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WATER HEATING DESIGN GUIDE

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PREPARED BY:

Primary Author(s):
Marc Hoeschele
Elizabeth Weitzel

Douglas Kosar
Paul Glanville
Hillary Vadnal

Davis Energy Group
123 C Street
Davis, CA 95616
Phone: 530-753-1100
www.davisenergy.com

Gas Technology Institute
1700 South Mount Prospect Road
Des Plaines, IL 60018
Phone: 847-768-0500
www.gastechnology.org

Contract Number: 500-08-060

Prepared for:

California Energy Commission

Bradley Meister, Ph.D., P.E.
Contract Manager

Virginia Lew
Office Manager
Energy Efficiency Research Office

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Robert P. Oglesby
Executive Director

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PREFACE

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- Renewable Energy Technologies
- Transportation

Water Heating Design Guide is an interim report, prepared by Davis Energy Group in conjunction with the Gas Technology Institute, for the Residential Water Heating Program project contract number 500-08-060. The information from this project contributes to Energy Research and Development Division's Buildings End-Use Energy Efficiency Program.

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ABSTRACT

Water heating is the single most significant residential end use for natural gas in California. Natural gas is used to heat water in nearly 90 percent of homes statewide and represents 49 percent of the average 354 therms of annual California household consumption per the 2009 Residential Appliance Saturation Survey. The 12.3 million California households that use natural gas water heaters could see their annual natural gas water heating consumption drop by 35 percent while increasing water efficiency and homeowner satisfaction by implementing improved design procedures and high efficiency equipment options.

A systems approach to building and water heating design is needed to achieve this goal. Basic building design is the starting point as it defines the physical relationship between potential water heater locations and hot water use points. Minimizing the distance from the water heater is a key goal in reducing distribution system waste and hot water waiting times. Selecting low-flow fixtures and appliances that provide superior customer satisfaction is the second step in improving system performance and efficiency. Installing a compact distribution system is critical to maximizing the advantages associated with intelligent home design. Piping systems are frequently inefficiently installed with oversized pipes that contribute to added waste and subpar delivery performance. Many new water heating technologies have entered the market, so it is important to select a water heater that offers high efficiency and low operating costs. Educating homeowners about their hot water system will allow them to operate the system efficiently and reliably for many years.

This design guide was developed to capture the best available information in these areas based on research carried out in this project as well as other recent efforts. The goal of the design guide is to advance the state of knowledge and to document current best practices.

Keywords: water heating, hot water distribution, models, field tests, lab evaluations, codes, standards, best practices.

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EXECUTIVE SUMMARY

Introduction

Industry design guides can be useful for conveying critical design information in an understandable format to builders, architects, and subcontractors. Residential water heating system design issues have largely been overlooked for several reasons including the lack of quantitative knowledge on how to compare and contrast distribution system performance and the lack of performance and efficiency differentiation among alternative water heater types. In recent years the availability of advanced water heating options has increased and there has been a growing understanding of distribution system performance impacts. A residential water heating design guide will be a useful component of the Gas Technology Institute's Residential Water Heating Program conducted for the California Energy Commission.

Project Purpose

The concept of a residential water heating "system" begins and ends with the water heater itself for many users. In California homes this appliance often sits in the corner of a garage and is generally neglected until the unit fails. Owner interaction during normal operation may go no further than occasional water heater setpoint adjustments to ensure that sufficient hot water is available.

The overall performance of the water heating system depends on the following primary factors:

- Building design as it impacts water heater and use point locations.
- Use points and usage characteristics.
- Distribution system including type, pipe materials, pipe length and diameter, pipe location and insulation.
- Water heater type, capacity, and efficiency.
- Climate, which affects hot water loads, cold water temperatures, and pipe loss.
- Occupants' hot water use.

The goal of this design guide was to assemble California-specific information to the extent possible in each of these areas to develop an improved understanding of current practices and performance implications, and to determine how a systems approach to water heating could be developed. Water heating research is ongoing among many organizations and individuals throughout the country, and new findings will advance the understanding and processes in the years ahead. This document was designed to convey the latest research information to allow the industry to develop better techniques in delivering high-performance residential hot water systems.

The Gas Technology Institute (GTI) project team included: Davis Energy Group (with subcontractors RASENT Solutions, Lutzenhiser Associates, and Amaro Construction);

Lawrence Berkeley National Laboratory (LBNL); Applied Energy Technology (AET); Pacific Gas & Electric's Applied Technology Services (ATS); Affiliated International Management (AIM); and GreenPlumbers® USA. Key stakeholders who participated as part of the Project Advisory Committee (PAC) included: Pacific Gas & Electric (PG&E) and Sempra Energy (Southern California Gas Company) staff; representatives from major water heater manufacturers AO Smith, Bradford White, Rheem, Rinnai, Noritz, and Navien,; Harvey Sachs of the American Council for an Energy Efficient Economy (ACEEE); Chris Brown of the California Urban Water Conservation Council (CUWCC); Craig Selover of the Masco Corporation; Hugo Aguilar of the International Association of Plumbing and Mechanical Officials (IAPMO); Dean Neff of Consol; and Larry Weingarten of Elemental Enterprises.

Project Results

The design guide relied heavily on project activities to inform the guide's content. The project activities that fed into the design guide included distribution and water heater modeling, input to the California 2013 Title 24 Energy Efficiency Standards, laboratory testing, advanced gas water heater field monitoring, new home plumbing surveys, and education and training.

For distribution and water heater modeling the Davis Energy Group (DEG) directed activities to enhance its HWSIM software, which analyzes energy and water use and waste in residential hot water distribution systems. The 2008 HWSIM version utilized a convective "UA" pipe heat loss model. Integrating radiant heat transfer algorithms was an important addition to the model's accuracy. In addition, extensive runs were done to compare simulated pipe heat loss to laboratory results from AET to confirm the validity of the model.

Several of the HWSIM enhancements were necessary preparations for the integration of water heater models into the simulation program. DEG coordinated with LBNL to successfully integrate atmospheric gas storage and tankless type water heater models with HWSIM.

A multi-nodal atmospheric center flue water heater model was integrated with HWSIM. This model was called TANK and was originally developed by Battelle Columbus Laboratories in 1993 for the Gas Research Institute. A single-nodal tankless model was also integrated with HWSIM. This model was called Type 940 and was originally developed for the TRaNsient SYstems Simulation (TRNSYS) software suite. The integration achieved a first-of-its-kind, whole house water heating system analysis tool capable of simulating interactive hot water generation and distribution and the resulting energy and water use and waste. These new modeling capabilities allowed DEG to conduct analyses to support the design guide effort.

Atmospheric gas storage and tankless type water heater models only provided an adequate representation of non-condensing equipment, but much of the advanced technology in the marketplace is now condensing. Although this proved sufficient for establishing best practices for the design guide, it was clear that future "next generation" models were needed to simulate the performance of condensing tank (storage) and tankless types of water heaters, as well as emerging hybrid products combining a tankless water heater with a buffer storage tank to eliminate tankless only performance drawbacks such as increased hot water delivery delays and cold water "sandwiches." In addition, application of modern programming code in these next

generation models was needed to overcome the complexities experienced with HWSIM integration of older, existing water heater models and the excessive simulation runtimes encountered in the resulting integration. LBNL completed initial models in modern Modelica programming language to create a strong starting point for more advanced models of condensing tank (storage) and tankless type water heaters and hybrid water heaters. These initial models were the first step in another longer-term effort to create modern and easily integrated models of entire water heating systems in buildings. This efforts was funded by the Energy Commission and the U.S. Department of Energy (DOE).

DEG provided input to the California 2013 Title 24 Energy Efficiency Standards adopted in mid-2012 along with later recommendations for future changes in the 2016 update over the course of this project. Key changes being implemented in 2013 for single family homes included:

- New mandatory requirements for gas (or propane) water heater installations regarding proper electrical outlet, vent category, and condensate drain features to facilitate the use of high efficiency water heating equipment.
- Pipe insulation requirements on all hot water distribution piping greater than ¾ inch in diameter as well as all piping from the water heater to the kitchen.
- The Point of Use Distribution multiplier now applies to systems with water heaters no more than five feet (of ¾ inch piping) from any point of use (10 feet of ½ inch, or 15 feet of 3/8 inch are acceptable alternatives). This measure required third-party Home Energy Rating System (HERS) field verification. Compact distribution system design has been added as a new compliance option credit. The furthest use point must be field-verified to be within a prescribed distance from the water heater by a HERS rater in order to use this approach.
- Additional optional HERS verification elements have been added to offer credits for verified pipe insulation installation on both recirculating and non-recirculating distribution systems.

The authors recommended two key areas for further study for the 2016 Title 24 revision for single family homes. Field studies in this program and elsewhere suggested that the 2008 Title 24 derating of eight percent (using a 0.92 multiplier) was reasonable for non-condensing tankless units, but appeared to be too little degradation for condensing tankless units. This should be investigated in more detail to determine the need for derating condensing and non-condensing tankless units differently. This may become irrelevant under the revised DOE EF test procedure that may well result in lower energy factor (EF) ratings across the board for tankless water heaters.

The area of distribution systems was a very important area for future research. Distribution system performance is very complicated and depends on a wide range of factors. The field survey of California plumbing layouts completed in this program and earlier suggested that installations were highly variable and dependent to some extent on the configuration of the house. The 2013 revisions attempted to move toward an improved design strategy, but resistance from the building industry eliminated one of the proposed components (limiting the length of one inch or larger piping). Education of the building community and the plumbing

industry is vitally important to improving future design and installation practice related to distribution systems. The value to the builder from improved distribution systems could be significant in terms of reduced cost from less piping, reduced water use, and improved customer satisfaction due to reduced waiting times at remote fixtures. This effect will be magnified with tankless water heaters, where the additional startup time delay compounds any distribution system associated delays. Distribution research in support of Title 24 improvements should include:

- Field data collection of distribution system performance in both new and existing homes. LBNL was leading efforts in the deployment and testing of advanced low-cost wireless sensors that will facilitate this kind of work under another Energy Commission funded project.
- Lab testing of alternative distribution system configurations (typical layouts and "improved" layouts) with realistic draw patterns at various use points. The testing would explore the impacts of different flow rates, hot water and environment temperatures, usage patterns and quantities, and behaviors.
- Validation of advanced distribution modeling tools.
- Completion of a comprehensive modeling study to assess performance of alternative distribution system configurations on different plumbing layouts with varying usage patterns.

Three sets of laboratory tests were completed. The first involved developing more accurate component models in the integrated hot water generation and distribution simulation program (HWSIM with tank and tankless water heaters) with empirical quantification of heat transfer parameters for selected water heaters. The second set of laboratory tests explored performance details of selected water heaters under controlled conditions to help explain phenomena seen in the field evaluations and to help understand feedback from participating homeowners regarding their experiences with advanced storage and tankless water heaters. The third set provided insight into alternative testing procedures (alternative draw profiles, for example) and their impacts on current water heater EF ratings for selected water heaters.

AET generated and analyzed laboratory datasets of hot water distribution piping thermal losses. GTI and PG&E's Applied Technology Services (ATS) lab generated and analyzed laboratory datasets of various performance characteristics of high-efficiency water heaters, with GTI focusing on tankless products and ATS focusing on tank (storage) products. Key findings from the laboratory testing included:

- Updated heat loss values for both ¾ and ½ inch rigid copper proved more consistent with HWSIM piping thermal loss predictions.
- Bundled versus single ½ inch PEX (high density cross-linked polyethylene) piping heat losses were up to 1.67 times higher due to active hot water pipe heat losses to cooler surrounding pipes.
- Storage water heater EFs were relatively unaffected by more distributed 24-hour hot water draw profiles of comparable daily volumes, but decreased daily volumes will decrease EFs due to an increased share of input energy diverted to standby losses.

- The modest gas savings achieved from transitioning from unpowered, minimum 0.62 EF to powered, Energy Star rated 0.67 EF storage water heaters when combined with added parasitic electricity could result in only modest positive, or even negative, net operating cost savings for customers under current energy pricing in California.
- Tankless water heater EFs were lowered when tested under hot water draw profiles with increased numbers of shorter duration draws that were typical of real world operation and increased thermal cycling losses, further supporting the current tankless EF derating assumed in Title 24.
- Compared to tank (storage) water heaters, tankless water heaters exhibit additional time delays to deliver hot water with cold start firing delays averaging three seconds, delays to exiting temperature at setpoint (95 percent of setpoint) up to 20 seconds cumulatively, and delays to stable exiting temperatures (+/- 5 percent of setpoint) averaging up to 36 seconds cumulatively depending on the control strategy.

The field monitoring activities provided detailed hot water usage data and water heater performance data, but the relatively small sample size (18 sites, with 12 in Southern California and six in Northern California) and broad selection of advanced water heaters limited the ability to make broad performance conclusions and observations. More field data were needed to bolster the findings in this report. Researchers made key findings in the areas of hot water demand and efficiency implications, hot water performance and economics, and customer reactions to advanced water heaters.

Key findings related to hot water demand and efficiency implications included:

- The average number of hot water draws was found to be 10 per person per day, ranging from five to 18 draws.
- Hot water consumption averaged 56.4 gallons per day (gpd) over the full monitoring period or 15.6 gpd per person. Household hot water consumption varied widely across the different sites from 21 to 138 gpd with significant day-to-day variations observed at all sites.
- The annual hot water recovery load averaged 27,200 British thermal units (Btu) per day, or about one-third less than assumed in the DOE EF test procedure despite occupancy levels above the national census average household size. This was due to warmer cold water inlet temperatures, lower water heater outlet temperatures, and lower overall hot water consumption. The implications of these lower loads were significant for California, with a 0.06 EF reduction (~10 percent of nominal) in annual performance for a conventional gas storage water heater.

Key findings related to water heater performance and economics included:

- All of the advanced water heaters saved site energy. The most dramatic savings occurred with tankless units, primarily due to the low observed recovery loads.
- Projected annual savings for the EnergyStar™ storage products were under 30 therms per year. Non-condensing and condensing tankless product savings ranged from 45 to 85 therms per year, respectively, and condensing storage product savings ranged from 30 to 60 therms per year.

- Projected simple paybacks for new construction are between nine and 15 years for tankless products, and from 13 to 32 years for storage products in the absence of tax credits and utility incentives. None of the projected simple paybacks were found to be less than 25 years in retrofit scenarios where implementation costs were considerably higher, especially for tankless models. These economic results were discouraging, especially for the retrofit market, and indicated the need for increased production volumes and alternative equipment designs to reduce installed costs. Low California natural gas rates for the foreseeable future and high California electric rates (a second order effect on savings) also contributed to a challenging environment for implementing gas water heater efficiency measures.

In general, participating homeowners who received the advanced water heaters at no cost were satisfied with the units provided to them. The only negative concern expressed by some customers who received a storage water heater replacement was related to increased noise due to combustion air blowers. A few tankless customers had similar concerns related to noise, and also generally noted the well-documented issues related to increased hot water wait times, problems satisfying low-flow rate draws, and occasional cold water sandwich concerns. Positive tankless feedback was received from most respondents in terms of hot water capacity, stable delivery temperatures, compact physical size, and perceived energy savings.

Tankless water heaters influenced hot water usage behavior to some degree. The sites retrofitted with tankless units indicated an increase in average hot water draw volume from 1.40 to 2.09 gallons per draw, which was largely offset by an average 23 percent reduction in the daily number of draws. The net impact was that at four of the six tankless sites there was essentially no change in the hot water recovery load between pre- and post-monitoring. Two of the sites appeared to show higher hot water recovery load after the conversion. Further study was needed to better document this impact.

Researchers made the following recommendations regarding advanced gas water heaters:

- This project tested a sample of the emerging high efficiency products that are now on the market. With only 18 field sites, further study by California utilities was warranted to develop a more robust understanding of performance impacts under different climates and load profiles.
- Evaluating customer satisfaction of these emerging technologies was an important step in directing future activities. Careful tracking of maintenance needs and the associated costs was needed to better define the overall economics of the different technologies.
- The Energy Commission and California utilities should stay abreast of emerging water heater technologies. The costs for many of these products should come down in the years ahead as production volumes increase.
- Evaluate combined hydronic systems as a strategy to improve high efficiency water heater cost effectiveness. These systems offer the advantage of utilizing one high efficiency heat source to provide both space and water heating. New product offerings from several manufacturers were expected in the near term.

- Direct future Title 24 field research toward better quantifying hot water loads, cold water inlet temperatures in various locations statewide, and identifying water heater setpoints at several hundred sites. This data could inform how water heating is modeled within the Title 24 code. The data collected here represented a first step in that process.

Amaro Construction under the direction of DEG surveyed hot water distribution piping installations by 20 different plumbing contractors in 97 new houses under construction, primarily in the greater Sacramento and inland Los Angeles areas. Findings included:

- Flexible polyethylene (PEX) had effectively replaced copper piping as the material of choice since the 2006 survey, largely driven by cost.
- Home-run systems linking dedicated water lines to individual fixtures from a single central manifold adjacent to the water heater were much less common than in 2006. Again, this appeared to be driven by cost. Distributed mini-manifold systems were the predominant system types.
- Average entrained pipe volumes were fairly consistent with the 2006 survey. The average entrained volume to any hot water use point was close to one gallon of water for a typical 2000 square foot house. There was large room for improvement in this regard.
- Installation issues led to significant variability in the installed hot water distribution system. There were many instances when a much more direct path could be followed, but for whatever reason the installer chose not to. The need for training was critical to optimize practices and residential plumbing designs should ultimately be required.
- Builders need to recognize that there is value in good design. Good design begins with locating the water heater as centrally as possible as the first step in minimizing the hot water distribution energy and water waste.

