rated flow.

This may not be how people actually draw water for baths, but it seems like a reasonable way to model bath draws for evaluating different hot water distribution systems. As with shower draws, the clearing draws for baths will vary depending on the configuration of the hot water distribution system.

Draw Schedule for Performance Assessment

Table F-1 presents the daily hot water draw, developed by adjusting a daily hot water draw schedule used by CEBEC-Res, for distribution performance assessment. Each draw event is presented as a row of data in the table. Fields of draw schedules are explained below along with a description of the source of the values.

Start Time

This is the date and time of the start of the use portion of the hot water draw.

Fixture ID

The Fixture ID is an abbreviation of the location and fixture. The Fixture IDs used in this analysis are shown in Table F-1.

The types of draws identified in the CBECC-Res draw patterns were used. The location of each draw was assigned based on research team's judgment. The choice of Sink 1 or Sink 2 in the Master Bathroom and Bathroom 2 were also assigned. There is no shower in Bathroom 3. The bath events were all assigned to the combination shower/tub in Bathroom 2. These assignments were kept the same for all cases. The fixtures in each wet room were not changed between the standard and compact design.

Bathroom 2 has a combination tub/shower. B2_SH represents the showers assigned to that combination tub/shower. B2_TB is for baths assigned there. The reference day, Day 4 in Table F-1 does not have any baths. Likewise, no baths were assigned to the tub in the Master Bathroom, MB_TB.

Wait for Hot Water?

This is set to 'Yes' for all showers and baths. It is also set to 'Yes' for faucet draws with flow rates greater than 0.25 GPM and use durations lasting more than 60 seconds. For all other draws this value is 'No'.

Include Behavior Wait?

Behavior wait is when someone engages in some other behavior after turning on the water for the shower, instead of waiting at the shower for the water to get hot. This is 'Yes' for showers.

Behavior Wait Trigger (second)

If hot water takes more time from when the user turns on the water than the behavior wait trigger, then the behavior wait will be added to the wait time. This only applies to showers. The behavior wait trigger is set to 15 seconds for this analysis.

Table F-1: Fixture IDs

Fixture ID	Location	Fixture
MB_SH	Master Bathroom	Shower
MB_SK1	Master Bathroom	Sink 1
MB_SK2	Master Bathroom	Sink 2
MB_TB	Master Bathroom	Bath
K_SK	Kitchen	Sink
K_DW	Kitchen	Dishwasher
LN_WA	Laundry Room	Clothes Washer
B2_SH	Bathroom 2	Shower
B2_SK1	Bathroom 2	Sink 1
B2_SK2	Bathroom 2	Sink 2
B2_TB	Bathroom 2	Bath
B3_SK	Bathroom 3	Sink

Source: Gary Klein and Associates

Behavior Wait (second)

If the behavior wait trigger is exceeded, then start of the shower is delayed past the arrival of hot enough water. The behavior wait is the amount time the past the arrival of hot enough water. The behavior wait is set to 45 seconds. This assumption is used to capture the key aspect of the large variation in user behavior.

Use Time (second)

This is the amount of time hot water is being used during the draw. It is the duration of the draws in the CBECC-Res draw pattern except for some shower and faucet draws.

For showers 5 minutes or shorter, the use time is the total duration of the event in the CBECC-Res. If the shower is longer than 5 minutes, then the total duration is reduced by 1 minute.

Faucet draws longer than 1 minute and flow rates over 0.25 GPM are shortened by 1 minute. This is to provide a reasonable approximation of use times for faucet draws where the user waited for hot water, instead of using whatever temperature water was available.

Flow Rate - Waiting (Gallon per Minute - GPM)

Flow rate while waiting is the flow rate of hot water only prior to use. This flow rate is used during the wait period for showers, baths, and long faucet draws. The waiting flow rate depends on the fixture.

For showers assigned to a combination tub/shower the flow rate while waiting is set to 2.8 GPM. This represents a tub spout being used to bring hot water to the fixture quickly. The shower only waiting flow rate is less than the maximum allowable flow rate for showers. This is due to anti-scald requirements. When turned full hot, 30% of the flow must still come from the cold-water line.

The flow rate is larger for kitchen sink faucets than for lavatory sink faucets. The waiting flow rates are shown in Table F-2.

Table F-2: Waiting Flow Rates

Fixture	Location	Flow Rate (GPM)
Shower	Shower/tub combo (Bathroom 2)	2.8
Shower	Shower only (Master Bathroom)	1.26
Faucet	Kitchen	1.8
Faucet	Lavatory (any Bathroom)	1.2

Source: Gary Klein and Associates

Flow Rate - Use (GPM)

This is the flow rate of the mixed temperature at the fixture during use. It is the flow rate used in the CBECC-Res draw patterns, except where the value is greater than that allowed in Title 20. The mixed flow rate of the combination tub/shower valve was set to 4 gpm. The mixed flow rate for showers was set to the maximum allowed by California standards, or 1.8 gpm. This is due to the universal use of pressure-compensating showerheads and shower valves that allow the user to change the mix of hot and cold water but not the flow rate of their shower. Table F-3 shows the daily hot water use pattern analyzed by this project.

Table F-3: Daily Hot Water Draw Schedule for Performance Assessment

Index	Start Time	Fixture ID	Use Duration (sec)	Wait for Hot Water?	Include Behavior Wait?	Flow rate - use (GPM)
1	12:09:00 AM	MB_SK1	19.98	No	No	1.2
2	5:55:12 AM	MB_SK2	10.02	No	No	0.317
3	7:54:36 AM	MB_SK1	10.02	No	No	0.317
4	8:26:24 AM	MB_SK1	40.02	Yes	No	0.962
5	8:31:48 AM	MB_SH	390	Yes	Yes	1.8
6	8:45:36 AM	MB_SK1	10.02	No	No	0.543
7	8:48:36 AM	MB_SK1	19.98	No	No	0.362
8	8:55:12 AM	B2_SK1	10.02	No	No	0.815
9	8:55:48 AM	B2_SK1	10.02	No	No	0.86
10	8:57:36 AM	B2_SH	250.02	Yes	Yes	1.8
11	8:58:48 AM	B2_SK1	10.02	No	No	1.2
12	9:04:48 AM	B2_SK1	10.02	No	No	1.2
13	11:58:48 AM	K_SK	10.02	No	No	0.317
14	4:10:48 PM	B2_SK2	10.02	No	No	0.407
15	4:43:12 PM	B2_SK2	40.02	Yes	No	0.872
16	4:46:12 PM	B2_SK2	40.02	Yes	No	0.872
17	5:53:24 PM	K_SK	19.98	No	No	0.566
18	5:54:00 PM	K_SK	30	No	No	0.74