AIM, assisted by IAPMO and GreenPlumbers® USA structured and executed a series of nine utility-hosted training workshops, three each with PG&E, Southern California Gas, and San Diego Gas & Electric. These workshops disseminated the program results to the plumbing trades, homebuilding professionals, and code officials. The full-day workshop consisted primarily of a slide presentation intermixed with interactive exercises. Workshop sessions were conducted in two separate time frames, with three workshops in the Spring of 2012 in San Francisco, Ontario, and San Diego, and six workshops in the Fall of 2012 in San Ramon, Stockton, Ventura, Downey, San Diego, and Los Angeles. Total attendance at the nine workshops was 222, averaging just under 25 per class.

Project Benefits

The benefits of this design guide will be realized as the information is translated to the design and construction community. For the design community, improved home design (compact plumbing core) which can then accommodate better plumbing designs is a critically needed first step. Contractor training is essential for getting the improved designs properly implemented in the field. Current installation practices are not often systematically completed, resulting in circuitous plumbing layouts with PEX piping. Plumbers must be made aware of the importance

of minimizing pipe sizes and pipe run lengths, which can improve performance and actually reduce costs.

In terms of broad statewide goals, the implementation of improved practices and higher efficiency water heating equipment was expected to reduce typical consumption of California residential water heaters by up to 35 percent. With statewide consumption of 2,111 million therms per year, the full technical savings potential is estimated at 739 million therms per year.

CHAPTER 1: Introduction

For most people, the concept of a residential water heating "system", begins and ends with the water heater itself. The appliance, which in California homes often sits in the corner of a garage, is neglected until the unit fails. Owner interaction during normal operation may go no further than occasional water heater setpoint adjustments to insure that sufficient hot water is available. The most critical hot water use in most households is by far the shower, where users demand a reliable, consistent stream of hot water. In reality, the overall performance of the water heating system depends on the following primary factors:

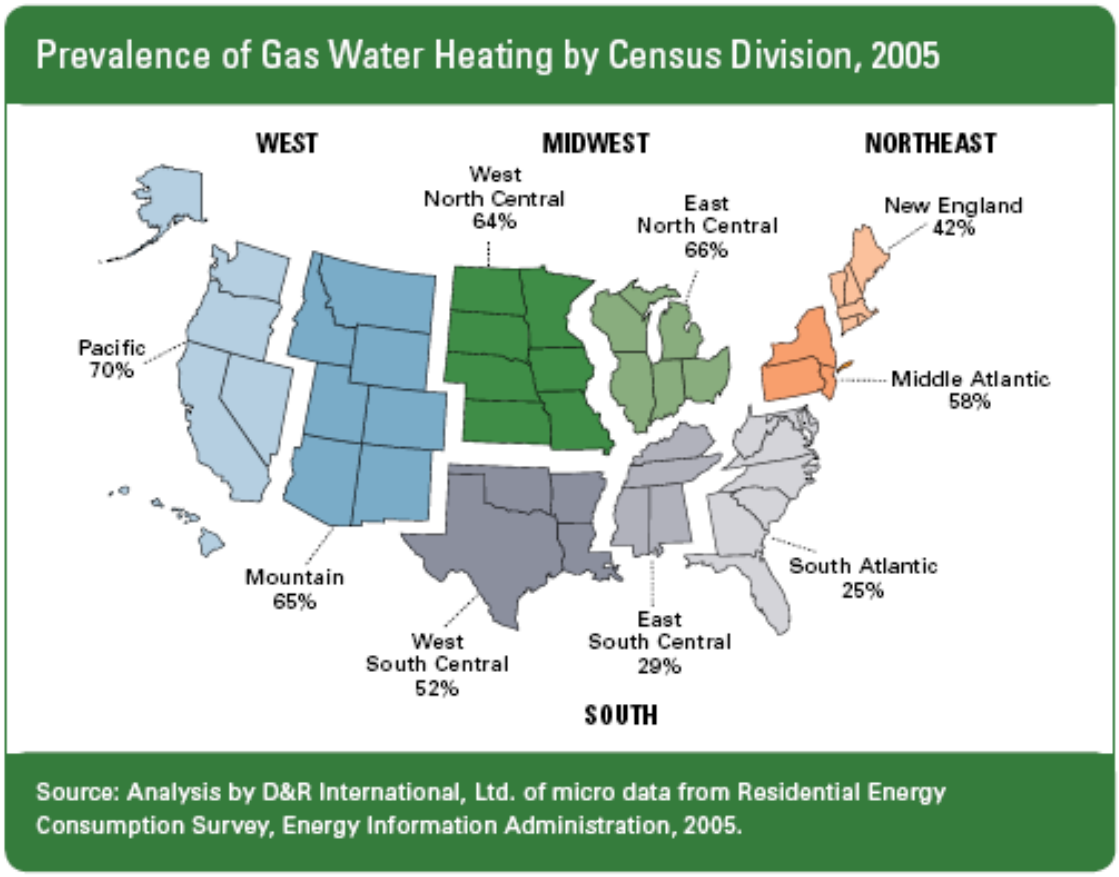
- Building design (as it impacts water heater and use point locations)
- Use points and usage characteristics
- Distribution system (type, pipe materials, pipe length and diameter, pipe location, insulation)
- Water heater (type, capacity, efficiency)
- Climate (affecting hot water loads, cold water temperatures, and pipe loss)
- and of course, the occupants

From this point forward, we will refer to the "system" as the combined sum of these five components. Although it is important to evaluate and understand each of these elements, system performance involves the interactions between all these components.

Realizing that typical household hot water consumption is on the order of 15-20 gallons per person per day (Lutz, 2011), an average family of three would only draw hot water from the water heater for 30-45 minutes a day . Understanding the complexities of hot water system performance involves characterizing the interactions between the building design, the plumbing layout, the climate (both in terms of cold water temperature and pipe heat loss environments), hot water flow quantities and patterns, and water heater type and efficiency.

According to the U.S. Energy Information Administration's 2005 Residential Energy Consumption Survey (RECS), annual residential water heating totals 2.11 quads of energy annually, or 20 percent of the energy delivered to residential buildings . Over the past seventy years, gas and electric storage water heaters have been the predominant water heater type in the United States . Recently, gas tankless water heaters have made inroads in market share with current industry projected gas tankless sales estimated at 400,000+ annually, and an expected higher growth rate than storage water heaters in the years ahead . Additionally, heat pump water heaters (HPWHs) are starting to gain a presence as they offer potential savings of 50 percent or more relative to electric resistance storage water heaters. Figure 1 presents a national perspective on natural gas water heating by region of the country.

Figure 1: National Distribution of Residential Gas Water Heaters



Source: DRI International, 2009. Water Heater Market Profile

For many areas, the lack of natural gas and the availability of inexpensive electricity has resulted in electric water heaters being the predominant water heating system type. In California, with widespread availability of natural gas to the major population centers, roughly 90 percent of households are served by a natural gas water heater. Two other factors also contribute to this trend:

1. The Title 24 Energy Code strongly promotes natural gas as a water heating fuel (vs. electric resistance water heating)
2. Electric rates are generally high (~1/3 higher than national average) relative to natural gas

The primary goal of this design guide is to educate key stakeholders and practitioners on the latest California-specific information focused on delivering high efficiency hot water systems to consumers. The design guide focus is directed primarily towards single dwelling units commonly served by individual water heaters, consistent with the research direction of the

California Energy Commission's sponsorship of the Gas Technology Institute (GTI) Water Heating research project, which funded the development of this design guide.

In 2008, GTI organized a research program of closely linked projects to achieve the California Energy Commissions' goals of reducing residential water heating natural gas consumption in California. The research program was comprised of the following key project activities:

1. Development of integrated hot water generation and distribution system analysis tools;
2. Develop efficient water heating equipment and piping system designs and best practices guide;
3. Water heater standard test method/rating and building/energy code developments;
4. Water heating and venting equipment laboratory evaluations;
5. Water heater field performance monitoring and consumer behavior studies;
6. Deliver advanced water heating system training for the plumbing trades and others.

The findings in this design guide draw heavily from the PIER research project and other California-based studies. The authors realize that the development of this design guide is part of an evolutionary process in integrating new research findings into a document to translate best practice information to the design and construction community. Advancements in modeling tools, lab and field performance evaluations of equipment and distribution systems, and the fundamental knowledge of how hot water is used will all factor into future enhancements of this design guide.

CHAPTER 2:
Water Heating Energy Use and Behavior

Water heating is a very behaviorally driven energy end use. Two identical houses with similar household size, occupant ages, and lifestyle patterns could very well see radically different annual water heating energy usage. Showering, tub, and clothes washer use typically represent the vast majority of hot water use in a home, but other, household characteristics can have a strong influence on overall consumption. For example, kitchen sink use is highly correlated to the level of in-home cooking, and tub use is also much more common with very young or elderly household members. To help foster a better understanding of use behaviors on a larger scale, the GTI Advanced Gas Water Heating project commissioned a survey of how people use hot water. Approximately 500 people (400+in the greater Los Angeles area, with the remainder in the San Francisco Bay Area) completed this survey. Although self-reported findings using this type of online survey process are subject to some level of uncertainty, the findings do provide insights on behavior, which should be beneficial in designing future more quantitative studies. A sampling of some the interesting survey findings include:

Bathroom and Kitchen Sinks

- ~30 percent never use hot water at the kitchen sink; of the remainder, nearly 2/3 let hot water run continuously while washing or rinsing dishes
- Only around one-quarter of respondents waited for hot water to arrive at bathroom or kitchen
- 8 percent typically wait over 1 minute for hot water at kitchen sink; 3 percent over 2 minutes
- Single lever behaviors: ~ ½ the people set bathroom faucets to full hot.
- Slightly more respondents (26 percent) said they "rarely wait" for hot water to arrive for kitchen use than "usually waited" (22 percent). This contrasts to bathroom behavior where 20 percent of respondents "rarely" and 33 percent "usually" waited for the hot water to arrive.

Showers and Tubs

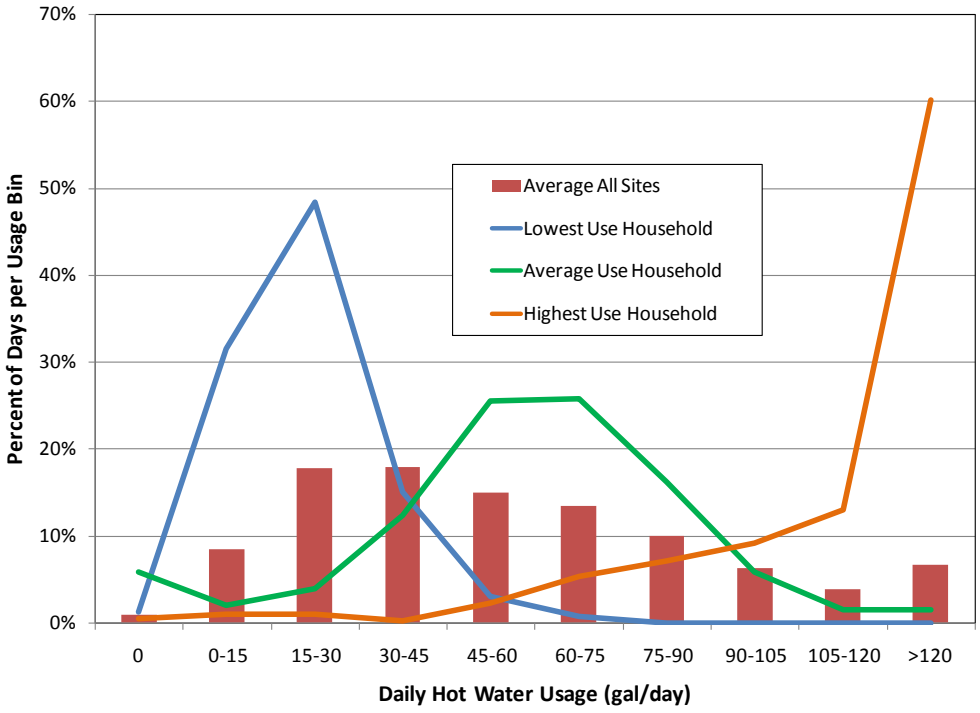
- 23 percent of households had one or more whirlpool or jetted tub, although they were used in only 10 percent of the households.
- On average "per person" shower use was found to be 4.9 showers per week, with an average 8.8 minute duration. Shower length was highly variable. The most common shower length response (1 out of 5) was 8 minutes; the next most common (1 in 10) was 3.5 and 13 (1 in 12).
- Overall, 13 percent of households used both tubs and showers while 87 percent took showers exclusively.

Other Comments

- 62 percent of respondents report that they never run out of hot water with their existing water heater.
- Respondents rarely adjusted or delayed using hot water to avoid fully depleting the tank.
- In estimating their annual hot water expenditures, ~70 percent of respondents had no idea. For the remainder, the average annual estimated cost was ~$340 (or nearly double typical California household costs). More significantly, the standard deviation was an astonishing $685.
- 1/3 of respondents report having a front-loading clothes washer (this is slightly higher than the 25 percent saturation indicated in the 2009 Residential Appliance Saturation Survey).
- At least one-third of all laundry loads were reported to exclusively use cold water.

Figure 2 shows a summary of hot water usage data from the eighteen homes monitored in the PIER field study (average household size of 3.6 occupants). The hot water usage data, monitored over a year long period, was disaggregated into usage bins (e.g. 30-45 gallons per day) to reflect the frequency of daily hot water consumption. The red bars which show that slightly under 20 percent of all days were represented by usage in both the "15-30 gal/day" and the "30-45 gal/day" ranges. The general trend is that as hot water loads increase, the percentage of days represented also decreases. (The exception to this is the "> 120" bin.) Average daily household usage among all sites over the year long period was ~ 57 gal/day. The three colored lines on the graph represent individual households: the blue line (lowest use household), green (average user), and orange (highest use). The average user shows a very symmetrical usage pattern with about ½ the days being represented by hot water loads ranging from 45-75 gal/day. The low use household has a much smaller variation in usage with about ½ the days represented by 15-30 gal/day, and no days >75. The high use household (family of six) averaged nearly 140 gal/day and was found to have 60 percent of days with usage exceeding 120 gal/day. Clearly household variation in hot water use is significant and has implications on overall system performance and the ability of the water heater to satisfy peak events.

Figure 2: Monitored Household Hot Water Usage Variations



The complications of understanding not only hot water load magnitude and pattern, but also user behaviors, for any one given household clearly represents a major challenge in accurately quantifying impacts and assessing improvement opportunities. Developing monitoring-based, California-specific representative hot water usage profiles is a key goal of ongoing research efforts. Jim Lutz of LBNL is leading an effort to collect detailed usage data from monitoring projects across the U.S. To date, not enough California-specific data has been collected to adequately characterize use patterns.

CHAPTER 3:
Components of Hot Water Systems

An optimally designed and performing hot water system will quickly and consistently deliver hot water under varying load and climate conditions, while minimizing energy use and water waste. From the homeowner's perspective, prompt delivery of hot water is the top attribute of a high performance hot water system. It is important to keep in mind that any water heating system can be overwhelmed by the confluence of events that contribute to peak (short duration) hot water demands. Unlike sizing of an air conditioning system for a given outdoor design temperature (which may be exceeded by 5-10 degrees F in any given year), a water heating peak event is much more spiky and random, as evidenced by the nearly 40 percent of people in the hot water behavioral study who indicated that they have, at some point in time, experience sub-standard hot water delivery.

Non-optimal performing water heating systems exhibit some level of performance degradation in the design, installation, and operational efficiency of the key system components. The following sections of the guide focus on the key components: Building Architecture, Hot Water Loads and Use Point Characteristics, Distribution Systems, Water Heaters, and Load Reduction Strategies. To the extent possible, the design guide focuses on California-specific results as identified from the GTI PIER study research findings.

3.1 Building Architecture

The basic building block for a hot water system begins with the design of the house and the relative location of the water heater(s) and hot water use points. The most geometrically simple house design (a circle or square) with the water heater centered in the structure represents the best configuration for a compact plumbing layout with minimized potential for water and energy waste. Deviations from this idealized optimal situation are, of course, to be expected when one builds real houses. However efforts should be taken in the schematic design phase to:

1. Minimize sprawling house designs where use points are distributed throughout the building
2. Logically group bathrooms and hot water use points (both horizontally and vertically) to minimize distance to the water heater
3. Locate the water heater(s) as centrally as practical[1] relative to the use points

These first steps are absolutely critical in providing a favorable starting point leading to the installation of a compact hot water system that can efficiently deliver energy and hot water throughout the house. Figure 3 below shows a reasonably typical two-story floor plan with the

[1] Center of building water heater locations imply potential venting complications which should be evaluated for both feasibility and cost.

water heater located in the far corner of the garage, the kitchen located at the opposite corner, and the master bath on the second floor at another corner. This configuration, not ununsual for typical California new home construction, immediately poses a challenge in the delivery of hot water to the two primary use points: the master bathroom and the kitchen.

Another floor plan, shown in Figure 4, depicts a very different house design. Here the water heater is located on the wall adjacent to the kitchen. Second floor baths and laundry are located immediately above the water heater. This house is off to a much better start in delivering a compact hot water design that should realize significant reductions in energy and water waste relative to the design in Figure 3.

One strategy in achieving a compact design involves use of an indoor mechanical closet. The advantage of this strategy is that both the water heater and the air handler for space conditioning can be centrally located within the structure, minimizing both piping runs and duct runs, and facilitating the installation of ducts within conditioned space. This first cost savings (and operational cost savings) would partially offset the expense of lost indoor floor area. Historically, the California building industry has not embraced this concept due to sacrificing valuable indoor space, but increasing pressures to achieve zero net energy residential designs may cause this to be reevaluated in the near future.

Figure 3: "Common" Production Home House Layout

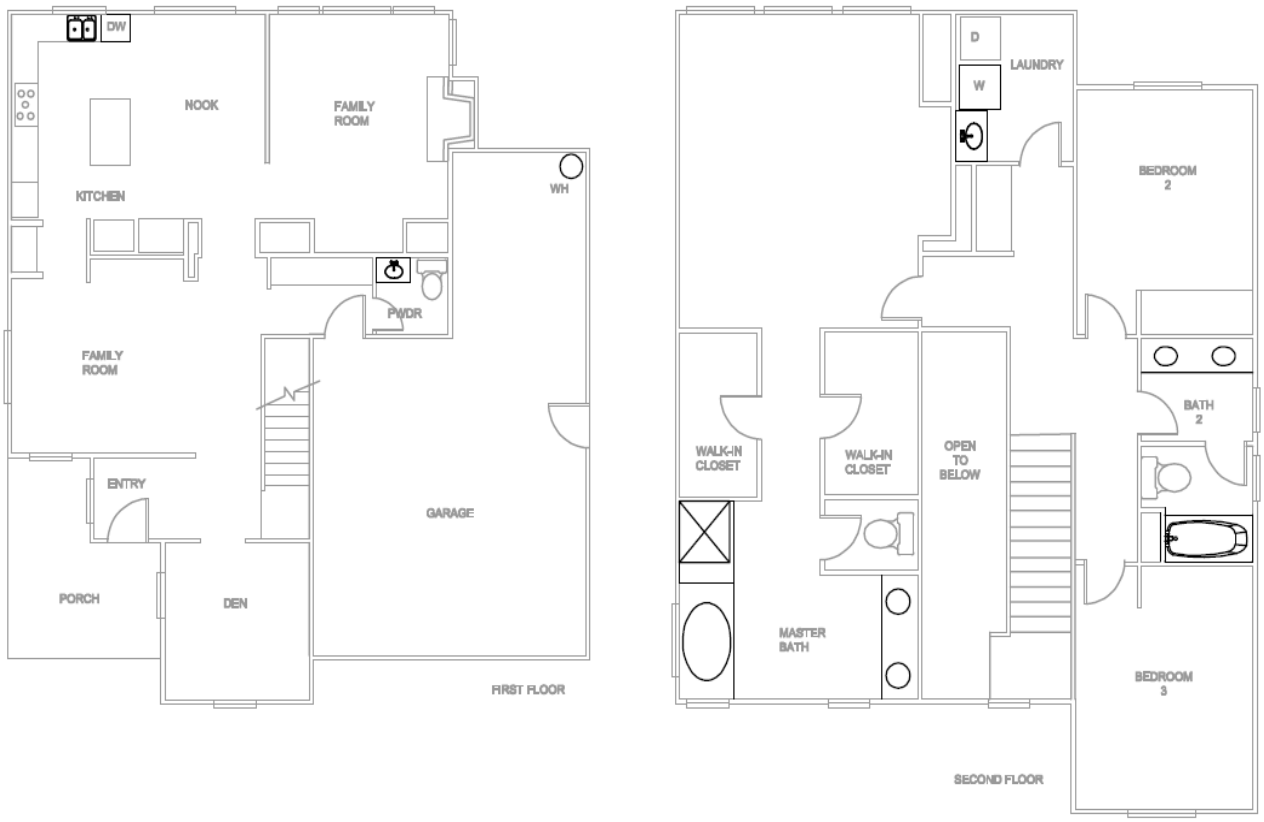
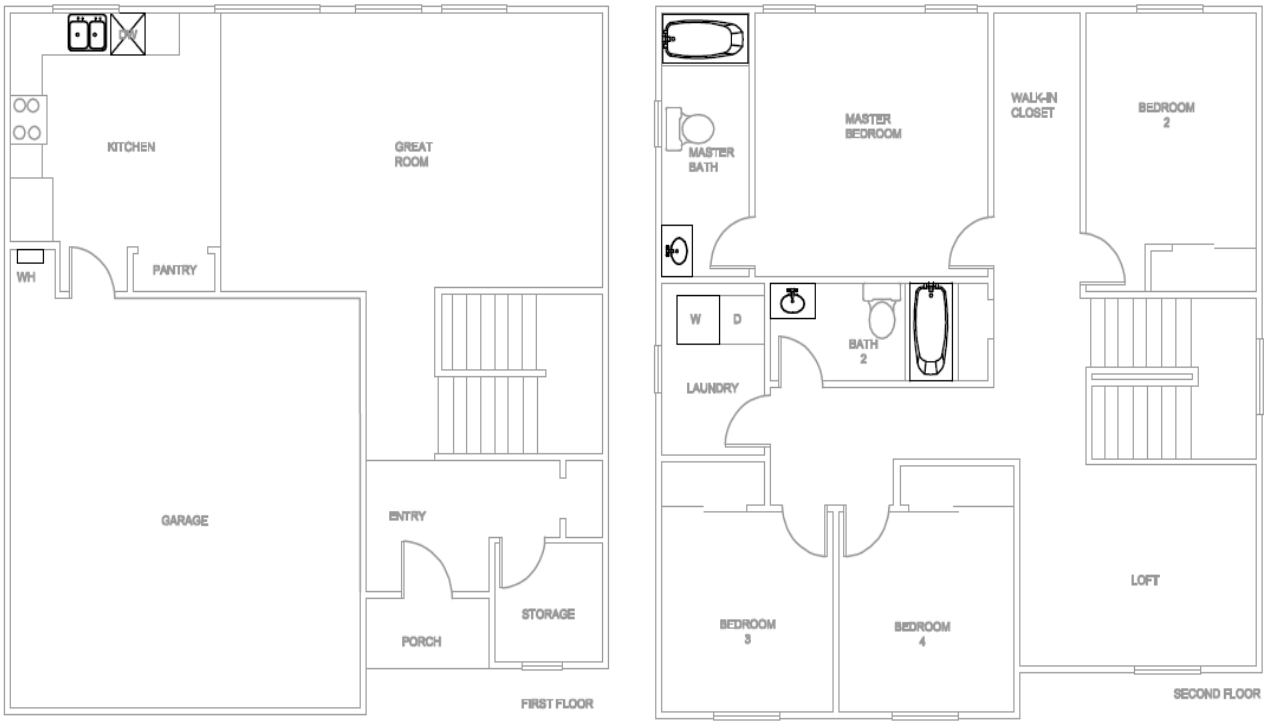


Figure 4: Good House Layout



Key Takeaway #1: House design plays a critical first step in determining whether the plumber will be handicapped in delivering a "good" hot water system. Prompt and consistent hot water delivery is highly desired by homeowners, with substandard delivery performance a common source of builder complaints.

Key Takeaway #2: Consider an indoor mechanical closet as an approach to centralize the water heater location. A mechanical closet would also contribute to improved space conditioning performance by shortening duct runs and facilitating installing ducts in conditioned space. An alternative is adding a second water heater. This choice must balance first cost and operating cost impacts, as well as the comfort benefit of improved hot water delivery characteristics.

3.2 Hot Water Loads and Use Point Characteristics

A hot water system has some similarities to a forced air HVAC installation in that a central plant generates the thermal energy which is delivered to use points throughout the house via a distribution (i.e. duct or pipe) system. There are, however, some clear distinctions to be made in this analogy. For space conditioning, typically all registers ("use points") deliver the conditioned air, while in a DHW system, where and how hot water is used is driven by the house layout, number of occupants, their usage patterns, and the characteristics of the devices

they are operating. What is most critical in a hot water system is efficiently satisfying the peak load events which occur when multiple uses occur simultaneously or within a short time period. To the extent one can mitigate the magnitude of the peak load events potentially contributes to lower energy use and greater homeowner system satisfaction.

3.2.1 Showerheads

The largest hot water use in most homes can be attributed to showering. This is a regular hot water use event which occurs for most occupants on nearly a daily basis (4.9 showers per person per week, as per the behavioral study survey findings). The U.S. Environmental Protection Agency (EPA) estimates that average daily household shower water use (hot + cold) is about 30 gallons per day, and that more efficient showerheads can reduce shower usage by over 20 percent[2]. EPA WaterSense® listed showerheads are required to have maximum flow rates of 2 gpm or less (at an operating pressure of 80 psig). Further energy and water savings are available with showerheads with maximum flow rates of 1.5 gpm or less. A 2008 showerhead study (Schuldt and Tachibana, 2008) found the mean flow rate of existing showerheads in 71 Pacific Northwest homes (139 showerheads) was 2.53 gpm at 73 psi. These homes were retrofitted with 2.0 gpm rated showerheads with a resulting maximum flow of 1.82 gpm (28 percent reduction).

Multi-head "rain" showers have achieved some market share in recent years, primarily in upscale remodels[3]. This is a trend to watch, since the energy and water use implications can be significant. In addition, increasing the flow requirements within a bathroom would likely increase distribution pipe sizings, with associated distribution loss impacts.

3.2.2 Clothes Washers

Clothes washers[4] are another key hot and cold water end use. EnergyStar rated clothes washers use about 35 percent less energy and water than competing conventional products. The Consortium for Energy Efficiency[5] publishes a list of products that meet the CEE criteria at either the Tier 1 (EnergyStar performance level), the Tier 2 level, or Tier 3. The current California saturation of efficient horizontal axis washers is ~25 percent (KEMA, 2010). In addition, cold water clothes washing is starting to gain some traction as evidenced by the findings from the project's behavioral survey, as well as recent national reporting on residential clothes washing trends[6]. With an estimated ¾ of laundry load energy use associated with the

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[2] http://www.epa.gov/WaterSense/products/showerheads.html

[3] The 100 home plumbing survey work completed under this PIER project found one home in the sample that featured a multi-head shower.

[4] http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=CW

[5] http://www.cee1.org/resid/seha/rwsh/rwsh-prod.pdf

[6] http://www.nytimes.com/2011/09/17/business/cold-water-detergents-get-a-chilly-reception.html?pagewanted=all

heating of water, continued movement towards both efficient horizontal axis washers and cold water washing will contribute to reduced overall water heating loads.

3.3.3 California Hot Water Loads

In a geographically diverse state such as California, cold water inlet temperature varies considerably both seasonally and with location. Climate (and associated cold water inlet temperatures) vary from year round cool North Coast conditions, to cold winter/moderate summer mountain area, to seasonally varying Central Valley, and finally to moderate/hot southern California. The field monitoring effort captured some pieces of this variation by monitoring water heater cold water inlet temperatures at eighteen sites (six each in PG&E, SCG, and SDG&E service territories). Figure 5 summarizes the average monthly cold water temperatures recorded only at times when flow was occuring into the water heater. The PG&E sites (located in Northern California from the San Francisco Bay Area to the greater Sacramento area) demonstrate 5-10°F lower average inlet temperatures than the southern California sites where inlet temperatures exceed 80°F in mid-summer. Warmer inlet water temperature reduces the load on the water heater in two ways:

1. Less heat needs to be added to bring the cold water up to temperature
2. Warmer cold water means less hot water is needed to mix to a final shower temperature

Another potential "hot climate" effect that is not currently well understood is the reduced summer desire for hot water for showering and handwashing, both in terms of volume and desired temperature.

Since water heater recovery load is a primary influencing water heater efficiency, it is important to understand how loads may vary in California due to variations in cold water inlet temperatures. Table 1 provides a simplified approximation of annual average cold water inlet temperatures for different regions of California. The values are derived from the field monitoring dataset in the PIER project, prior monitoring, and extrapolations. Variations will occur due to factors such as whether the supply water is from wells or surface water.

Given the Table 1 data, California county population estimates, and an estimation of what fraction of the county population fits within each temperature range, we project that roughly 75 percent of California's population resides in areas with average annual cold water inlet temperatures in the 70-75°F range. As shown in Figure 6, this means that typical water heater recovery loads (at a 60 gal/day hot water use level) are about 1/3 less than the Energy Factor test assumption. The only case where projected loads are expected to exceed the Energy Factor recovery load level, is the "50 140" mountain region case, where "50" represents the average inlet water temperature and "140" the average tank outlet water temperature. A review of California county population data suggests that less than 0.5 percent of California's population resides in areas with inlet water temperatures that cold.

Figure 5: Monitored Water Heater Cold Water Inlet Temperatures

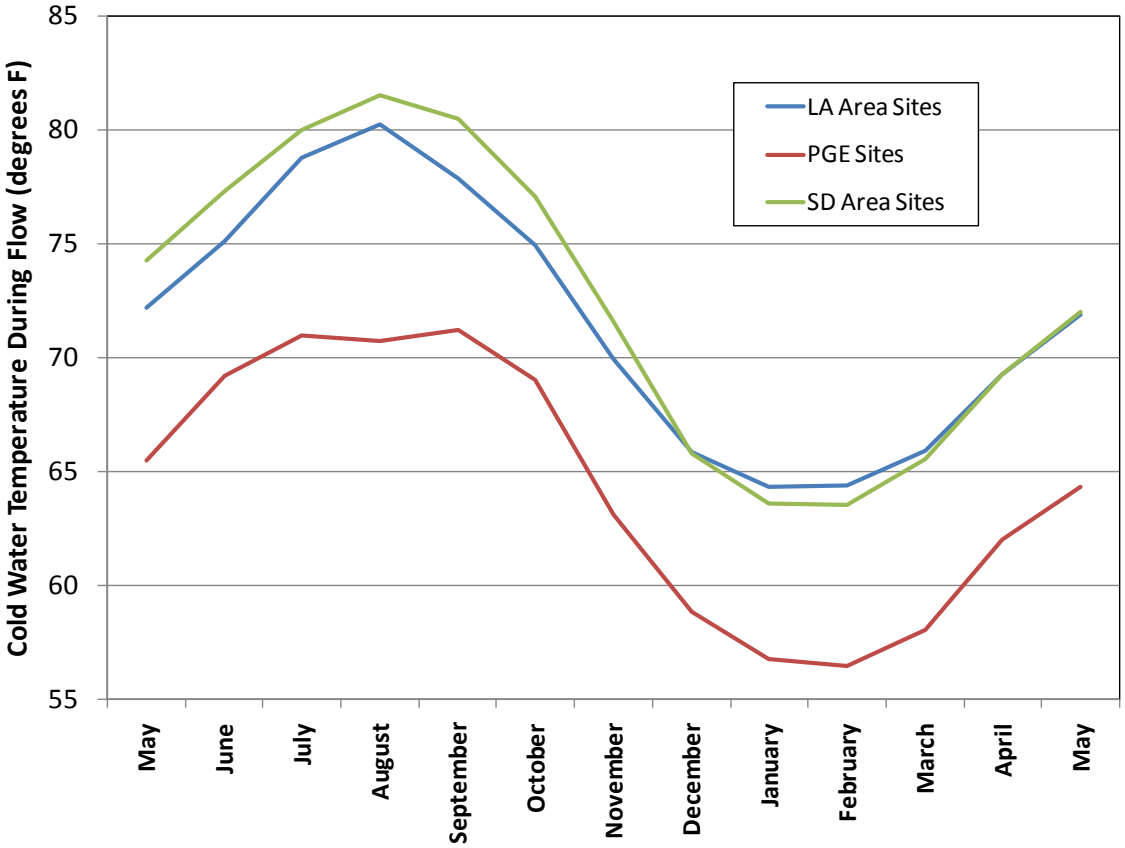


Table 1: Assumed Cold Water Inlet Temperature by California Climate Type

Climate Characterization	Assumed Annual Average Cold Water Temperature
Mountain Region	50°F
Northern Coastal areas, higher elevation foothills	60°F
Central and Southern coast areas, LA and San Francisco transitional areas, lower foothills, moderate Central Valley areas	70°F
Inland LA area	75°F
Hot desert regions	80°F

Figure 7 plots monitored average per capita recovery load from the California field monitoring study, which averaged 7,700 Btu/person-day. All but three sites have daily per capita recovery load < 10,000 Btu/day. Northern California PG&E sites averaged 25 percent higher than the statewide average and the southern California sites (SCG and SDGE) averaged 13 percent less.