Index	Start Time	Fixture ID	Use Duration (sec)	Wait for Hot Water?	Include Behavior Wait?	Flow rate - use (GPM)
19	5:55:12 PM	K_SK	40.02	Yes	No	1.075
20	5:56:24 PM	K_SK	10.02	No	No	0.407
21	5:58:12 PM	K_SK	10.02	No	No	0.407
22	6:01:12 PM	K_SK	10.02	No	No	0.453
23	6:01:48 PM	K_SK	60	Yes	No	1.162
24	6:04:12 PM	K_SK	30	No	No	1.026
25	6:05:24 PM	K_SK	30	No	No	0.423
26	6:12:00 PM	K_SK	19.98	No	No	0.838
27	6:12:36 PM	K_SK	10.02	No	No	0.543
28	6:13:48 PM	K_SK	10.02	No	No	0.407
29	6:14:24 PM	K_SK	60	Yes	No	0.815
30	6:15:36 PM	K_SK	10.02	No	No	0.407
31	6:16:12 PM	K_SK	10.02	No	No	1.268
32	6:17:24 PM	K_SK	30	No	No	1.207
33	6:20:24 PM	K_SK	30	No	No	0.981
34	6:23:24 PM	K_SK	49.98	Yes	No	1.195
35	6:42:36 PM	K_SK	30	No	No	1.026
36	6:43:48 PM	K_SK	19.98	No	No	0.838
37	7:00:36 PM	K_SK	19.98	No	No	1.568
38	7:02:24 PM	K_SK	30	No	No	1.072
39	7:07:48 PM	K_SK	10.02	No	No	0.407
40	7:16:48 PM	K_SK	10.02	No	No	0.407
41	7:45:00 PM	MB_SK1	30	No	No	1.2
42	7:51:36 PM	MB_SK1	40.02	Yes	No	0.838
43	7:52:12 PM	B2_SK1	10.02	No	No	0.543
44	7:54:00 PM	B2_SK1	49.98	Yes	No	0.58
45	7:55:48 PM	MB_SK1	30	No	No	0.74
46	7:56:24 PM	MB_SK1	30	No	No	1.072
47	7:57:00 PM	B2_SK1	30	No	No	0.543
48	7:58:12 PM	B2_SK1	19.98	No	No	0.838
49	7:58:48 PM	MB_SK1	19.98	No	No	0.634
50	8:00:00 PM	MB_SK1	19.98	No	No	0.973
51	8:00:36 PM	B2_SK1	30	No	No	0.83
52	8:01:12 PM	B2_SK1	19.98	No	No	0.521
53	8:03:00 PM	MB_SK1	10.02	No	No	0.407
54	8:03:36 PM	MB_SK1	10.02	No	No	0.407
55	8:04:48 PM	B2_SK1	19.98	No	No	0.702
56	8:05:24 PM	B2_SK1	10.02	No	No	0.64
57	8:10:48 PM	MB_SK2	19.98	No	No	0.702
58	8:11:24 PM	MB_SK2	30	No	No	0.423

Index	Start Time	Fixture ID	Use Duration (sec)	Wait for Hot Water?	Include Behavior Wait?	Flow rate - use (GPM)
59	8:15:00 PM	LN_WA	220.02	No	No	1.298
60	8:21:36 PM	MB_SK2	10.02	No	No	0.407
61	8:30:36 PM	LN_WA	109.98	No	No	1.337
62	8:38:24 PM	LN_WA	210	No	No	1.334
63	8:48:00 PM	LN_WA	30	No	No	0.794
64	8:48:36 PM	LN_WA	30	No	No	0.749
65	8:49:48 PM	MB_SK2	10.02	No	No	0.498
66	9:10:12 PM	B2_SK1	19.98	No	No	0.838
67	9:11:24 PM	B2_SK1	19.98	No	No	0.634
68	9:34:12 PM	B3_SK	19.98	No	No	1.2
69	9:37:12 PM	B2_SK1	10.02	No	No	1.2
70	9:37:12 PM	B3_SK	19.98	No	No	0.973
71	9:46:12 PM	B2_SK1	10.02	No	No	0.407
72	10:10:48 PM	B2_SK2	10.02	No	No	0.996
73	10:12:36 PM	MB_SK2	19.98	No	No	0.702
74	11:43:12 PM	MB_SK1	10.02	No	No	0.317
75	11:52:48 PM	B2_SK1	10.02	No	No	0.679
76	11:53:24 PM	B2_SK1	10.02	No	No	0.543
77	11:54:00 PM	MB_SK1	10.02	No	No	1.2

Source: Gary Klein and Associates

APPENDIX G: ADDITIONAL INFORMATION ON THE DISTRIBUTION PERFORMANCE MODEL

Performance Assessment Tool Input and Output Parameters

The performance assessment tool is implemented using Excel. The Excel tool takes input of a distribution system design and hot water draw schedules and provide output of performance analysis.

Hot Water Draw Schedule Input

Each draw event is presented as a row of data in the spreadsheet tool. The same set of draw schedule is applied to all distribution design cases. Fields of draw schedules are explained below along with a description of the source of the values.

Day

This is the number of the daily hot water draw pattern being used.

Event Index

Every draw is given a sequential index number. This is used internally in the model.

Start Time

This is the date and time of the start of the use portion of the hot water draw.

Fixture ID

The Fixture ID is an abbreviation of the location and fixture. The Fixture IDs used in this analysis are shown in Table F-1 in Appendix F..

Wait for Hot Water?

This is set to 'Yes' for all showers and baths. It is also set to 'Yes' for faucet draws with flow rates greater than 0.25 GPM and use durations lasting more than 60 seconds. For all other draws this value is 'No'.

Include Behavior Wait?

Behavior wait is when someone engages in some other behavior after turning on the water for the shower, instead of waiting at the shower for the water to get hot. This is 'Yes' for showers.

Behavior Wait Trigger (second)

If hot water takes more time from when the user turns on the water than the behavior wait trigger, then the behavior wait will be added to the wait time. This only applies to showers. The behavior wait trigger is set to 15 seconds for this analysis.

Behavior wait (second)

If the behavior wait trigger is exceeded, then start of the shower is delayed past the arrival of hot enough water. The behavior wait is the amount time the past the arrival of hot enough water. The behavior wait is set to 45 seconds. This assumption is used to capture the key aspect of the large variation in user behavior.

Use time (second)

This is the amount of time hot water is being used during the draw. It is the duration of the draws in the CBECC-Res draw pattern except for some shower and faucet draws.

Flow rate - waiting (Gallon per Minute - GPM)

Flow rate while waiting is the flow rate of hot water only prior to use. This flow rate is used during the wait period for showers, baths, and long faucet draws. The waiting flow rate depends on the fixture.