Figure 6: Estimation of Recovery Load as a Function of Inlet and Outlet Water Temperatures

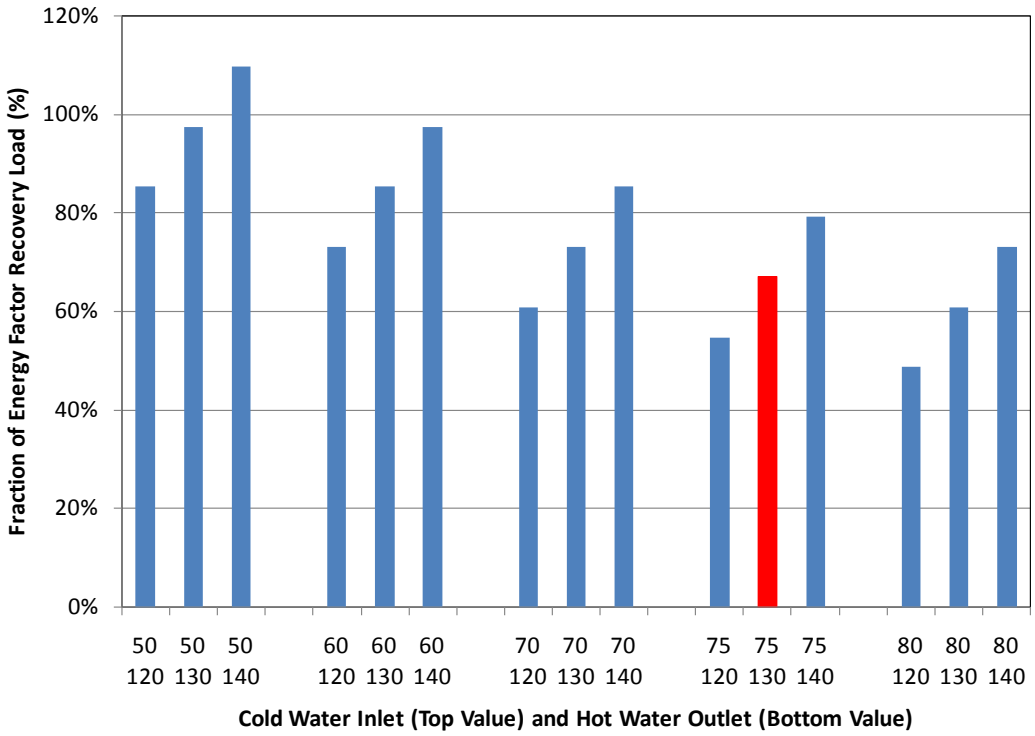
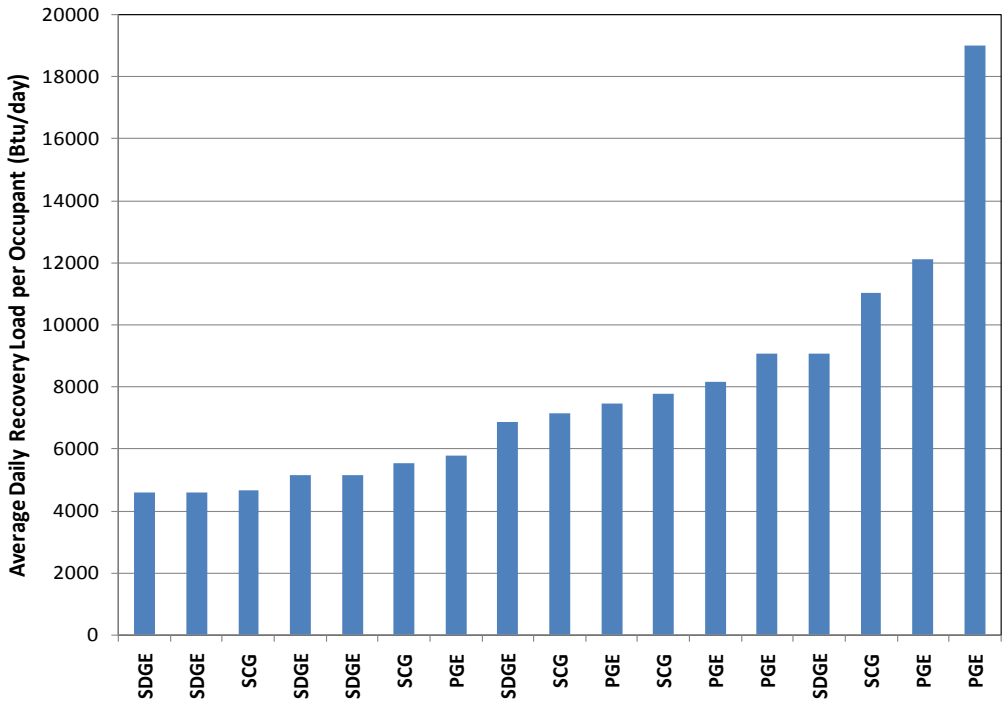


Figure 7: Average Monitored Recovery Load (per capita) at California Field Test Sites



Key Takeaway: Opportunities exist to reduce hot water demands both in new construction and retrofit. Selecting efficient appliances, showerheads, and faucets is often the most cost-effective hot water system improvement option available.

Historically, hot water load has been characterized in terms of gallons per day. The thermal load on the water heater (recovery load), is likely a better indicator of water heater performance. Typical monitored California household hot water recovery loads are ~40 percent lower than assumed in the Energy Factor test that rates most residential water heaters. Improved low-flow showerheads and faucets, as well as efficient appliances can contribute to further load reductions.

3.3 Distribution Systems

3.3.1 Overview

Hot water distribution systems in California have evolved over the past ten to fifteen years as plastic pipe has made significant inroads relative to copper piping which had been the norm for more than forty years. The primary plastic piping material seen in California in recent years is cross-linked polyethylene piping (PEX), although CPVC pipe also was found to have a small market presence in recent field plumbing surveys. California's statewide acceptance of PEX in the California Plumbing Code in 2009[7], the rising cost of copper over the past ten years, and ongoing concerns over liability due to solder joint failures and pipe pitting have been the

[7] http://www.uponor-usa.com/Misc/Applications/California-PEX.aspx

primary factors leading to the widespread use of PEX. Plastic pipes have other apparent non-cost advantages over copper, with a primary benefit being that for a given nominal pipe size, the plastic pipes have considerably less entrained volume per 100 feet of pipe length. Figure 8 plots the entrained volume in "gallons per 100 feet" for copper (type L and M), PEX (SDR 9), and CPVC (SDR 11). An additional relationship to look at is the relative volume of smaller to larger diameter piping. Relative to ½" PEX, ¾" PEX contains nearly twice the volume per foot, and 1" PEX contains 3.25 times as much. The entrained volume of water that remains in a pipe after a hot water draws is a strong indicator of energy and water waste associated with the distribution system. As a general rule, the larger the entrained volume to a use point, the greater the energy waste, water waste, and hot water wait time.

Table 2 summarizes key PEX advantages and disadvantages. Field survey of plumbing piping installations in 2006 and 2011 has indicated that one of PEX's main positive attributes (flexible pipe promotes ease of installation) has also resulted in abuses in terms of inefficient plumbing layouts.

Figure 8: Entrained Pipe Volume Comparison - Copper vs. Plastic Pipe

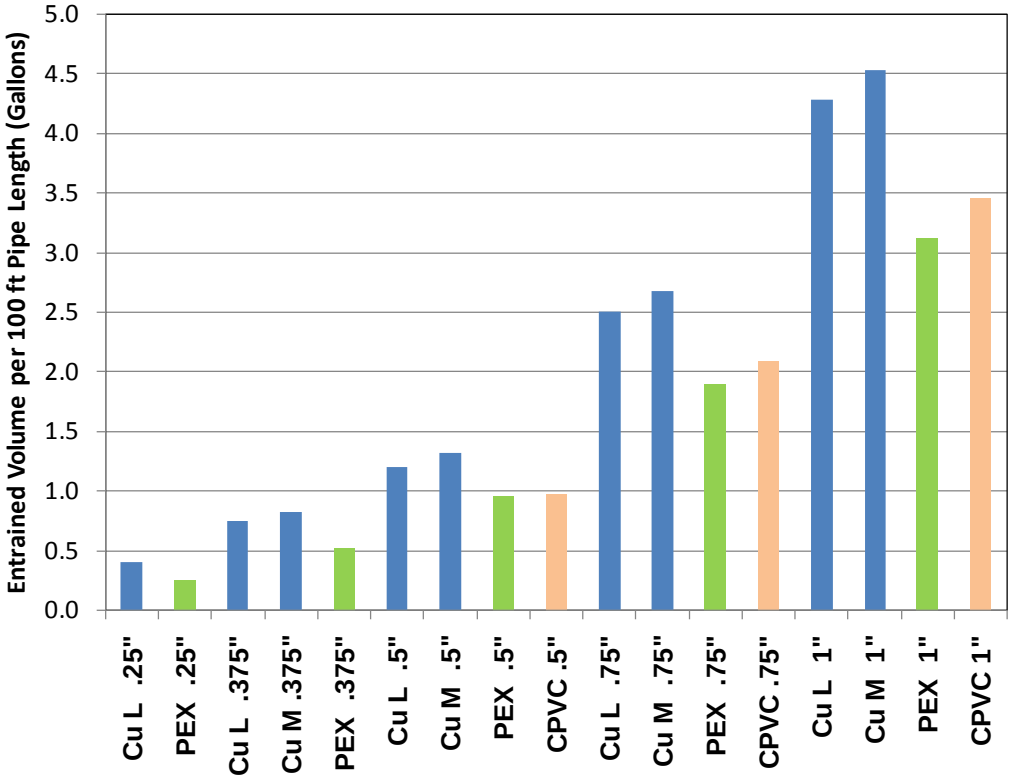


Table 2: Comparison of PEX Pros and Cons

Pros	**Cons**
Pipe flexibility and ease of handling	Higher heat loss than copper if uninsulated or unburied in insulation (radiant effects)
Potential for direct routing of piping	Little data on long term fitting reliability
Less entrained volume per foot than copper pipe (hot water faster to the fixture for a given flow rate)	Low material cost and ease of handling may encourage ease of installation over optimal installation practice
Elimination of solder joints reduces leak potential	Degradation from sunlight (generally not an issue)
Lower installed cost than copper	
Less likely to suffer freeze failure	

Unlike copper distribution systems which require a moderate level of installer skill to properly solder fittings and Tees, plastic pipe is simpler to install. There are two common techniques for making PEX connections: crimp connections and the use of expansion fittings. The PEX Design Guide for Residential Supply Plumbing Systems[8] provides more information on these techniques (shown in Figures 9 and 10). CPVC utilizes slip fitting connections that require solvent cement[9].

Figure 9: PEX Piping Connection Options

http://plasticpipe.org/pdf/pex_designguide_residential_water_supply.pdf

[8] (http://plasticpipe.org/pdf/pex_designguide_residential_water_supply.pdf)

[9] http://www.nibco.com/assets/CPVCMAN2.pdf

Figure 10: PEX Crimp Ring Connection

http://www.pexinfo.com/images/1pexinfocopper3b-6x4.jpg

3.3.2 Pipe Heat Loss

The heat loss from distribution system piping has several direct impacts on overall system performance:

1. The heat loss from distribution piping diminishes the temperature of supplied hot water relative to the temperature leaving the water heater.
2. The volume of water between the water heater and the use point defines a minimum[10] wasted hot water volume before "useful" hot water arrives at the use point. For the unsatisfactory "quality" water that is dumped, the full energy content of that volume has been lost.
3. The volume of water wasted from a cold start will be further increased if a tankless water heater is installed, as the majority of these units require 15-30 seconds to approach the setpoint delivery temperature.
4. A final human component of the distribution system delivery inefficiency, is how the occupant responds to the time delay between start of water draw and availability of hot water at the use point. Slow hot water delivery times may support wasteful behaviors leading to more waste, as the user is trained to become less mindful of when hot water actually arrives.

All of these factors come into play in real world situations. Understanding and quantifying these effects requires a detailed understanding of the distribution system layout, climate, usage patterns, and behaviors. These effects can then be input to a model to extrapolate to full season

[10] The actual water waste for a cold start situation is higher than the entrained pipe volume and is dependent upon temperatures and flow rate, as discussed in the Hiller/AET reports.

effects. One part of the puzzle that is now fairly well understood, is the quantification of pipe heat loss and energy/water waste associated with different piping materials. Table 3 reports detailed laboratory measured steady state pipe heat loss results completed by Applied Energy Technology over the past five years and reported in numerous ASHRAE papers (Hiller, 2005, 2006, 2008, 2011). Pipe heat loss was calculated by measuring the hot water temperature drop over a long length of pipe (~100 feet) at fixed inlet water and environmental temperature conditions. Results shown are presented for both uninsulated pipe "in air", and "in air" pipe insulated with nominal one inch pipe insulation[11]. The most interesting, and perhaps non-intuitive finding, is that low thermal conductivity plastic piping materials (PEX and CPVC) have 10-30 percent higher heat loss per foot than copper pipe. This is primarily due to the fact that the emissivity of plastics (~ 0.91) are higher than that of new copper pipes[12]. Insulated piping was found to have roughly comparable heat loss among the different piping materials, as one would expect since the pipe insulation represents the dominant thermal resistance to pipe heat loss.

Table 3: Laboratory Measured Pipe Heat Loss (Btu/hr-ft-°F) at 1.0 gpm Flow Rate

Pipe Material Type	Nominal Pipe Diameter		
	3/8"	1/2"	3/4"
Uninsulated			
Copper Type L	--	0.345	0.417
PEX	0.368	0.438	0.545
CPVC	--	--	0.460
Insulated (1")			
Copper Type L	--	0.117	0.148
PEX	0.121	0.130	0.180
CPVC	--	--	0.160

(Data from AET test summaries)

3.3.3 Distribution System Types

Davis Energy Group has completed two field assessments evaluating how hot water distribution systems (HWDS) are being installed in new California production homes. The first study, completed in 2006 (DEG, 2006), surveyed sixty homes throughout California in the pre-drywall stage. The second assessment, completed as part of the current PIER project, surveyed another 100 homes throughout California. At each site, measurements were made to accurately define:

[11] Additional lab test results look at pipe buried in sand, in attic insulation, and in contact with drywall.

[12] Reported copper emissivities ranging 0.02 (highly polished), to 0.15 (slightly polished), to 0.78 (black oxidized) Siegel and Howell, Thermal Radiation Heat Transfer 2nd Edition. Appendix D.

- Pipe material (length and diameter),
- Pipe location (garage, attic "in air", attic "buried in insulation", between floors, exterior wall, interior cavity), and
- Presence of pipe insulation.

Table 4 summarizes the locations of the sites surveyed for each of the studies. In the 2006 study, during California construction boom years, we planned on limiting the number of surveyed homes to a maximum of three to four per plumbing company, in an effort to get as broad a representation as possible. This was much more challenging in the 2011 study due to consolidation amongst the industry. The net result was that in both field survey efforts, the work of about 20 plumbing contractors were represented in the statewide survey findings.

Table 4: Location of Plumbing Survey Sites by Field Survey Phase

Title 24 Climate	Number Of Sites	Site Locations
2005-2006 Field Survey		
6	6	San Juan Capistrano, Costa Mesa
8	3	Tustin
10	1	Menifee
11	6	Lincoln, Redding
12	29	Woodland, El Dorado Hills, Elk Grove, Rancho Cordova, San
15	15	Indio, Palm Springs, Desert Hot Springs
2009-2011 Field Survey		
7	2	Carlsbad, Chula Vista
8	3	Yorba Linda
10	29	Menifee, Temecula, Moreno Valley, Beaumont, Murietta,
11	6	Roseville, Rocklin
12	35	Folsom, El Dorado Hills, Rancho Cordova, Davis, Manteca,
13	19	Bakersfield, Fresno
15	1	Palm Desert

Figure 11 shows a central home run manifold system, with the manifold being fed with hot (red) and cold (blue) from the top, and distributing to each use point with ½" PEX from the manifold ports. Tube bundling, as shown in Figure 12, provides for more coherent pipe runs, but this approach has negative thermal implications due to heat transfer to adjacent hot/cold pipes and also a tendency to keep bundles together longer, resulting in backtracking to some of the use points. The central home run manifold is generally installed in close proximity to the water heater, although the ¾" or 1" line feeding the manifold from the water heater may take a

circuitous path. The 2006 survey found the average length between the water heater and manifold was 20.2 feet, and contained and average of 0.55 gallons of volume, or nearly 60 percent of the average entrained volume between the water heater and the hot water use points. (This finding led to a 2008 Title 24 requirement limiting the water heater to manifold to length to 15 feet. A pending proposal for 2013 Title 24 Standards will provide a small credit for installations with a maximum five foot water heater to manifold pipe run length.)

Figure 11: Home Run Manifold

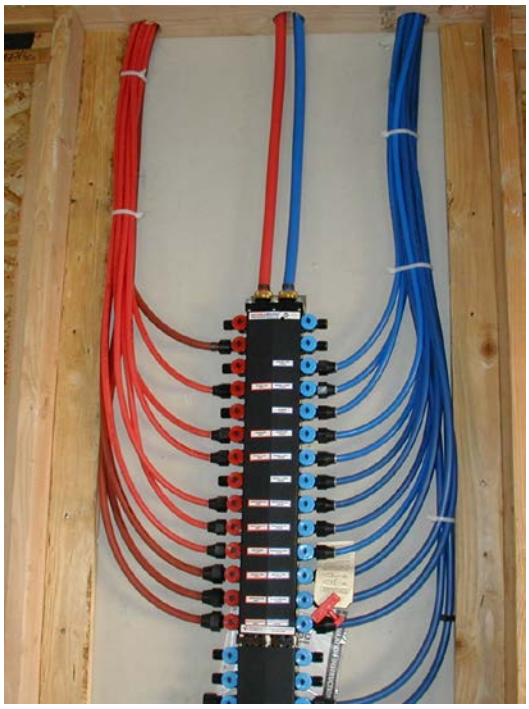


Figure 12: Common Pipe Bundling for Home Run Systems

The central home run manifold systems were found to be fairly common in the 2006 survey (found in ~40 percent of surveyed sites), but have only been observed in a few percent of the sites during the 2011 survey. Feedback from the field suggests that home run manifolds are too costly in the current hyper price sensitive construction market. In its place, we found that distributed mini-manifolds were the predominant system (~60 percent of installations). An example mini-manifold installation is shown in Figure 13. Generally the manifolds are plastic and uninsulated, although more expensive brass or copper manifolds are also occasionally observed. The manifolds are commonly fed with ¾″ inlet lines which then feed multiple ½″ lines that typically serve 4-5 use points. They are often installed in a series configuration (as shown in Figure 13) where the main ¾″ feeder line continues on to the next manifold. Performance-wise the mini-manifolds can mimic the performance of a home run system if they are all located within 15 feet of the water heater. In reality, where they are located in homes was found to be highly variable, and often based more on installer preference rather than on a systematic approach to reduce entrained pipe volume and minimize water and energy waste.

Figure 13: Plastic Mini-Manifold

3.3.4 Recirculation System Types

Recirculation systems are generally designed for larger homes, especially custom homes where cost concerns are less pronounced. A recirculation design essentially brings the hot water supply outlet closer to the fixtures by employing a pumped loop that circulates hot water close to end use points. A hot water demand draws hot water off the loop, resulting in much faster delivery of hot water, and reduced water waste. The water and time savings is countered by the added cost of piping[13], pipe insulation, controls, and pump; and increased energy use due to pumping and thermal losses from the loop. Single family recirculation control strategies

[13] Piping costs are higher since the loop supply line must be sized to meet the full flow requirements of simultaneous draws. Often this results in much of the recirculation loop being 1″ or ¾″ piping.

include continuous pump operation, timer control, temperature control, and demand control. The strategies are listed in terms of least efficient to most efficient, since the general trend is a decrease in loop operating hours.

3.3.4.1 Continuous

By recirculating hot water continuously, the occupant of the house with a well laid out loop is able to have rapid access to hot water at any time. The disadvantage of this approach is that pump is operating 8760 hours per year, and the pipe thermal losses are therefore continuous. Shoddy pipe insulation installation contributes to even greater thermal losses. Typical recirculation loop flow rates are on the order of 1 gpm.

3.3.4.2 Timer Control

Timers can be used to activate the recirculating pump on a schedule dictated by occupant schedules. This offers flexibility, but also results in situations where the owner may increase pump operating hours beyond what is generally needed to insure that all expected hot water use schedules are covered. It is important to remember with any intermittent pumping strategy that initiation from a cold startup condition requires the entire loop to be primed[14].

3.3.4.3 Temperature Control

A temperature controlled recirc system involves installation of a surface mount temperature sensor installed on the recirculation return line (under the pipe insulation) either at the use point branch furthest from the water heater or where the return line returns to the water heater. The temperature sensor provides input to a controller which energizes the pump to maintain a minimum sensed return water temperature. Ideally this control should provide a reduction in the pump run time by 50 percent or more, but our experiences indicate that the low recirculation flow rate and higher than anticipated pipe heat loss result in much greater pump operation that anticipated.

3.3.4.4 Time/Temperature Control

A time/temperature control combines the two functions and theoretically provides the benefits of both timer operation and temperature control.

3.3.4.5 Demand Control

A demand control strategy utilizes a user-activated control to initiate pump operation when the recirculation line is below a useable temperature. Push buttons or occupancy sensors installed at the primary use points[15] allows the pump to be energized "on demand". Since this approach will operate the pump much less frequently than other system types, the energy lost in the recirculation loop and the pump energy are both reduced significantly relative to conventional recirculation strategies. Due to the infrequent operation, a larger pump is needed to more quickly deliver the hot water. A temperature sensor, typically installed at end of the supply

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[14] Similarly pump shutdown and loop decay results in the heat of the full entrained pipe volume being lost.

[15] Pump activation may or may not be necessary for laundry rooms and powder rooms.

loop, shuts the pump off once it notices a rise in temperature at the sensor. Push buttons are the preferred control strategy, since activation represents clear intent from the occupant. This control strategy does require the user to interact with the system, which will be an issue for some people. Occupancy sensors, which resolve the need for direct interaction, will result in unintentional pump cycles as people will enter the bathroom or kitchen with no intention to use hot water. Strategic placement of the sensor can help reduce the number of false signals, although there is no definitive monitoring data to document the added energy use associated with unintended occupancy sensor pump initiations. Despite concerns about the occupancy sensor, the demand recirculation strategy clearly represents the best recirculation approach, if a recirculation system is indeed needed.

3.3.5 Pipe Insulation

Properly installed pipe insulation serves the vital role of reducing heat loss during hot water flows and extending pipe cool down times at the end of draws, potentially resulting in available hot water for the next draw. The "during draw" benefits result in an approximate 2/3 reduction in pipe heat loss as determined by the lab testing completed by AET (Table 3 data). The energy savings benefit of pipe insulation is most pronounced in distribution systems that contain or circulate hot water for most of the day. As loads decrease and approach zero, the benefit of pipe insulation from a cost-effectiveness viewpoint (energy saved per dollar invested) is reduced. Most households with non-recirculating distribution systems will see hot water flow occurring anywhere from 30-100 minutes per day[16]. The "during draw" benefit of pipe insulation is reduced relative to a recirculation case, but pipe insulation also offers benefits in delaying pipe thermal decay time, which means subsequent draws will benefit from insulation if the water remains above a minimum desired use temperature, resulting in avoided waste.

The cool down benefit is difficult to quantify since it is highly dependent on load patterns within a house (how clustered hot water draws are), the plumbing layout (pipe location and which pipes see flow at what time during the day), and climate and seasonal effects (heat loss to environment). The 18 home field survey data indicated that on average, ~45 percent of hot water flows occur within ten minutes of a prior draw, and 30 percent occur at an interval greater than 60 minutes. Some fraction of the draws in the "< 10 minute interval" would see a benefit if flows are occurring at different legs of the distribution system, however none of ">60 minute" interval draws would see a benefit. An educated guess might suggest that half of the draws in a typical household would be favorably affected by pipe insulation.

In the development of the 2013 Title 24 Standards, simulation runs were completed to assess the cost effectiveness of pipe insulation of six different house floor plans under "typical" hot water

[16] A rough rule of thumb to apply to hot water flow is to assign a reasonable average hot water flow rate of 1 gpm to the estimated daily usage. A 30 gallon per day load would therefore have 30 minutes of hot water flowing per day, while a 60 gallon load would be 60 minutes. Typical per person use ranges from 15-20 gallons per day.

use profiles. Findings of the evaluation[17] indicate that insulating ¾″ or larger piping is cost effective on a life cycle basis at a (conservative) insulation installed cost of $3.87 per foot[18]. Insulating half inch piping was not found to be cost effective under typical usage assumptions, largely due to the reduced flow and less entrained pipe volume for the smaller pipe. This is not to say that ½″ piping should not be insulated, since benefits will accrue, only that under the Title 24 consensus cost assumptions, insulating ½″ pipe was not found to be cost-effective.

3.3.6 Current State of New Home Distribution Systems

The field survey efforts completed in this project, as well as the prior effort in 2006, provides useful data on the preferred plumbing layouts and how those systems are installed. We have represented the data in the form of average entrained pipe volume from water heater to use points, as a key metric for comparing the different types. This is not a perfect approach but it does provide a method to get a sense of how much volume exists in the installed hot water distribution systems and can therefore be used to develop "typical" input conditions for modeling tools. Table 5 compares the 2006 and 2011 datasets by normalizing the average volume by house floor area (per 1000 ft^2). Key conclusions include:

- Home run manifold systems, popular in 2006, have largely been supplanted by the mini-manifold design approach.
- Excluding home run and recirculation systems, the average volume per 1000 ft2 is ~ 0.5 gallons (a 2,000 ft2 "typical" house would have, on average, ~ 1 gallon of water sitting in the pipe between the water heater and any use point). The 2006 and 2011 findings are virtually identical in terms of gallons/1000 ft2.
- Both central home run manifold systems and recirculation system entrained volumes were significantly lower in the 2011 survey. Since both the home run and the recirc samples are not statistically significant (three and seven sites, respectively), further study is warranted.

Another significant finding in the 2011 survey relates to the use of larger diameter 1″ piping in non-recirculating residential applications. In some cases this may be dictated by pipe sizing requirements in the Uniform Plumbing Code. A review of Figure 14, which plots the length of 1″ piping as function of house floor area (each data point represents one house), indicates that there is no clear relationship between the amount of 1″ piping and the size of the house. One would expect such a relationship to exist, since larger homes will as a rule have more bathrooms and use points, which will affect pipe sizing as the number of fixture units increase.

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[17] http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Residential/Water_Heating/2013_CASE_R_SEMPRA_Single_Family_DHW__percent20Sept_2011.pdf

[18] Title 24 Standards cost effectiveness calculations require the use of conservative (i.e. high) cost assumptions.

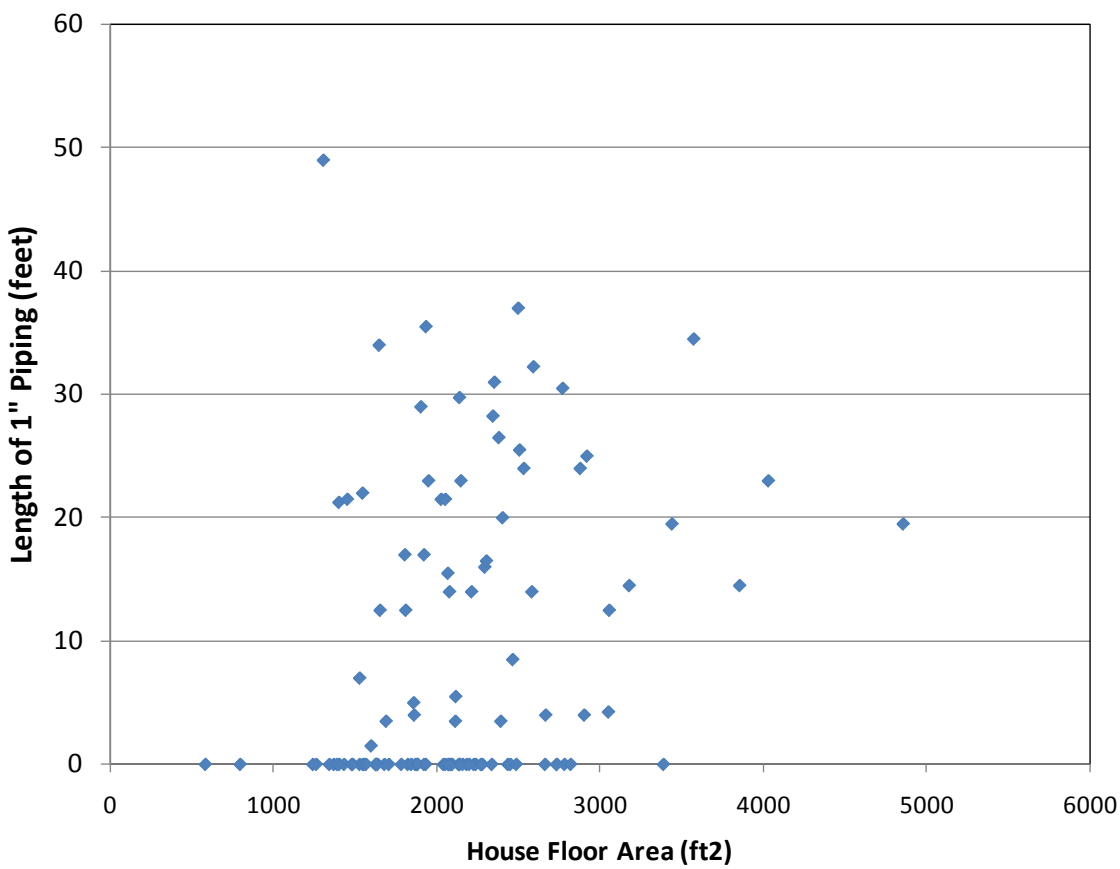
Our assessment of this situation is that the use of 1″ piping is based on what the plumber is comfortable installing, suggesting that more industry education and training is needed.

Table 5: Average Entrained Volume to Use Point per 1000 ft2 of Floor Area

System Configuration	2006 Survey (gallons/ 1000 ft2)	2011 Survey (gallons/ 1000 ft2)
Conventional Trunk and Branch	0.49 (12)	0.48 (27)
Central Home Run Manifold	0.39 (23)	0.29 (3)
Hybrid Systems (includes mini-	0.43 (13)	0.45 (60)
Recirculation Systems	0.82 (12)	0.45 (7)

"()" = number of sites that were included as part of that sample

Figure 14: Length of 1" Pipe vs. House Floor Area



3.3.7 Modeling of New Home Distribution Systems

A key component of the GTI water heating research project involved advancing the state of current water heating system modeling tools. This included integrating improved water heater models into the HWSIM hot water distribution system simulation model, as well as enhancing

some of pipe heat loss modeling capabilities. The model was used to provide some example projections of distribution system performance for this design guide. It is important to recognize that modeling in this area is highly complex as it brings together a wide range of factors that combine to define the performance of a water heating system. These factors include the configuration of the house, the layout of the plumbing system, the location of the pipes, the climate, the type of hot water using fixtures and appliance in the house, the occupancy of the house, and most importantly, the occupants themselves. The HWSIM tool is capable of accomodating these inputs, but our current level of understanding in some of these areas is limited and evolving as more research in the field is performed.

An example of the variablity that exist is shown in Figure 15 where the monitored distribution of hot water draw events from the 18 field monitoring sites is plotted against the elapsed time between hot water draws. The graph shows that on average (red line) nearly 45 percent of hot water draw events at these sites occurred within 10 minutes of a prior draw, and 55 percent within 20 minutes. However, the variation among the individual sites (shown as gray lines) is very large. The implications of this site-by-site variation are significant in many respects, since the time between hot water draws is a key determinant of whether energy within the piping may be "useful" for subsequent hot water draws, and also whether pipe insulation has more or less value in a given application. In non-recirculating hot water distribution systems, pipe insulation is least effective in the extreme conditions of draws that are highly clustered, or draws that well spaced out in time. Pipe insulation is most effective when the draw pattern falls between the two extremes, whereby insulation can slow the pipe heat loss sufficiently to provide benefit for the next draw. As a general rule, pipe insulation can extend the usefulness of entrained hot water from ~15 minutes (uninsulated) to ~40 minutes (if insulated).

To explore typical performance impacts of different hot water distribution systems and hot water usage quantities, a series of HWSIM runs were completed on a 2,496 ft^2 floor plan. The first and second floor layout, shown in Figures 16 and 17, is representative of many homes of that size. To evaluate performance, runs were completed with three hot water usage levels (26, 49, and 78 gallons per day) and several different distribution types. The modeled distribution system types included:

- Conventional practice (PEX with mini-manifolds, "typical" piping layout)
- Improved practice (better water heater location; shorter, more direct piping runs)
- Demand recirculation[19] (with "typical" recirculation loop system layout)
- Improved demand recirculation (with improved recirc system layout & water heater location)

[19] Assumes manual pushbutton control of the demand recirculation system. Occupancy sensor control would have higher energy use.