Flow rate - use (GPM)

This is the flow rate of the mixed temperature at the fixture during use. It is the flow rate used in the CBECC-Res draw patterns, except where the value is greater than that allowed in Title 20. The mixed flow rate of the combination tub/shower valve was set to 4 gpm. The mixed flow rate for showers was set to the maximum allowed by California standards, or 1.8 gpm. This is due to the universal use of pressure-compensating showerheads and shower valves that allow the user to change the mix of hot and cold water but not the flow rate of their shower.

Hot Water Temp (F)

The hot water temperature is set to 125 ^{o}F for this analysis. This is the temperature of the water entering the hot water distribution system at the water heater.

Threshold Temp (F)

The threshold temperature is the temperature of water that is hot enough to use. It is used to determine when the use phase begins in showers and long faucet draws. It is also the final temperature of baths. For this analysis it is set at 105 ^{o}F.

Ambient Temp (F)

Ambient temperature refers to the air temperature surrounding the pipes in the house. A constant temperature of 70^{o}F is used here.

Cold water Temp (F)

The cold-water temperature is set to 70^{o}F. It is the temperature of the cold water entering the fixture. The mix of cold and hot water is adjusted for shower, long faucet, and bath uses.

Model 0utput

The outputs and intermediate calculation results from the model are listed below along with an explanation of each. As with the inputs, there is one row of output data for each draw in the draw pattern. The different aspects of performance are used to group the outputs: time, energy, water, and service. Fixture_ID is used to summarize the outputs for an entire day. The daily outputs are described in the section following this one.

Time Calculations and Outputs

The following intermediate calculation results outputs are related to time and duration.

End Time

This is the time the use portion of the draw is completed. For draws with waiting periods, this can vary due to the plumbing configuration and the time since prior draws.

Event duration (Min)

This is the total duration of the event in minutes.

Event duration (Sec)

This is the total duration of the event in seconds.

Structural Waiting (Sec)

This is the duration of the structural waiting of the draw. This is the time it takes for the water to reach the threshold temperature.

Behavior Waiting (Sec)

This is the duration of the behavioral waiting on showers, if it occurred.

Total Waiting (Sec)

This is the sum of the structural and behavioral waiting.

Use Duration (Sec)

This is the duration of the use portion of the draw.

Time Efficiency %

This is the ratio of Use Duration to Event Duration as a percent. For draws with no waiting, the Time Efficiency is 100%. This is the case for short faucet draws as well as clothes washers, dishwashers and baths

Flow Path volume (gal)

This is the volume in the hot water distribution system from the water heater to the fixture along the path to the fixture. It is calculated as the sum of the length of the pipe segments multiplied by the inside pipe diameter expressed in gallons.

Time to clear flow path volume (second)

The time to clear the flow path volume is the length of time for a volume of water equal to the flow path volume to arrive at the fixture during the draw.

Wait increase - structural only (%)

The structural wait increase is the ratio of the structural waiting to the time to clear flow path volume. This ratio can be smaller than 100% if hot water at a temperature above the threshold temperature is already nearby in the flow path to the fixture from a previous draw, either on the same fixture or other upstream fixtures.

Wait increase - include behavior (%)

This wait increase is the ratio of the total waiting to the time to clear flow path volume. As with the structural wait increase, this can be a percentage less than 100, if water above the threshold temperature is nearby.

Energy Calculations and Outputs

The following outputs are the result of the energy calculations. The energy referred to here is the thermal energy in the hot water distribution. The energy input to the water heater(s) is not included.

HW Supply Energy (Btu)

This is the thermal energy content of the water provided to the hot water distribution system at the water heater for the entire draw. Both the use and waiting periods are included in this amount.

HW Energy To fixture – used

This is the thermal energy content of the water delivered to the fixture during only the use portion of the draw.

HW Energy To fixture – wasted

This is the thermal energy content of the water delivered by the fixture during the waste portion of the draw. It is calculated from the temperature of delivered mixed hot and cold water.

HW Energy Stored in Water

This is the thermal energy content of the water in the flow path at the end of the draw.

HW Energy Stored in Pipe and Insulation

This is the thermal energy content of the pipe material and pipe insulation along the flow path at the end of the draw.

HW Energy Lost to Ambient - during use

This is the thermal energy lost to ambient during the use portion of the draw.

HW Energy Lost to Ambient – cool down

This is the thermal energy lost from the water and insulation to ambient room air. This occurs after each draw.

Recirc Loop Pipe Heat Loss (Btu)

This is the thermal energy lost from the water, pipe and insulation to ambient room air due to the operation of the circulation pump. It includes the supply and return portions of the circulation loop

Energy Efficiency %

This is the ratio of the thermal energy content of the water delivered to the fixture during use to the total energy content of the hot water supplied by the water heater during the draw.

Service Provided Calculations and Outputs

The next parameters are used to calculate the service provided during the draw. The theoretical service and service provided during use are expressed in BTUs.

Theoretical HW Demand (Btu)

The theoretical hot water demand is the thermal energy content of the actual delivered hot water during the use periods, assuming that there are no losses in the hot water distribution system. In the model, it is the energy content the delivered hot water would contain if it had been delivered at 125 ^{o}F to each fixture and appliance. It implies an "ideal" hot water distribution system.

HW Demand During Use (Btu)

This is the service provided, in terms of Btu of hot water at the fixture. For showers, long faucet draws and baths, hot water energy use at the fixture matches the theoretical hot water demand. For short faucet draws, clothes washers and dishwashers, this is the thermal energy content of the actual delivered water during the use period.

Load Not Met (Btu)

For uses that begin only after the threshold temperature has been reached, showers, long faucet draws, and baths all the demand is met. The demand not met for those draws is zero. For draws that begin before the threshold temperature has been met, the demand not met is the theoretical hot water demand minus the thermal energy content of the water delivered to the fixture during the use portion of the draw.

Service Efficiency

This is the ratio of the service provided at the fixture to the theoretical service implied by the users behavior. It is expressed as a percentage.

Water Calculations and Outputs

The next four parameters are for the water performance of the fixture during the draw. They are analogous to the energy-related parameters.

Water Volume Supplied (Gallon)

This is the total water volume supplied to the fixture during the draw. This includes both the hot and cold water.

Water Volume Used (Gallon)

This is the total water volume supplied to the fixture during the use portion of the draw. This includes both the hot and cold water.

Water Volume Wasted (Gallon)

This is the difference between the water volume supplied and the water volume used.

Water Efficiency %

This is the ratio of the water volume used to the water volume supplied expressed as a percentage.

APPENDIX H:
Detailed Modeling Results

The four tables in this appendix display the results of the performance modeling conducted during the research project.