Figure 15: Monitored Time between Hot Water Draws from 18 Home Field Survey

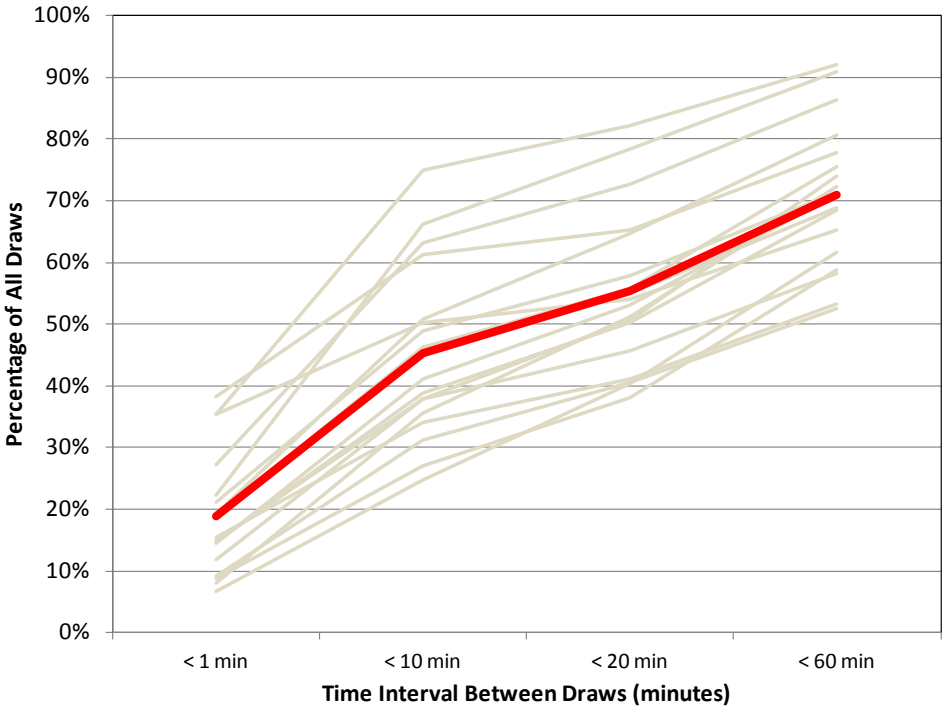


Figure 16: First Floor Layout (2,496 ft^2 Production Home)

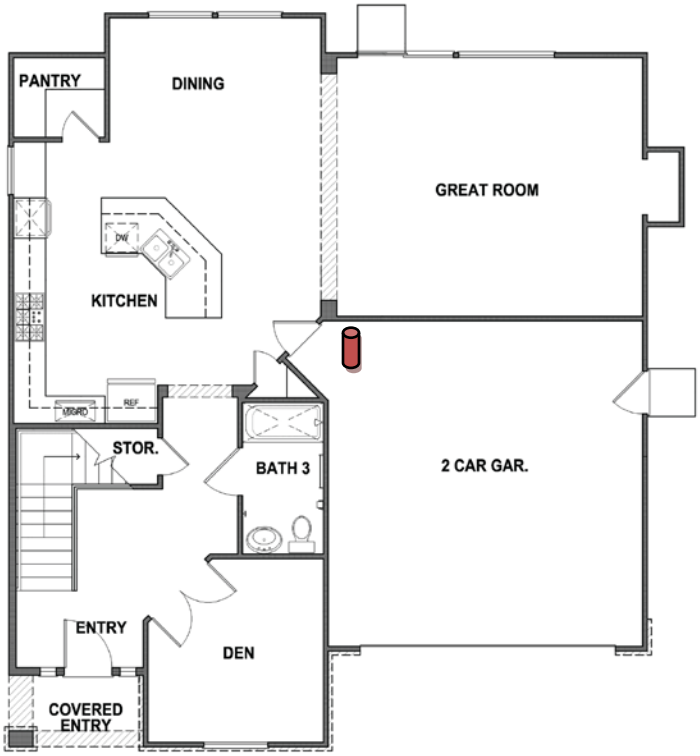
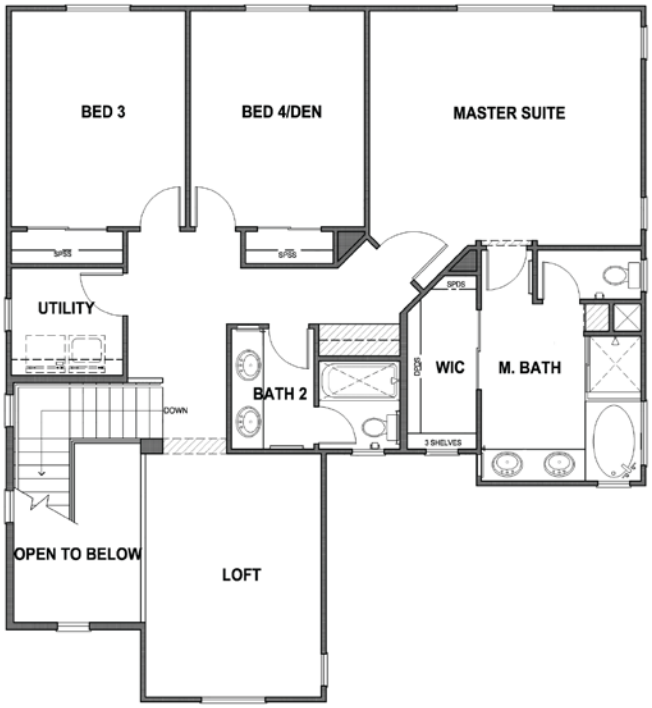


Figure 17: Second Floor Layout (2,496 ft^2 Production Home)



Results from the simulations are included in Table 6 for estimated annual water heater gas consumption (for a 0.59 EF atmospheric water heater) and wasted hot water volume for each of the distribution system cases evaluated. Base annual gas usage ("conventional practice") varies from 122 to 246 therms/year. Improved conventional practice results in a projected 10-12 percent reduction in gas consumption (15-31/year therm savings). The demand recirculation case (with "typical" piping layout) is estimated to result in slightly higher annual gas use (ranging from 1 therm saved to 8 therm increase), while the improved demand recirc case shows usage only slightly higher than the improved conventional case.

In terms of hot water waste, base case ("conventional practice") shows daily water waste ranging from about 6-15 gallons per day (2,125 to 5,318 gallons per year). Improved conventional practice shows a 6-7 percent reduction in hot water waste. Recirculation systems show a 40-60 percent reduction in waste for the "conventional" recirculation system, increasing to over 80 percent for the improved recirculation system.

It is important to note that these performance projections are based on reasonable input assumptions, but variations in behavior and use pattern will have a significant influence on savings. As better data becomes available and modeling tools improve, these projections can be refined.

Table 6: HWSIM Results Summary

System Configuration	26 gal/day average hot water	49 gal/day average hot water	78 gal/day average hot water use
Estimated Annual Gas Use			
Conventional Practice	122	180	246
Improved Conventional Practice	107	162	215
Conventional Demand Recirc	121	183	254
Improved Demand Recirc	109	164	218
Estimated Annual Water			
Conventional Practice	2,125	2,758	5,318
Improved Conventional Practice	1,998	2,593	4,946
Conventional Demand Recirc	1,158	1,226	3,021
Improved Demand Recirc	451	543	892

Key Takeaways:

#1: Plumbing Design- Centrally locate the water heater to the extent possible. Provide input to the architectural design to avoid sprawling hot water layouts. A bad plumbing design and layout institutionalizes waste over the life of the house.

Central Manifold Home Run Systems- Minimize the length of piping between the water heater and the manifold. More than half of the entrained volume between the water heater and use points can be found here, therefore minimizing this length is more critical than minimizing the pipe length between the manifold and the use point.

Bathroom Sinks- Use a single ½" line to feed adjacent bathroom sinks as opposed to individual dedicated lines.

Distributed Mini-Manifold Designs- Bring manifolds close to the water heater as this will reduce the overall entrained volume of water, reducing heat loss, water waste, and hot water wait times.

Whirlpool Tubs- The high flow rate requirements of tubs creates pipe sizing problems that often contribute to added waste throughout the distribution system, since the piping is sized to accommodate simultaneous flows.

Recirculation Systems- Carefully consider the need for a recirculation system. Recirculation systems may be needed due to the following factors: 1) a very large house, 2) poor architectural design (use point locations spread out), 3) poor plumbing layout, 4) clients who demand rapid hot water delivery. Recirculation systems will consistently save water and reduce hot water waiting times, but only a demand recirculation system <u>can potentially</u> save energy. Care should be taken to minimize the length and entrained pipe volume of the

recirculation loop. If the house layout suggests two loops, install a second recirculation system rather than one oversized loop serving the entire house. As an alternative to recirculation, consider the costs and benefits of adding a second water heater, recognizing that there may be cost savings by eliminating some pipe runs.

Pipe Insulation- Pipe insulation offers benefits in reducing heat loss, delivering hotter water to fixtures, and reducing hot water waste associated with cool downs between draws. All piping ¾" or larger should be insulated. Attic piping should be buried in blown insulation (4" coverage) were possible. Insulating all piping certainly represents a Best Practice approach, but is likely not cost-effective for most ½" and smaller piping.

Pipe location- For piping installed in attics, make every effort to keep piping in the blown insulation (4" minimum coverage desired). If mini-manifolds are buried by insulation, provide a flag that denotes where the manifold is located (for future service).

3.4 Water Heaters

Most water heaters used in single family applications are rated according to the U.S. DOE's Code of Federal Regulations (10CFR430, Subpart B)[20]. According to the standard, residential water heaters are rated according to the following three parameters:

- "**First Hour Rating** means an estimate of the maximum volume of hot water that a storage-type water heater can supply within an hour that begins with the water heater fully heated (i.e. with all thermostats satisfied). It is a function of both the storage volume and the recovery rate."
- "**Recovery Efficiency** means the ratio of energy delivered to the water to the energy content of the fuel consumed by the water heater." Standby losses are a minor component of this factor, and it is roughly equivalent to the Thermal Efficiency rating for large water heaters.
- "**Energy Factor** means a measure of water heater overall efficiency." It is a combination of energy recovery efficiency following a series of water draws and 24-hours of standby loss.

The 24 hour test draws a total of 64.3 gallons of hot water in six equal draws of 10.7 gallons. Each draw is separated by one hour, and the remainder of the 24 hour test is designed to capture system standby energy use.

Table 7 summarizes current and proposed 2015 water heater Energy Factor (EF) requirements based on fuel type and water heater type. In 2015, the key distinction is that gas water heaters with greater than 55 gallon storage will be required to be condensing, and the larger electric water heaters will be required to be HPWHs.

[20] Covers gas storage water heaters with input ratings of <= 75 kBtu/hour and volume between 20 and 100 gallons, gas tankless units with input ratings between 50 and 200 kBtu/hour and a volume of <2 gallons.

Table 7: Federal Water Heater Current and April 16, 2015 Standards

Product Type	**Current Requirement**	
Gas Storage	EF = 0.67 – (0.0019 x Volume)	
Electric Storage	EF = 0.970 – (0.00132 x	
Gas Tankless	EF = 0.67 – (0.0019 x Volume)	
	Effective April 16, 2015	
Product Type	**Volume <= 55 gallons**	**Volume > 55 gallons**
Gas Storage	EF = 0.675 – (0.0015 x	EF = 0.8012 – (0.00078 x Volume)
Electric Storage	EF = 0.960 – (0.0003 x	EF = 2.057 – (0.0013 x Volume)
Gas Tankless	EF = 0.82 – (0.0019 x Volume)	

Table 8 presents the current EnergyStar criteria for eligible water heater products. Eligible gas storage products must exceed 0.67 EF, gas tankless > 0.82 EF, and HPWHs must exceed 2.0 EF.

Table 8: EnergyStar Water Heater Minimum Critieria

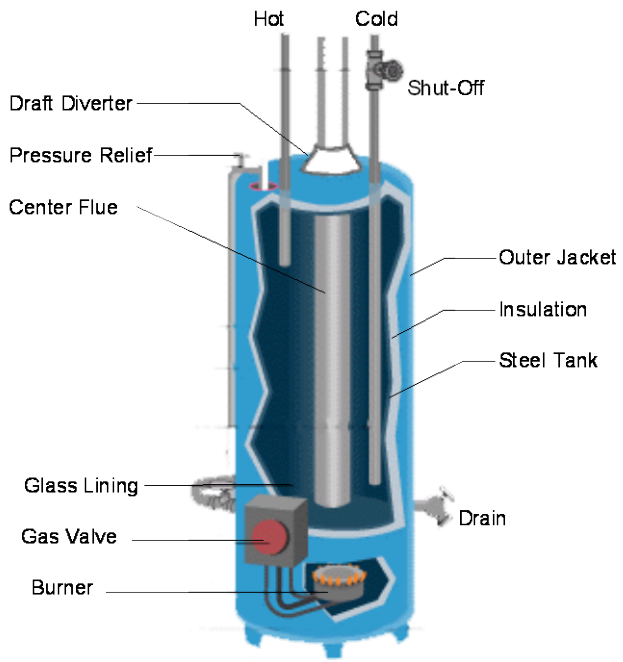
Product Type	Efficiency	First Hour Rating	Minimum Warranty	Safety
Gas Storage	0.67 EF	> 67 gal/hour	6 years on sealed system	Compliance with ANSI Z21.10.1/CSA 4.1
Gas Tankless	0.82 EF	> 2.5 gpm @ 77°F	10 years on heat exchanger; 5 years on parts	Compliance with ANSI Z21.10.1/CSA 4.1 or Z21.10.3/CSA 4.3, depending on burner size
Gas Condensing	0.80 EF	> 67 gal/hour	8 years on sealed system	Compliance with ANSI Z21.10.1/CSA 4.1
Heat Pump	2.0 EF	> 50 gal/hour	6 years on sealed system	Compliance with UL 174 and UL 1995
Solar	0.50 Solar Fraction	n/a	10 years on collector, 6 years on storage tank, 1 year on piping and parts, 2 years on controls	OG-300 certification from SRCC

The following sections provide a brief overview of the various water heating technologies on the market.

3.4.1 Storage Gas Water Heaters

Atmospheric storage gas water heaters (Figure 18) represent the vast majority of water heaters installed in California. These units have a gas burner located at the bottom storage tank, with typical tank volumes between 30 and 50 gallons. Typical water heater setpoints range from 120°F to 140°F, although outlet temperatures can vary considerably due to the wide hysteresis band in the thermostatic control. Heat from the burner is transferred to the water through both the concave tank bottom and the walls of the center flue that extends upward through the tank. Typical recovery efficiencies are in the range of 76-78 percent. A standing pilot ignites the burner when the tank thermostat indicates the tank has fallen below the temperature setting. The gas input rating typically ranges from 34,000 to 40,000 Btu/hour, with higher capacity models (up to 75,000 Btu per hour) available. The vast majority of storage gas water heaters are atmospherically vented, although some are direct vented and some employ fans to assist venting.

Figure 18: Storage Water Heater Schematic



The continuously burning pilot consumes about 400-500 Btu/hour, which in many situations provides enough heat to offset typical tank standby losses. Actual burner firing time in response to hot water loads is on the order of 1 hour per day[21], meaning that for the vast majority of the time the water heater is in standby mode. This low utilization rate (~5 percent) highlights one of the inherent inefficiencies of storage water heaters. In fact, extrapolating the

[21] 35,000 Btu/hour input capacity translates to about 50 gallons of hot water per day at a 65°F temperature rise.

typical 40 therms a year of pilot energy to the 88 percent of California single family households with natural gas water heaters (KEMA, 2010), amounts to a total of 27.5 billion cubic feet of natural gas consumption, or almost 6 percent of the California Energy Commission estimated 2009 statewide residential gas consumption[22]. In applications where a home requires a second water heater, think carefully of the implications of raising the annual standby energy from 40 to 80 therms.

Higher efficiency gas storage water heaters have historically been a small part of the total number of the nearly 8 million residential water heaters shipped nationally[23]. In the past few years an increasing number of higher efficiency storage models have entered the market. As of September 2010, Energy Star has a program in place for high efficiency gas and electric water heaters[24]. To meet the EnergyStar 0.67 Energy Factor efficiency level, the manufacturers have included measures such as automatic flue dampers, electronic ignition, and power vent technology. Most of the available condensing storage products are primarily intended for the combined hydronic or small commercial market (larger in input capacity and storage volume) and are therefore not rated under the Energy Factor test procedure. The thermal efficiency ratings of these units reflect their steady state combustion efficiencies, not a seasonal value as intended by the EF rating. All of these EnergyStar or higher efficiency water heaters require an electrical connection for controls, combustion fans, and in some cases pumps. The need for an electrical connection may increase installation costs, adds parasitic usage (roughly on the order of 100 kWh/year), and adds vulnerability during power outages.

3.4.2 Gas Tankless Water Heaters

Tankless gas water heaters integrate a high capacity burner, a heat exchanger (typical volume of less than one gallon), and controls, to provide hot water only when there is demand. Water is heated in a single pass through the heat exchanger. Supply water temperatures are maintained by either modulating the firing rate in proportion to the water flow rate, mixing cold and heated water to maintain a stable outlet temperature, or some combination of the two approaches. Both condensing and non-condensing tankless units are on the market. Despite the fact that non-condensing tankless units have combustion efficiencies roughly equal to that of conventional atmospheric gas storage water heaters, tankless units have been found to demonstrate consistent gas savings versus atmospheric gas storage units based largely on the elimination of standby losses (Bohac et al, 2010, Davis Energy Group, 2007). Tankless water heaters operate most efficiently with larger volumetric loads, whereby the energy required to bring the heat exchanger up to temperature is a smaller fraction of the total energy consuming during firing. Conversely small loads result in more inefficient operation, as the initial energy required to bring the heat exchanger to temperature is a large fraction of the energy consumed.

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[22] http://energyalmanac.ca.gov/naturalgas/residential_natural_gas_consumption.html

[23] http://www.ahrinet.org/App_Content/ahri/files/Statistics/Monthly percent20Shipments/2011/Dec percent2011 percent20Stat percent20Release.pdf

[24] http://www.energystar.gov/index.cfm?c=water_heat.pr_crit_water_heaters

All newer models include electronic spark ignition and combustion air blowers to achieve higher output and efficiency, and to allow horizontal "direct" venting. Higher capacity models are capturing a larger market share[25] because of their increased ability to satisfy multiple simultaneous hot water loads. Input capacities range from roughly 140,000 to 240,000 Btu/hour, or roughly 5-8 times greater than a gas storage water heater. The higher capacity is needed since water must be instantaneously heated. Larger gas lines, increased venting costs, and the need for a 120 V electrical connection contribute to higher installation costs, particularly in retrofit applications. In recent years, condensing tankless water heaters appear to be capturing a larger fraction of the tankless market. Although the water heater itself is roughly 15-20 percent more expensive than a non-condensing tankless unit, use of plastic vent piping may reduce installed costs relative to the more costly, proprietary vent systems for the non-condensing units.

Since hot water generation for tankless units is very different from a conventional storage water heater, we have highlighted a few of key performance differences:

Time delay from cold start: Tankless units undergo an initial pre-firing sequence (which takes a few seconds), and then must come to temperature before useful heat is delivered from the unit. This results in added delay in hot water delivery, resulting in increased water waste and potential homeowner inconvenience.