Table H-1: Distributed Wet-Rooms, Normal Flow Rates

Pipe Layout Method	Water Heater Location	Pipe Size	Energy into HWDS (BTU)	Water into HWDS (gallons)	Time Water is Flowing (seconds)	Load not Met (BTU)
	Ideal	Reference	11529	25.2	2700	0
Trunk & Branch	Garage, top left corner	Normal	15100	33.0	3055	2440
Trunk & Branch	Garage, top right corner	Normal	14708	32.2	3022	2382
Trunk & Branch	Near master bathroom	Normal	14925	32.7	2973	2042
Trunk & Branch	Near kitchen	Normal	14671	32.1	2960	1890
Trunk & Branch	Garage, bottom left (far) corner	Normal	15312	33.5	3075	2540
Hybrid (Mini-Manifold)	Garage, top left corner	Normal	15251	33.4	3077	2492
Hybrid (Mini-Manifold)	Garage, top right corner	Normal	14867	32.5	3045	2478
Hybrid (Mini-Manifold)	Near master bathroom	Normal	15257	33.4	3004	2250
Hybrid (Mini-Manifold)	Near kitchen	Normal	15676	34.3	3057	2001
Hybrid (Mini-Manifold)	Garage, bottom left (far) corner	Normal	15450	33.8	3096	2608
Central Manifold	Garage, top left corner	Normal	15203	33.3	3064	2726
Central Manifold	Garage, top right corner	Normal	16043	35.1	3094	2525
Central Manifold	Near master bathroom	Normal	15441	33.8	3022	2555
Central Manifold	Near kitchen	Normal	13926	30.5	2938	2140
Central Manifold	Garage, bottom left (far) corner	Normal	16939	37.1	3192	2914
Two Heaters	Garage, top left corner / near master bathroom	Normal	13181	28.8	2846	2344
Two Heaters	Near 2nd bathroom / near master bathroom	Normal	12950	28.3	2830	2026
One Zone	Garage, top left corner	Normal	15597	34.1	3113	2277
One Zone	Near master bathroom	Normal	16275	35.6	3087	2065
One Zone	Garage, bottom left (far) corner	Normal	16174	35.4	3178	2530
Trunk & Branch	Garage, top left corner	Use 3/8" pipe	15022	32.9	3047	2357
Hybrid (Mini-Manifold)	Garage, top left corner	Use 3/8" pipe	14840	32.5	3037	2343
Central Manifold	Garage, top left corner	Use 3/8" pipe	13862	30.3	2934	2527
Two Heaters	Garage, top left corner / near master bathroom	Use 3/8" pipe	13039	28.5	2833	2257
One Zone	Garage, top left corner	Use 3/8" pipe	15497	33.9	3102	2185
Trunk & Branch	Garage, top left corner	No 1" pipe	14533	31.8	2997	2360
Hybrid (Mini-Manifold)	Garage, top left corner	No 1" pipe	14656	32.1	3016	2426
Central Manifold	Garage, top left corner	No 1" pipe	15036	32.9	3046	2632
Two Heaters	Garage, top left corner / near master bathroom	No 1" pipe	0	0.0	0	0
One Zone	Garage, top left corner	No 1" pipe	14686	32.1	3021	2195
Trunk & Branch	Garage, top left corner	Use 3/8" pipe & no 1" pipe	14451	31.6	2989	2290
Hybrid (Mini-Manifold)	Garage, top left corner	Use 3/8" pipe & no 1" pipe	14278	31.2	2980	2265
Central Manifold	Garage, top left corner	Use 3/8" pipe & no 1" pipe	13711	30.0	2918	2448
Two Heaters	Garage, top left corner / near master bathroom	Use 3/8" pipe & no 1" pipe	0	0.0	0	0
One Zone	Garage, top left corner	Use 3/8" pipe & no 1" pipe	14618	32.0	3014	2116

Source: Gary Klein and Associates

Table H-2: Compact Wet-Rooms, Normal Flow Rates

Pipe Layout Method	Water Heater Location	Pipe Size	Energy into HWDS (BTU)	Water into HWDS (gallons)	Time Water is Flowing (seconds)	Load not Met (BTU)
	Ideal	Reference	11529	25.2	2700	0
Trunk & Branch	Away from fixtures (Garage, top left corner)	Normal	15032	32.9	3055	2159
Trunk & Branch	Near fixtures (In laundry room)	Normal	13495	29.5	2898	1737
Hybrid (Mini-Manifold)	Away from fixtures (Garage, top left corner)	Normal	15648	34.2	3114	2458
Hybrid (Mini-Manifold)	Near fixtures (In laundry room)	Normal	13706	30.0	2918	2004
Central Manifold	Away from fixtures (Garage, top left corner)	Normal	14832	32.5	3025	2682
Central Manifold	Near fixtures (In laundry room)	Normal	13457	29.4	2888	2126
One Zone	Away from fixtures (Garage, top left corner)	Normal	15372	33.6	3085	2513
One Zone	Near fixtures (In laundry room)	Normal	14953	32.7	2986	1523
Trunk & Branch	Away from fixtures (Garage, top left corner)	Use 3/8" pipe	14939	32.7	3046	2081
Trunk & Branch	Near fixtures (In laundry room)	Use 3/8" pipe	12966	28.4	2843	1697
Hybrid (Mini-Manifold)	Away from fixtures (Garage, top left corner)	Use 3/8" pipe	15412	33.7	3093	2301
Hybrid (Mini-Manifold)	Near fixtures (In laundry room)	Use 3/8" pipe	13064	28.6	2854	1900
Central Manifold	Away from fixtures (Garage, top left corner)	Use 3/8" pipe	13679	29.9	2914	2482
Central Manifold	Near fixtures (In laundry room)	Use 3/8" pipe	12453	27.2	2790	1907
One Zone	Away from fixtures (Garage, top left corner)	Use 3/8" pipe	15285	33.4	3075	2389
One Zone	Near fixtures (In laundry room)	Use 3/8" pipe	14876	32.5	2978	1432
Trunk & Branch	Away from fixtures (Garage, top left corner)	No 1" pipe	14516	31.8	2999	2075
Trunk & Branch	Near fixtures (In laundry room)	No 1" pipe	13227	28.9	2872	1658
Hybrid (Mini-Manifold)	Away from fixtures (Garage, top left corner)	No 1" pipe	15034	32.9	3049	2326
Hybrid (Mini-Manifold)	Near fixtures (In laundry room)	No 1" pipe	13549	29.6	2900	1954
Central Manifold	Away from fixtures (Garage, top left corner)	No 1" pipe	14689	32.1	3010	2579
Central Manifold	Near fixtures (In laundry room)	No 1" pipe	13369	29.2	2879	2042
One Zone	Away from fixtures (Garage, top left corner)	No 1" pipe	14213	31.1	2967	2384
One Zone	Near fixtures (In laundry room)	No 1" pipe	14782	32.3	2967	1490
Trunk & Branch	Away from fixtures (Garage, top left corner)	Use 3/8" pipe & no 1" pipe	14431	31.6	2990	2000
Trunk & Branch	Near fixtures (In laundry room)	Use 3/8" pipe & no 1" pipe	12729	27.8	2820	1598
Hybrid (Mini-Manifold)	Away from fixtures (Garage, top left corner)	Use 3/8" pipe & no 1" pipe	14826	32.4	3030	2170
Hybrid (Mini-Manifold)	Near fixtures (In laundry room)	Use 3/8" pipe & no 1" pipe	13010	28.5	2842	1814
Central Manifold	Away from fixtures (Garage, top left corner)	Use 3/8" pipe & no 1" pipe	13525	29.6	2899	2387
Central Manifold	Near fixtures (In laundry room)	Use 3/8" pipe & no 1" pipe	12363	27.0	2781	1862
One Zone	Away from fixtures (Garage, top left corner)	Use 3/8" pipe & no 1" pipe	14117	30.9	2957	2272
One Zone	Near fixtures (In laundry room)	Use 3/8" pipe & no 1" pipe	14690	32.1	2957	1405

Source: Gary Klein and Associates

Table H-3: Distributed Wet-Rooms, Low Flow Rates

Pipe Layout Method	Water Heater Location	Pipe Size	Energy into HWDS (BTU)	Water into HWDS (gallons)	Time Water is Flowing (seconds)	Load not Met (BTU)
	Ideal	**Reference**	**11529**	**25.2**	**2700**	**0**
Trunk & Branch	Garage, top left corner	Normal	13253	29.0	3058	2095
Trunk & Branch	Garage, top right corner	Normal	12831	28.1	3022	2032
Trunk & Branch	Near master bathroom	Normal	13106	28.7	2980	1660
Trunk & Branch	Near kitchen	Normal	12826	28.1	2964	1452
Trunk & Branch	Garage, bottom left (far) corner	Normal	13485	29.5	3081	2184
Hybrid (Mini-Manifold)	Garage, top left corner	Normal	13395	29.3	3079	2129
Hybrid (Mini-Manifold)	Garage, top right corner	Normal	12989	28.4	3045	2116
Hybrid (Mini-Manifold)	Near master bathroom	Normal	13450	29.4	3012	1872
Hybrid (Mini-Manifold)	Near kitchen	Normal	13825	30.2	3061	1611
Hybrid (Mini-Manifold)	Garage, bottom left (far) corner	Normal	13621	29.8	3101	2233
Central Manifold	Garage, top left corner	Normal	13347	29.2	3066	2214
Central Manifold	Garage, top right corner	Normal	14203	31.1	3098	2020
Central Manifold	Near master bathroom	Normal	13637	29.8	3030	2111
Central Manifold	Near kitchen	Normal	12123	26.5	2946	1672
Central Manifold	Garage, bottom left (far) corner	Normal	15062	33.0	3192	2413
Two Heaters	Garage, top left corner / near master bathroom	Normal	11378	24.9	2854	1989
Two Heaters	Near 2nd bathroom / near master bathroom	Normal	11120	24.3	2835	1646
One Zone	Garage, top left corner	Normal	13848	30.3	3127	1968
One Zone	Near master bathroom	Normal	14463	31.6	3094	1762
One Zone	Garage, bottom left (far) corner	Normal	14306	31.3	3178	2193
Trunk & Branch	Garage, top left corner	Use 3/8" pipe	13178	28.8	3051	2062
Hybrid (Mini-Manifold)	Garage, top left corner	Use 3/8" pipe	13006	28.5	3042	2011
Central Manifold	Garage, top left corner	Use 3/8" pipe	12043	26.3	2940	2015
Two Heaters	Garage, top left corner / near master bathroom	Use 3/8" pipe	11277	24.7	2844	1932
One Zone	Garage, top left corner	Use 3/8" pipe	13765	30.1	3119	1915
Trunk & Branch	Garage, top left corner	No 1" pipe	12691	27.8	3001	1992
Hybrid (Mini-Manifold)	Garage, top left corner	No 1" pipe	12811	28.0	3020	2041
Central Manifold	Garage, top left corner	No 1" pipe	13246	29.0	3056	2137
Two Heaters	Garage, top left corner / near master bathroom	No 1" pipe	0	0.0	0	0
One Zone	Garage, top left corner	No 1" pipe	12858	28.1	3027	1873
Trunk & Branch	Garage, top left corner	Use 3/8" pipe & no 1" pipe	12608	27.6	2993	1961
Hybrid (Mini-Manifold)	Garage, top left corner	Use 3/8" pipe & no 1" pipe	12435	27.2	2984	1911
Central Manifold	Garage, top left corner	Use 3/8" pipe & no 1" pipe	11905	26.0	2926	1960
Two Heaters	Garage, top left corner / near master bathroom	Use 3/8" pipe & no 1" pipe	0	0.0	0	0
One Zone	Garage, top left corner	Use 3/8" pipe & no 1" pipe	12790	28.0	3019	1842