Minimum hot water flow rate: A minimum flow rate is required to initiate the firing sequence. This is typically in the 0.4 to 0.75 gpm range. Although most household hot water uses are at higher flow rates, some tankless customers have expressed dissatisfaction that certain low flow rate draws cannot be satisfied. Conversely, it has been observed in field monitoring studies that many of these short, low flow rate draws simply disappear resulting in a small energy savings benefit.

Outlet temperature stability: Once tankless units come up to temperature, they generally maintain very stable outlet temperatures under steady flow conditions (and if the load is less than output capacity). Moderate change in flow rates from steady state flow may contribute to outlet temperature fluctuations. Different control logic used by different manufacturer's results in varying performance.

Cold water sandwich: A potential comfort issue can occur whereby a hot water draw occurs, followed by a short interval of no flow, and then flow resumes. In this case, a slug of cooler water can be delivered by the unit, before the tankless unit refires.

These issues have been identified over the past years and manufacturers are continually looking at how to improve the delivery performance of their products.

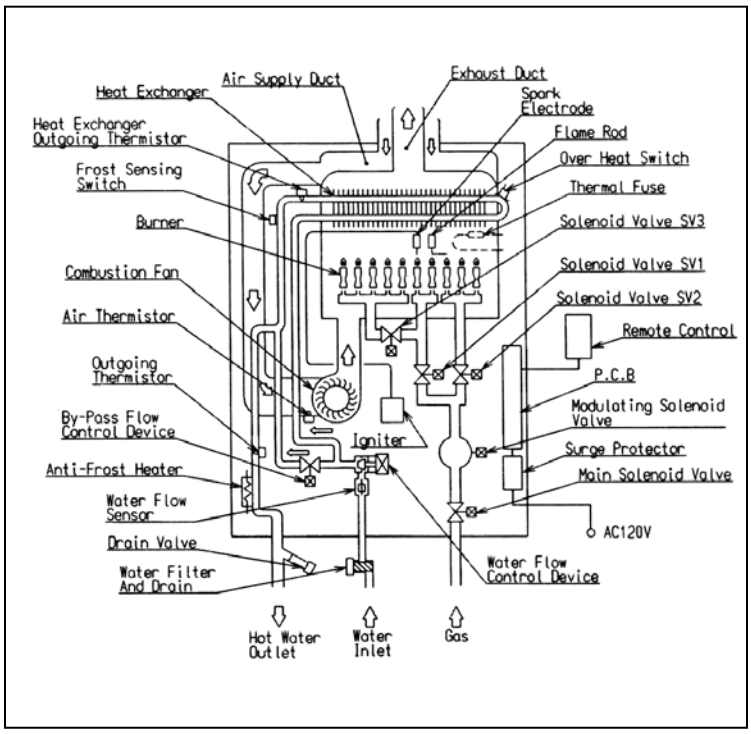
Figure 19 shows a typical garage installation of a tankless unit, and highlights several key installation benefits of tankless units: the units are small, typically wall mounted, and can be

[25] 2011 Navigant study for Oak Ridge National Laboratory estimates that the gas tankless share of the national gas water heater market was about 10 percent.

sidewall vented. Units can also be located in exterior water heater closets, interior closets (with proper ventilation), and mechanical rooms. Unlike storage water heaters which require seismic strapping, tankless water heaters do not. The schematic shows key components including the heat exchanger, multiple gas solenoids for controlling the combustion process, combustion air fan, and temperature and flow sensors.

The need for ongoing maintenance of tankless water heaters is an issue that is currently not well understood[26]. Tankless units, with small diameter heat exchanger flow pathways, are more susceptible to experiencing significant flow and performance degradation in situations with hard water. Preferred maintenance in areas with hard water include inlet water treatment or water softening, and/or flushing of the heat exchanger with mild acid solution to remove scale deposits. Little data is currently available on how well installed units have been maintained, the costs associated with that maintenance, and the number of tankless units which have experience heat exchanger failures due to lack of maintenance.

Figure 19: Typical Tankless Installation and Unit Schematic



3.4.3 Hybrid Storage/Tankless Products

A new emerging product class has come to the market which combines a tankless unit with a downsized storage tank (~25 gallons). This product was designed to combine the benefits of tankless and (downsized) storage technologies, deliver condensing levels of performance, while maintaining a retrofit option were gas line upsizing is not needed. The AO Smith NEXT is the

[26] http://www.wqa.org/detergent/SWB_Studies.pdf

current existing hybrid product on the market[27]. This product class offers interesting potential since the incorporation of storage should alleviate any of the identified tankless performance issues, while operating at a lower standby loss than a full sized storage unit. Limited monitoring has been completed to date. The potential of applying intelligent controls may be a key future enhancement to achieve optimal storage performance.

3.4.4 Electric Storage Water Heaters

Storage electric water heaters are common to much of the U.S., particularly in the Southeast where they represent over half of the installed water heaters. Storage electric units typically have two 4500 Watt electric elements, one located at the bottom of the tank, and one at the top. The controls are interlocked, so only one element is energized at a time. Typically the lower element fires as the lower thermostat is tripped, typically when cold water enters the dip tube during hot water draws. If heavy hot water demand triggers the upper thermostat, the upper element is energized and the lower element is de-energized. The heating capacity of an electric storage water heater is roughly 40-50 percent that of a typical gas water heater, so electric units are more prone to running out of hot water, requiring homeowners to be more mindful of hot water usage patterns.

From the "source[28]" energy perspective employed under California's Title 24 energy code, electric resistance storage water heaters are not highly regarded, despite the fact that from a strict Btu viewpoint, electric storage standby losses are considerably lower than for a center flue atmospheric gas water heater[29]. However coupling renewable technologies, such as solar thermal, with electric storage may well be a viable option. Solar water heating is the logical renewable technology, but there are other potential renewable strategies that can complement electric storage units as well. One strategy is to utilize off-peak (excess) wind generation to charge electric resistance tanks to high temperatures, and coast through next day utility peak periods[30]. Electric water heating technologies coupled with renewable generation also simplify the pathway to achieving true net zero energy homes.

3.4.5 Instantaneous Electric Water Heaters

Instantaneous electric water heaters offer an alternative to electric storage water heaters. Similar to the comparison between gas storage and gas tankless, instantaneous electric offers

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[27] http://www.hotwater.com/water-heaters/residential/hybrid/next-hybrid-gas/

[28] Source energy reflects the energy consumed at the power plant (as well as transmission and distribution system losses) to deliver 1 kWh to the end user. Historically the California Energy Commission has assumed 1 kWh delivered requires 3 kWh of "source" energy. In recent years the source energy calculation has become more sophisticated.

[29] The center flue design of a standard gas storage water heater results in significantly higher standby losses. The 78 percent recovery efficiency of a center flue water heater is reduced 23 percent to approximately 60 percent (0.60 EF) with standby losses. Conversely an electric storage water heater is reduced only about 10 percent, from 99 percent recovery efficiency to 0.90 EF.

[30] http://www.steffes.com/off-peak-heating/renewable-energy-storage.html

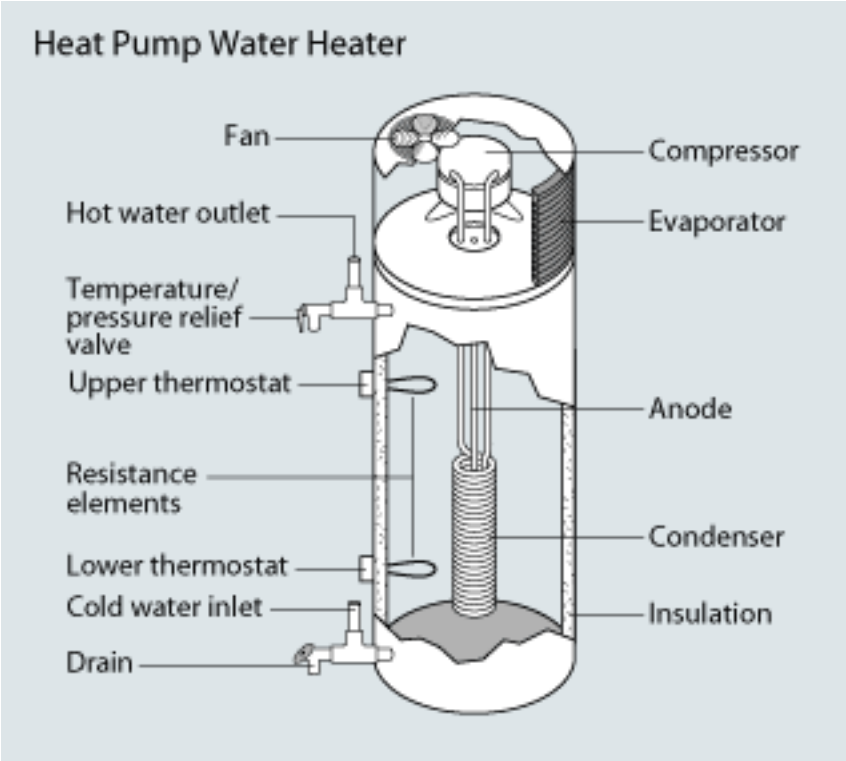
the advantage of small physical size and elimination of standby losses, however the efficiency benefit due to eliminating tank standby losses is smaller than for gas tankless vs. atmospheric gas storage. The real performance advantage of instantaneous water heaters lies in point of use applications where hot water distribution losses can be eliminated. Instantaneous electric water heaters come in sizes ranging from 120 V units that serve individual bath faucets, to the more typical 240 V units with capacities ranging from 9 to 32 kW. The 240 V units require significant electrical capacity (with resulting peak electrical demand implications), which may prove challenging to implement, especially in retrofit applications. The larger capacity units cost more than standard electric water heaters, but may result in a first cost advantage if significant distribution piping costs can be eliminated.

Ideal applications for instantaneous electric water heaters would be locations with low electric rates, houses with widely spread out use points, and applications where a fairly constant source of year round supplemental heat could be used to deliver pre-heated water allowing downsizing of the required heater and also minimize the use of inefficient electric heat. This supplemental heat could be in the form of solar water heating, or some sort of waste heat recovery.

3.4.6 Heat Pump Water Heaters

Heat pump water heaters (HPWHs) offer the potential for significant energy savings relative to electric resistance water heaters. A HPWH system is comprised of a storage tank, a refrigeration system (compressor, fan, and heat exchangers for extracting heat from the air, and for delivering heat to the storage tank), controls, and in some cases a pump to circulate water. The unit can either be "integrated" with the storage tank (as shown in the schematic in Figure 20) or be an add-on module that is mounted on or adjacent to a conventional electric water heater. Pumps, activated when the compressor operates to circulate water to the condenser, are used with some models, depending upon the configuration. All models currently on the market provide the user control over the extent to which the unit utilizes electric resistance heating to supplement heat pump operation. This feature is desirable in some situations, since the heat pump recovery capacity is lower than for standard gas and electric water heaters, as shown in Table 9.

Figure 20: HPWH Schematic of Integrated Unit with Immersed Heat Exchanger



http://www.eere.energy.gov/basics/buildings/water_heaters_heat_pump.html?print

Table 9: Heating Rate Comparison by System Type

System	Typical capacity	Heating Rate (Btu/hr)
HPWH (compressor capacity)	0.5 to 1.0 ton	6,000 to 12,000
HPWH backup electric heat	2.0 to 4.5 kW	6,830 to 15,350
Typical electric storage capacity	4.5 kW	15,350
Typical gas storage WH capacity	33,000 – 40,000 Btu/hr	33,000 to 40,000

In the heat pump mode of water heating operation, refrigerant is vaporized at the evaporator coil (extracting heat from the surrounding environment), compressed to a high temperature gas via mechanical work (compressor input), and then condensed, delivering heat to the storage volume. With current conventional refrigerants, the thermodynamics dictate that the energy added to the water is roughly 2-3 times greater than the electrical energy consumed by the compressor and fans. Efficiency degradation in the heat pump cycle occurs as tank water temperatures become hotter and the air entering the evaporator becomes cooler.

HPWH controls allow the user to select both the tank setpoint and an operating mode, which determines whether system operation is biased towards "heat pump only" operation, or electric

resistance heating. "Heat pump only" mode offers the highest efficiency, but also the lowest recovery capacity since it relies only on heat pump heating. "Resistance only" operation provides performance comparable to a standard electric storage water heater, hence no energy savings. The hybrid mode, which may turn out to be how most users utilize these systems, offers a balance between the two extremes. Each manufacturer utilizes a different hybrid control strategy to balance heat pump and resistance heat operation. Data from the field is informing the manufacturers on hot controls should be modified to improve performance without compromising hot water delivery.

Relative to gas and electric storage water heaters, HPWHs require a significant volume of air (typically 700-1000 ft^3) to insure that operation will not overcool the space, resulting in low evaporator inlet air temperatures, leading to a low temperature cut-out situation (typically at around 45°F). All of the listed HPWHs require 240V electrical service which is not an issue in new construction (or in retrofit applications if an existing electric water heater is being replaced), however it would represent an added cost a gas water heater were being replaced. In many California applications, these units will be installed in garages. Since HPWH heating capacity and efficiency are proportional to the evaporator inlet air wet bulb temperature, colder climates and colder operating environments will reduce system performance. Indoor HPWH installations offer the potential for improved performance in cooling-dominated climates where additional cooling is beneficial.

3.4.7 Lab Findings on Advanced Water Heater Performance

One element of the PIER project was to utilize both laboratory and field testing results to better characterize the performance characteristics of high-efficiency gas-fired water heaters. Lab testing is generally more useful for precisely identifying performance characteristics and control nuances under very controlled conditions, while field testing allows for real world effects to be observed and quantified. In support of this effort, the Gas Technology Institute and Pacific Gas & Electric (PG&E) evaluated high-efficiency water heaters in their test labs, focusing on two classes of products:

- **High-Efficiency Storage Water Heaters** (PG&E effort) – Driven by both the change in EnergyStar® requirements and the 2015 change in the federal minimum efficiency standards, manufacturers have filled out their gas-fired storage water heater (SWH) product families to meet these efficiency requirements. In addition to new condensing, power/direct vent, and hybrid gas-fired SWH offerings, many new products are compatible with Category I venting, including features such as small combustion air blowers & inducers and powered vent damper. Unlike the common minimum efficiency products, these > 0.67 EF products are powered, resulting in parasitic energy consumption and susceptibility to power outages.
- **Tankless Water Heaters** (GTI effort) – Gaining popularity over the past decade, tankless water heaters (TWH) have enjoyed increasing market share due to their high-efficiency relative to standard gas-fired SWHs, marketing of "endless hot water", and incentive programs. Deficiencies in the field versus EF rated efficiency of tankless water heaters are a known issue (Davis Energy Group, 2007; Bohac et al, 2010) due to the minimum draw rate

requirements and startup sequence delays. The GTI lab effort focused on characterizing physical parameters, start up sequences, standby capability, and ability to maintain temperature stability under varying hot water loads.

PG&E testing was completed on a group of water heaters listed in Table 10[31]. Tests were completed according to the Energy Factor procedure to replicate results and also determine the first hour rating. Two more realistic draw profiles developed by GTI were also used: the "mid" case had loads equal to the 64 gal/day EF test, but distributed in a more realistic use pattern, while the "low" use case featured a 30 gal/day load, also with a more realistic profile. The key points to highlight in Table 10 are:

- The general agreement of manufacturer and tested EF ratings at the "DOE Std Draw" condition.
- The minimal impact the EF six draws vs. GTI Mid "real" draw pattern has on the EF.
- The impact of the "Low" draw pattern on overall efficiency and the implications for climates with lower recovery loads, such as California.

Table 10: EF Results for Storage Water Heaters

Description	**DOE First Hour Rating**		**DOE Std Draw**		**GTI Mid Draw**	**GTI Low Draw**
	Mnfr.	Test	Mnfr.	Test	Test	Test
"15 Year Old" Water Heater	63	80	0.64	0.59	0.60	0.44
0.62 EF Atmospheric	71	70	0.62	0.60	0.60	0.48
0.67 EF Atmospheric/Vent Damper	67	70	0.67	0.66	0.66	0.57
0.67 EF Power Vent	70	89	0.67	0.64	0.64	0.53
0.67 EF Direct Vent	73	76	0.67	0.64	0.64	0.53
0.70 EF Atmospheric/Fan Boost	70	77	0.70	0.66	0.66	0.54
Hybrid	189	130	90 percent	0.68	0.68	0.56
Condensing Storage	123	148	90 percent	0.74	0.73	0.62

[31] Note that the "15 year old" water heater was one of the existing units removed as part of the field test.

As water heater recovery loads go down, not only is the efficiency of the water heater reduced, but the absolute savings are reduced, affecting cost-effectiveness. Since all the >.67 EF water heaters require electrical input, there is also the question of electrical energy use. With typical standby consumption of 5 Watts for controls, plus more during operation (combustion fans), the electrical energy use can start to erode the value of the gas savings.

The four tankless water heaters tested by GTI are shown in Table 11. One non-condensing and three condensing units were tested. The variation in water side volume has implications for hot water delivery characteristics. The fourth unit, with the 2 liter buffer tank, has the ability to heat the buffer tank on a schedule (from 0 to 24 hours per day), providing improvement in hot water delivery characteristics at the expense of added energy use.