Source: Gary Klein and Associates

Table H-4: Compact Wet-Rooms, Low Flow Rates

Pipe Layout Method	Water Heater Location	Pipe Size	Energy into HWDS (BTU)	Water into HWDS (gallons)	Time Water is Flowing (seconds)	Load not Met (BTU)
	Ideal	Reference	11529	25.2	2700	0
Trunk & Branch	Away from fixtures (Garage, top left corner)	Normal	13210	28.9	3061	1877
Trunk & Branch	Near fixtures (In laundry room)	Normal	11689	25.6	2906	1378
Hybrid (Mini-Manifold)	Away from fixtures (Garage, top left corner)	Normal	13827	30.3	3120	2121
Hybrid (Mini-Manifold)	Near fixtures (In laundry room)	Normal	11887	26.0	2924	1625
Central Manifold	Away from fixtures (Garage, top left corner)	Normal	13000	28.4	3030	2183
Central Manifold	Near fixtures (In laundry room)	Normal	11650	25.5	2896	1717
One Zone	Away from fixtures (Garage, top left corner)	Normal	13510	29.6	3086	2272
One Zone	Near fixtures (In laundry room)	Normal	13151	28.8	2994	1255
Trunk & Branch	Away from fixtures (Garage, top left corner)	Use 3/8" pipe	13114	28.7	3052	1812
Trunk & Branch	Near fixtures (In laundry room)	Use 3/8" pipe	11162	24.4	2851	1365
Hybrid (Mini-Manifold)	Away from fixtures (Garage, top left corner)	Use 3/8" pipe	13589	29.7	3099	2020
Hybrid (Mini-Manifold)	Near fixtures (In laundry room)	Use 3/8" pipe	11244	24.6	2860	1572
Central Manifold	Away from fixtures (Garage, top left corner)	Use 3/8" pipe	11869	26.0	2922	1992
Central Manifold	Near fixtures (In laundry room)	Use 3/8" pipe	10622	23.2	2796	1574
One Zone	Away from fixtures (Garage, top left corner)	Use 3/8" pipe	13418	29.4	3076	2182
One Zone	Near fixtures (In laundry room)	Use 3/8" pipe	13061	28.6	2985	1179
Trunk & Branch	Away from fixtures (Garage, top left corner)	No 1" pipe	12702	27.8	3006	1735
Trunk & Branch	Near fixtures (In laundry room)	No 1" pipe	11445	25.0	2882	1304
Hybrid (Mini-Manifold)	Away from fixtures (Garage, top left corner)	No 1" pipe	13209	28.9	3055	1980
Hybrid (Mini-Manifold)	Near fixtures (In laundry room)	No 1" pipe	11726	25.7	2907	1587
Central Manifold	Away from fixtures (Garage, top left corner)	No 1" pipe	12888	28.2	3019	2107
Central Manifold	Near fixtures (In laundry room)	No 1" pipe	11549	25.3	2885	1644
One Zone	Away from fixtures (Garage, top left corner)	No 1" pipe	12356	27.0	2969	2125
One Zone	Near fixtures (In laundry room)	No 1" pipe	12988	28.4	2976	1198
Trunk & Branch	Away from fixtures (Garage, top left corner)	Use 3/8" pipe & no 1" pipe	12622	27.6	2998	1662
Trunk & Branch	Near fixtures (In laundry room)	Use 3/8" pipe & no 1" pipe	11020	24.1	2835	1304
Hybrid (Mini-Manifold)	Away from fixtures (Garage, top left corner)	Use 3/8" pipe & no 1" pipe	13002	28.4	3036	1862
Hybrid (Mini-Manifold)	Near fixtures (In laundry room)	Use 3/8" pipe & no 1" pipe	11182	24.5	2847	1502
Central Manifold	Away from fixtures (Garage, top left corner)	Use 3/8" pipe & no 1" pipe	11714	25.6	2906	1937
Central Manifold	Near fixtures (In laundry room)	Use 3/8" pipe & no 1" pipe	10529	23.0	2786	1532
One Zone	Away from fixtures (Garage, top left corner)	Use 3/8" pipe & no 1" pipe	12262	26.8	2959	2016
One Zone	Near fixtures (In laundry room)	Use 3/8" pipe & no 1" pipe	12903	28.2	2967	1112

APPENDIX I: Technology/Knowledge Transfer Report

1. Introduction

The purpose of this research project was to investigate ways to significantly improve domestic hot water system energy and water efficiency. The research analyzed the feasibility of a variety of practical solutions to improve hot water distribution systems by assessing the performance of these designs with a variety of flow rates. The team wanted to understand the interactions of low flow rates and pipe size. Recommendations have been made to the Energy Commission based on what was learned, including future code changes related to hot water distribution systems.

It is critical to share the knowledge gained during this research project with a wide variety and number of people and organizations. These groups include builders, building system designers, plumbing engineers and installers, researchers, energy efficiency practitioners, building officers, building code developers, Energy Commission staff in charge of codes and standards development – both Title-20 and Title-24, and representatives of other government agencies.

Section 2 describes the plan for technology/knowledge transfer and Section 3 presents examples of the outreach undertaken by the project team to date, and plans for activities after the contract is complete.

2. Methods for Transferring Knowledge Gained During this Project

Public and key decision-makers were informed of the knowledge gained, experimental results, and lessons learned in multiple ways. This chapter provides the overview of these activities.

Technical Advisory Committee

The project team formed a Technical Advisory Committee (TAC) that included representatives from all relevant areas, including builders, building system designers, plumbing engineers and installers, researchers, energy efficiency practitioners, building officers, building code developers, Energy Commission staff in charge of codes and standards development – both Title-20 Appliance Efficiency Regulations and Title-24 Building Energy Efficiency Standards, and representatives of other government agencies.

The TAC meetings were held in late August and late September 2018. The TAC members were asked to review and comment on project reports. In addition, some members were asked to assist with specific aspects of the research based on their particular expertise.

Industry and Consumer Outreach

The project team sought input from a wide range of industry practitioners to assess market barriers to high-performance design practices. These practitioners included builders, building system designers, plumbing engineers and installers, researchers, energy efficiency practitioners, building officers, building code developers, Energy Commission staff in charge of codes and standards development – both Title-20 and Title-24, and representatives of other government agencies. This was done through personal communications and through conducting informal sessions at various conferences and meetings. Team members shared how to implement the knowledge gained from the research through courses and presentations made at relevant industry associations in California. Where appropriate, the project team submitted papers for publication in peer-reviewed and industry journals. It is likely that, if selected for publication, this will happen after the project is completed.

Why would these groups of practitioners be willing to assist us? Here are a few examples. Builders are interested in reducing the costs of construction. Plumbing engineers would like to design systems based on current and future flow rates. Energy Commission staff would like to include provisions that improve the energy efficiency of hot water systems into future revisions to the Building Energy Efficiency Standards.

Conferences

The project team participated in conferences both as organizers and presenters to inform the audiences about the knowledge gained from the research and to obtain feedback from them on any concerns they had. When the project began in June 2017, several conferences had already been identified. These included the 2017 ASHRAE Summer meeting, the 2018 ASHRAE Winter Meeting, the 2018 ASHRAE Summer meeting, the 2018 ACEEE Hot Water Forum, and the 2018 Emerging Water Technology Symposium. Other conference opportunities have come up since that time and are documented in Chapter 3.

Regulatory Activities

One of the key audiences for the results of this project is the Energy Commission and Title 20 and 24. Energy Commission staff will be invited to participate in the TAC. In the fall of 2018 the project team briefed staff in the Building Efficiency Division about how to incorporate the findings of this project into the Building Energy Efficiency Standards (Title 24).

Other regulatory activities included participation in the development of the 2021 International Plumbing Code (IPC) and the 2021 International Energy Conservation Code (IECC) and the 2021 Uniform Plumbing Code (UPC).

The International Code Council (ICC) develops the IPC and the IECC. The ICC is a member-focused association with over 64,000 members. It is dedicated to developing model codes and standards used in the design, build and compliance process to construct safe, sustainable, affordable and resilient structures. I-Codes®, published by ICC, provide minimum safeguards for people at home, at school and in the workplace. These codes are developed on a 3-year revision cycle. The current cycle is for 2021.

The International Association of Plumbing and Mechanical Officials (IAPMO) has been protecting the public's health and safety for ninety years by working in concert with government and industry to implement comprehensive plumbing and mechanical systems around the world. IAPMO uses an open consensus process to develop the Uniform Plumbing Code® and Uniform Mechanical Code®. These codes are established through scientific research, debate, and analysis, strengthening our position at the forefront of the plumbing and mechanical industries. The Uniform Plumbing Code forms the basis of the California Plumbing Code.

3. Outreach During Project and Beyond

Industry and Consumer Outreach

1. Mr. Klein met with Shawn Oram, Director of Engineering and Design, Ecotope, Inc. in Seattle September 5, 2017. We discussed the implications of their research on multi-family hot water systems to the Energy Commission research project. In particular, their concept of reducing the overall heat transfer coefficient (UA) of the hot water distribution system is very applicable. This involves reducing the length of the piping, reducing the diameter and insulating like crazy. Their minimum specification is 2-inch wall thickness for all hot water piping, compared to the California Plumbing Code requirements that the wall thickness be at least equal to the nominal diameter of the pipe for all diameters up to 2 inch pipe.
2. Mr. Klein met with Plumbing Manufacturers Institute research committee (Matt Sigler, CJ Lagan, John Finch) with Paul Sturman at the Biofilm Research Center at Montana State university in Bozeman, Montana September 6-8, 2017. We discussed how research that PMI is doing with the Biofilm Research Center and what we are doing for the Energy Commission are complementary and how we should be able to learn from each other's findings. Water borne pathogens live in the biofilms found in the supply piping, both hot and cold. They are trying to find the critical velocities that cause biofilms to slough off the piping. If the biofilm can be removed at a velocity that does not significantly increase the pressure drop, it would be another way to improve the health and safety of the building water supply system. It may also allow for selecting smaller diameters of piping than currently allowed in the plumbing codes when the pipe size is better matched with the flow rate of the plumbing fixtures or appliances it is connected to.
3. Mr. Klein met with Alexis Karolides and her team with Point Energy in San Francisco, CA, December 6, 2017 to share ideas on house floor plans with the water heater and the wet rooms located such that there would be a very compact hot water distribution system. They are one of the firms working on the rebuilding effort after the fires north of San Francisco. They also do a great deal of design work on multi-family applications with central water heating systems.
4. Mr. Klein participated in discussions with the Rebuilding Green Coalition to help them incorporate the concepts of very compact hot water distribution systems into their outreach events in Sonoma and Napa planned for the 1st quarter of 2018.
5. Mr. Klein and Mary Ann Dickinson (TAC member) served on the first Water Jury at the Solar Decathlon, Denver, CO, October 8-11, 2017. Our team judged all of the homes based on their water efficient designs and features, including the efficiency of the hot water system. We had the opportunity to talk with each student group and share with them the importance of getting the plumbing right in highly water and energy efficient dwellings. Suffice it to say that there is still a great deal of room for improvement.
6. Mr. Klein gave a presentation on "How Low Can We Go?" for the American Society of Plumbing Engineers (ASPE) and the International Association of Plumbing and Mechanical Officials (IAPMO) Sacramento Chapters October 12, 2017.
7. Mr. Klein gave a presentation during the CBIA Countdown to 2020 event held on October 17, 2017 in Sacramento CA. Klein's presentation discussed the best ways to

design the dwelling to reduce the distance between the water heater and the plumbing fixtures and appliances. He used the conference room as a dwelling and volunteers as fixtures to demonstrate the principles involved. Danny Tam (TAC member) and others from the Energy Commission shared the best ways to meet the goals of the latest Building Energy Efficiency Standards.

8. Mr. Klein gave a presentation on "How Low Can We Go?" for the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) Sacramento Chapter October 25, 2017.
9. Mr. Klein participated in the Rebuild Green Expo held in Sonoma County on February 23, 2018. He gave two talks on how to design new homes to be most (hot) water efficient and moderated a talk on selecting efficient water heaters and drain water heat recovery devices.
10. Mr. Klein gave a half-day session in Sonoma CA June 1, 2018 titled "Water, Energy and Time Efficient Hot Water Systems for New Homes". Pacific Gas and Electric Company sponsored the session as part of their response to the 2017 Sonoma fires. The purpose of the 5-part series was to help people rebuild their homes in the most efficient manner possible.
11. Mr. Klein and Mr. Lutz participated in a workshop sponsored by the National Institute of Standards and Technology (NIST) held August 1-2, 2018 in Gaithersburg MD. The workshop was about the Measurement Science Needs for Water Use Efficiency and Water Quality in Premise Plumbing Systems. Team members contributed to workshop planning, recommendations for participants, defining priorities, and identifying future research topics. Synthesis of the workshop, organized by the National Institute of Standards and Technology, the U.S. Environmental Protection Agency, and the Water Research Foundation is contained in Measurement Science Roadmap Workshop for Water Use Efficiency and Water Quality in Premise Plumbing Systems August 1-2, 2018.

Conferences

1. Mr. Klein and Mr. Lutz attended the ASHRAE Summer meeting in Long Beach CA June 24-28, 2017. We participated in SPC 90.1, SPC 118.1, SPC 118.2, SPC 124, SPC 189.1, and SPC 191 committee meetings. Prior to the ASHRAE meeting, we held a half-day session at the Southern California Gas Company's Energy Resource Center in Downey CA for members of the 90.1 committee to demonstrate the issues related to lowering flow rate and pipe diameter. We explored flow rates and pressure drop in 0.5 inch and smaller diameter piping.
2. Mr. Klein gave two presentations to the Texas Society of Architects during their 78th Annual Convention and Design Expo in Austin, TX November 9-11, 2017. One presentation was titled "Water Use Efficiency in High-Performance Buildings" held in a 3-hour early bird workshop. The other presentation was titled "Hot Water Systems in High-Performance Buildings" held as part of the main conference. We discussed the principles of our research project in both sessions, although we went into much more depth during the hot water session.
3. Mr. Klein gave a presentation to the 2017 Plumbing Manufacturers International Conference held in Sonoma, CA November 13-16, 2017. Presentation was titled "How Low Can We Go; How Close Can We get?" Met with John Koeller, one of the members

of the research team and with Mary Ann Dickinson (Alliance for Water Efficiency and California Water Efficiency Partnership), Matt Sigler (Plumbing Manufacturers Institute) and Pete DeMarco (IAPMO), three members of the TAC.

4. Mr. Klein and Mr. Lutz attended the ASHRAE Winter meeting in Chicago, January 19-24. Attended SPC 90.1, SPC 118.1, SPC 118.2, SPC 124, SPC 189.1, and SPC 191 committee meetings. Gave two presentations on hot water systems one titled "Best Practices in Residential Hot Water System Design" in AHR Expo Session 5 "Keeping Occupants Happy and Healthy Through Affordable and Flexible Air and Water Control Strategies" and the other titled "How Low Can You Go? How Close Can You Get?" in Seminar 65 "It's Not Just the Water Heater Anymore" on January 24. 2018.
5. Mr. Klein and Mr. Lutz are on the planning committee of the ACEEE Hot Water Forum held in Portland OR from March 19-23. Mr. Lutz organized panels on "Verification and Validation of Hot Water System Simulations", "Designing Hot Water Distribution, Delivery, and Plumbing Systems", "Legionella and Other Microorganisms", and "Do We Need Hot Water for Handwashing?" Mr. Lutz gave a presentation titled "Are There Savings in Lower GPM Showerheads?" Mr. Klein organized the two demonstration days held in conjunction with the Hot Water Forum for conference attendees and local plumbers at the UA 290 training center in Tualatin, OR. He also gave a presentation titled "How Low Can We Go; How Close Can We Get: A Summary of Water Energy Research for the California Energy Commission". We also held informal discussions with many of the participants in order to share what we are learning from the research and to get their insights on the project.
    - Jim Lutz: https://aceee.org/sites/default/files/pdf/conferences/hwf/2018/1b-lutz.pdf
    - Jim Lutz, https://aceee.org/sites/default/files/pdf/conferences/hwf/2018/2c-lutz.pdf
6. At the 2018 Emerging Water Technology Symposium May 15-16, 2018 in Ontario CA Jim Lutz gave a presentation on "In Search of Missing Shower Head Water Savings" and Gary Klein gave a presentation on " What You Don't Know You Don't Know About (Hot) Water". We also held informal discussions with Mary Ann Dickinson, Matt Sigler, Pete DeMarco and Billy Smith (TAC members) as well as many of the participants in order to share what we are learning from the research and to get their insights on the project.
    - Jim Lutz, http://www.iapmo.org/Documents/2018_EWTS/9%20-%20Lutz%20-%20Are%20There%20Savings%20in%20Lower%20GPM%20Showerheads.pdf
    - Gary Klein, http://www.iapmo.org/Documents/2018_EWTS/8%20-%20Klein%20-%20What%20You%20Dont%20Know%20You%20Don%27t%20Know%20About%20(Hot)%20Water.pdf
7. Jim Lutz presented a description of the "Code Changes and Implications of Residential Low Flow Hot Water Fixtures" project and some initial findings at the Summer 2018 Zero Net Energy Zero Carbon Retreat in Arcata CA July 26-28, 2018.
8. Mr. Klein participated in the Plumbing Innovation and Opportunities Meeting held at Purdue University on December 10, 2018. The meeting was held to discuss progress on one of two EPA funded research projects looking into the safety of public water

supplies: https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/10736/report/0?_ga=2.249036357.351450447.1564609801-942365114.1564609801

9. Mr. Klein gave a presentation — Analysis of Architectural Compactness — at the 2019 Dry Climate Forum held in Yosemite, February 11-13, 2019.
10. Mr. Klein gave a presentation — How Low Can We Go; How Close Can We Get? — at the 2019 RESNET Conference held in New Orleans, LA, February 25-27, 2019.
11. Mr. Klein, Mr. Lutz, and Mr. Zhang gave a presentation — How Low Can We Go; How Close Can We Get? — at the 2019 ACEEE Hot Water Forum held in Atlanta, GA, March 12-13, 2019.
12. Mr. Klein gave a half-day workshop — Good Design Lowers Cost: The Case for Plumbing & Mechanical Cores — at the 2019 North American Passive House Network (NAPHN) Conference held in New York, NY, June 26-28, 2019.
13. Mr. Klein is scheduled to make a presentation at the American Society of Plumbing Engineers (ASPE) Technical Symposium to be held in Pittsburgh, PA, October 25-27, 2019.
14. Mr. Klein is scheduled to make a presentation at the 2019 Plumbing Manufacturers Institute (PMI) to be held at St. Pete Beach, FL, November 5-7, 2019.
15. Members of the team will propose talks at conferences to be held in 2020 as appropriate.

Regulatory Activities

1. Mr. Klein worked with Tim Keane, a colleague from New Jersey to submit code change proposals to the International Plumbing Code in January 2018. These code changes were discussed by the Development Committee in April 2018 and will be voted on at the Annual Meeting in October 2018. The code changes were on the theme of how low can we go related to hand washing in public restrooms. According the Center for Disease Control (CDC) and others, the temperature of the water does not affect the efficacy of hand washing; scrubbing for at least 10 seconds and using regular soap does. Proposals included changing the break point between hot and tempered water and enabling the use of water below 80F for hand washing,
2. Mr. Klein submitted code change proposals for the 2021 Uniform Plumbing Code. He participated in the code hearing in May 2018. He plans to attend the hearing in September 2018. A key result of the May hearing was that IAPMO formed a task group to develop a more thorough version of one of the key proposals related to flow rates, scalding and pathogen risk. Mr. Klein is one of the members of that task group. The task group worked through the fall of 2018 to resolve issues. The resulting language was submitted for review by the UPC Development Committee, which approved the modified proposal in the Spring of 2019. IAPMO members will vote on the proposal at their September 2019 meeting.
3. Mr. Klein reviewed and provided comments on the 45-day language for the 2019 Building Energy Efficiency Standard, Docket No. 17-BSTD-02 TN#: 222874. He focused his comments, submitted on March 5, 2018 on Sections 110, 120, 150, RA3.6 and RA4.4. All of these sections contain provisions on hot water. The majority of the

comments were related to the internal consistency of the provisions. The complete comments can be found at https://efiling.energy.ca.gov/Lists/DocketLog.aspx?docketnumber=17-BSTD-02

4. Mr. Klein submitted code change proposals for the 2021 International Energy Conservation Code (IECC). RE-162 is based on the results of this project. It gives credit for architectural compactness: http://media.iccsafe.org/code-development/group-b/2019-Group-B-CAH-compressed.pdf This proposal was approved at the development hearing in April 2019. It will be voted on by the ICC membership in October 2019.
5. Mr. Klein, Mr. Lutz, and Mr. Zhang plan to be involved in the 2022 Building Energy Efficiency Standards Proceeding.

Photos

Figure I-1: John Koeller presenting at the 2017 PMI Conference

Source: Plumbing Manufacturers International (PMI)

Figure I-2: Gary Klein Presenting at the 2017 PMI Conference

Source: International Association of Plumbing and Mechanical Officials (IAPMO)

Figure I-3: Jim Lutz Presenting at the 2018 EWTS

Source: International Association of Plumbing and Mechanical Officials (IAPMO)

Figure I-4: PG&E Class at the North Coast Builders Exchange in Sonoma, CA

Source: Bill Burke, Pacific Gas and Electric Company