Table 11: Tankless Water Heater Description and Model Numbers

Description	Firing Rate (Btu/hr)		Certified Performance			Unit Weight (lbs)	Water side volume (L, measured)
	Min	Max	EF	Max GPM	at ΔT (°F)		
Non-condensing	11,000	199,900	0.82	4.3	77	54	0.875
Condensing #1	9,500	199,000	0.93	4.4	77	70.5	1.7
Condensing #2	19,900	199,000	0.91	6.7	55	74	0.92
Condensing with small 2 liter buffer tank	17,000	199,000	0.95	5.1	77	86	3.7

Table 12 reports the test results under the DOE EF test conditions as well as the GTI mid and low use tests. The degradation in efficiency from the rated EF is apparent, although less so for Condensing #1 & 2. The continuous (24 hour) heating of the buffer tank has a sizable impact on the EF reducing it from 0.85 to 0.67.

Table 13 summarizes average and maximum time delays for draws included in the GTI mid draw profile. For most of the units, the average time delay to fire is about 5 seconds, with typical delays in delivering water at 95 percent of setpoint between 15 to 30 seconds. Longer delays were experienced in the buffer tank unheated case. These time delays are of course compounded by the time delays related to getting the heated water from the water heater to the use point.

Table 12: Summary of 24 Simulator Use Test Data

	EF	Estimated EF		Average Delivered T (°F)		
	DOE	Mid	Low	DOE	Mid	Low
Non-condensing	0.77	0.75	0.73	129.6	125.3	129.9
Condensing	0.92	0.90	0.87	127.5	123.7	123.8
Condensing (Buffer tank heated)		0.67			126.4	
Condensing (Buffer tank unheated)		0.85			119.8	

Table 13: Summary of Delays from GTI-Mid Draw Schedule Testing

	Average Time Delay (seconds)		Maximum Time Delay (seconds)	
	To fire	**To reach 95 percent of final temperature**	**To fire**	**To reach 95 percent of final temperature**
Non-condensing	4.5	15.1	6.0	28.0
Condensing #1	5.4	27.1	6.0	32.0
Condensing (Buffer tank heated)	6.5	13.1	7.0	31.0
Condensing (Buffer tank unheated)	11.3	13.4	18.0	54.0

These laboratory findings should be taken as a snapshot view of a sample of currently available products, and not necessarily representative of the product class as whole. The key goal of presenting this information was to inform the reader of observed performance characteristics in a laboratory setting.

3.4.8 Field Findings on Advanced Water Heater Performance

The PIER field monitoring efforts collected data at the eighteen California field sites (six in Northern California and twelve in the Los Angeles and San Diego areas) over a period of 14 months from spring 2010 to summer 2011. Detailed base case monitoring spanned seven to nine months, at which time advanced gas water heaters were retrofitted at the sites. Post retrofit monitoring continued for four to five months. Detailed data were collected on hot water flows, temperatures in and out of the water heater, and energy consumed by the water heater.

Figure 21 presents an "input-output" plot from one site, showing daily pre- and post-retrofit thermal energy input (gas use) as a function of thermal energy delivered from the water heater. In the example shown, the existing atmospheric gas water heater was replaced with a condensing tankless water heater (CTWH). The blue symbols, representing the base case water heater, indicate higher consumption per unit of energy output than the CTWH unit. Of special note is the Y-axis intercept which identifies the energy required at zero load (standby energy).

The input-output data from each site was averaged among similar units in its product class, defined as:

- Entry level EnergyStar (0.67 – 0.70 EF),
- Non-condensing tankless
- Condensing tankless, and
- Condensing storage.

Figure 21: Sample Daily Input-Output Curve

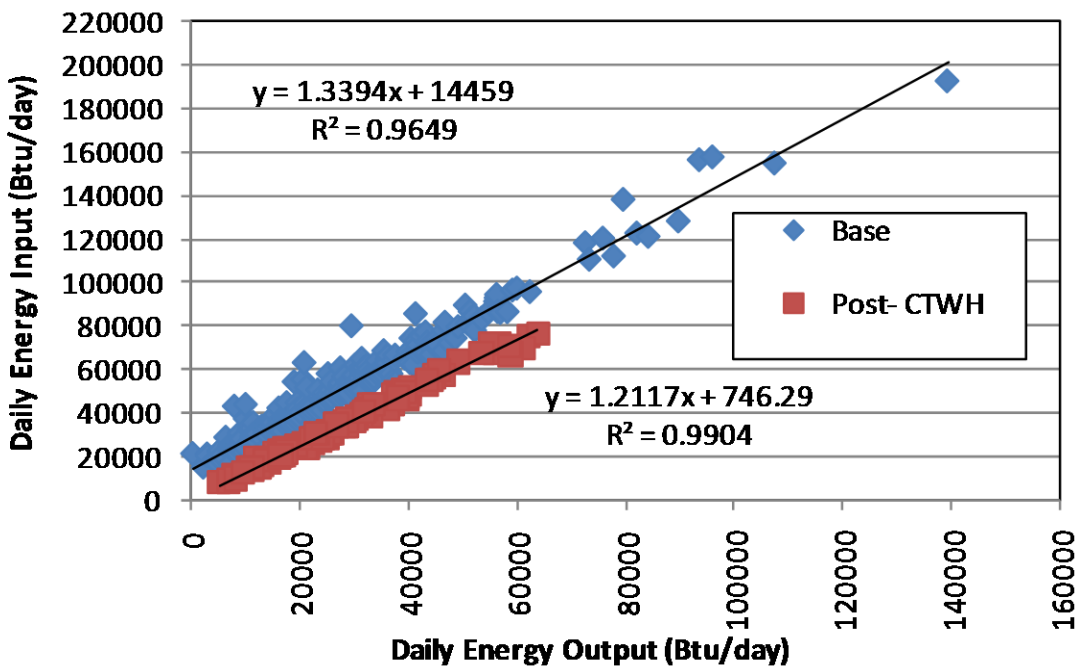
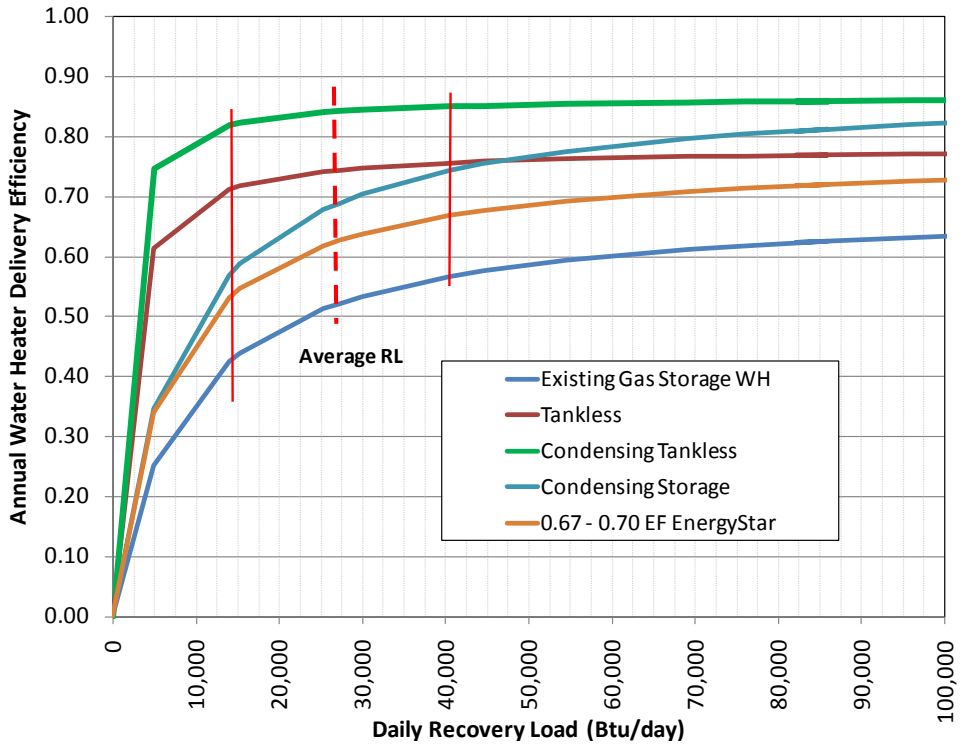


Figure 22 depicts how the efficiency of a particular product class varies with recovery load, based on the monitored performance. The vertical "Average RL" line depicts the observed average load at the 18 sites (over 1/3 lower than the 41,050 Btu Energy Factor recovery load level). (One standard deviation above and below the mean are also shown on the plot.) The key takeaway from this plot is how different water heater product types respond to changes in hot water loads. The existing atmospheric storage gas water heaters show the most degradation from rated efficiency at small loads and tankless units show the least. EnergyStar and

condensing storage water heaters show little advantage at very low load levels, with increasing benefits as the loads increase. As loads exceed the Energy Factor level (41,050 Btu/day), condensing storage projected efficiencies surpass those of the tankless water heater.

Figure 22: Gas Water Heater Comparative Performance as a Function of Recovery Load



Appendix A contains a detailed step-by-step procedure for completing a cost-effectiveness calculation for advanced water heater options for different climates, hot water loads, and utility rates. This tool was developed for DOE's Building America program and is based on the PIER project performance results and HPWH field data provided by the CARB Building America Team.

Key Takeaways:

#1: Water Heater Ratings- Clear evidence from laboratory and field testing indicate that EF ratings do not accurately reflect the performance of water heaters in California. Tankless water heaters are overrated by 8-10 percent, since hot water draws (and therefore cycling impacts) are underestimated in the test procedure. Gas storage water heater performance is (on average) overestimated by at least that much, since typical California water heating loads are 35-40 percent lower than assumed in the test procedure, increasing the impact of standby losses on overall annual performance.

#2: Entry level EnergyStar water heaters (0.67-0.70 EF) are the least cost-effective of the advanced gas water heaters for most California customers. Relatively cheap natural gas and expensive electricity result in gas savings being significantly depreciated due to the 80-100 kWh electrical consumption of these water heaters.

#3: Gas tankless water heaters offer reasonable economics, especially in new construction, but the need for maintenance (in hard water areas) may offset savings.

#4: Gas tankless water heaters do offer a different hot water delivery experience relative to storage water heaters. Increased hot water wait time, no hot water at very low flow rates, and "cold water sandwich" effects will occur. For most customers this may not be a significant issue. For others, it may be an inconvenience.

#5: Trends in water and energy conservation are pushing hot water loads lower and lower. This has implications on performance (storage unit performance is further degraded; tankless unit minimum flow rate issues and hot water waiting times become more significant), as well as economics.

#6: HPWHs offer significant potential as an energy efficient alternative to electric storage water heaters. In California, electric water heating is not that common, representing slightly over 10 percent of residential customers. High electric rates in much of the state, also contribute to poor economics relative to natural gas water heating. The best applications may be zero net energy projects where HPWHs can be an effective component of an all-electric home.

3.5 Load Reduction Strategies

The movement towards more efficient water heating systems in the years ahead will ultimately lead the industry to develop and implement strategies that reduce the load on the gas or electrically driven water heaters. Examples of such load reduction strategies include solar thermal systems, drain heat recovery devices, desuperheaters, and possibly grey water heat pump pre-heaters.

Solar thermal is an attractive renewable technology to combine with conventional water heating strategies to reduce fossil fuel water heating energy use. Ideally an effective solar thermal system would provide year round consistent contributions to the daily hot water load, allowing for conventional system downsizing (e.g. reduced capacity tankless unit) or improved performance (e.g. lower load on a HPWH would likely reduce resistance heat operation). In reality, for many U.S. climates, the solar contribution can be large during the summer, but contribute little in the winter months when water heating loads are highest. Solar integration and optimization are important areas to explore in the pursuit of a high performance domestic water heating system. This study will not address these issues in any detail, but refers readers to the Building America Best Practices Series on Solar as a starting point (Baechler et al, 2007)[32].

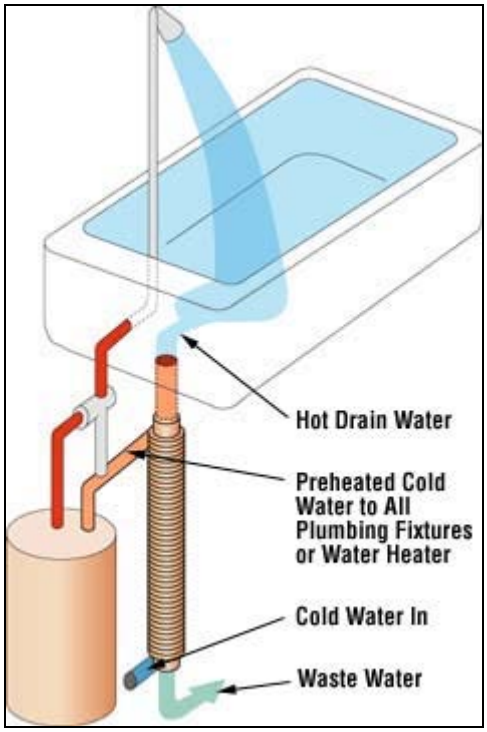
Other potential water heating load reduction strategies that should be explored include drain water heat recovery systems which reclaim heat from water used in showers. As shown in Figure 23, the system (a copper heat exchanger that pre-heats cold inlet shower water with warm/hot shower drain water) will reduce the required hot water flow rate at the shower since the cold water is warmer. The system requires a second story shower, or first story if there is a basement, but the beauty of the design is that it will reliably reduce the load on the water heater year round. The benefit of the device is proportional to the flow of water through it and the temperature difference between drain water and entering cold water. Conceptually drain heat recovery systems have positive benefits for a variety of water heating system types. HPWHs would benefit from lower loads by experiencing fewer second stage heating events, and lower capacity gas tankless water heaters could potentially be developed that wouldn't require a gas line upsizing for retrofit applications[33]. Further research is needed to assess these impacts.

It is important to realize that any load reduction technology will reduce the load on the primary water heater, which has implications on the operating efficiency, as characterized in Figure 22.

[32] http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/41085.pdf and http://www.nrel.gov/gis/femp.html#water

[33] A potential concern exists in matching drain heat recovery with gas tankless units in warm or hot climates, since hot water flows may fall below the unit's minimum flow rate.

Figure 23: Drain Heat Recovery Schematic



Source: http://www.toolbase.org/Technology-Inventory/Plumbing/drainwater-heat-recovery

CHAPTER 4:
Design Recommendations

Architects, builders, and contractors all have an opportunity to positively influence the performance and efficiency of domestic hot water systems in new and existing buildings. Existing buildings are clearly a much bigger challenge since retrofit costs and site difficulties complicate more aggressive efforts to improve overall system performance. The goal should always be to reduce the load on the water heater, despite the fact that this may contribute to lower water heater efficiency.

The load on the water heater can be reduced in several ways:

1. By developing a house design that increases the efficiency of the distribution system (lower losses, reduced distance and entrained pipe volume between the water heater and the use points) [NEW CONSTRUCTION],
2. By selecting more efficient fixtures and appliances which reduce the need for hot water,
3. By offsetting a portion of the load through waste heat recovery or renewable sources, and
4. By educating homeowners on behaviors that contribute to lower hot water consumption.

By reducing the water heater recovery load, matching an appropriate water heater to the load, and educating the consumer on how to achieve optimal performance, one can achieve energy savings and improved system performance in terms of reduced water waste and waiting summary. A summary of the key elements follows:

Building Design From a Plumbing Perspective ("short and central")

The process begins, in the case of new homes, with the architectural design and the location of the water heater and hot water end use points in the home. One water heater centrally located relative to the use points (or two separated water heaters, each centrally located) represent an ideal configuration, in that the entrained volume between the water heater and the use points can be significantly reduced, if the plumbing layout is efficent and properly sized. A centrally located water heater improves hot water waiting time, and reduces water waste and energy losses from the piping. A smaller plumbing design also often eliminates the need for a recirculation system, since the driving factor in selecting a recirculation system is often unsatisfactory hot water waiting times. In some large homes, a second water heater may be a logical solution to add water heating capacity (and some level of supply redundancy), improve hot water delivery efficiency, and reduced distribution related waste. (Care should be taken in the selection of the second water heater, since it is generally not advisable to have two storage water heaters, each with significant standby energy consumption.)

In cases where centrally locating the water heater is problematic (e.g. exhaust venting is complicated or costly), every effort should be made to at least locate the water heater in a

location that balances "central-ness" vs. added installation cost. Remember that the first cost savings associated with installing a gas tankless unit on an exterior garage wall (easy install), maybe more than offset by the added cost associated with a larger distribution system which will affect the consumer every day.

The architect must also take a hard look at the building design in terms of grouping hot water end points so that synergies can be achieved. The example shown in Figure 3 highlights how putting the master bath and kitchen "back-to-back" increases the likelihood of draws benefitting from existing hot water in the lines providing hot water for subsequent kitchen draws, and vice versa. Small distribution systems, with clustered use points, should be the goal of all designs.

Fixture and Appliance Selection

Showerheads represent the primary hot water end use in most households, conservatively representing ~ 20 percent of total indoor (hot and cold) water use in the U.S[34] (Mowris, 2010). EPA supported the development of a WaterSense showerhead standard[35] at a level of 2.0 gpm, 20 percent lower than the Federal standard of 2.5 gpm. In addition, significant testing was completed to characterize "performance" of WaterSense qualified showerheads with regards to temperature, shower force, coverage, rinsing action, and noise (Mowris, 2010). So as well as requiring less hot water, these units have been shown to provide high levels of consumer satisfaction. Directing designers, builders, and plumbers towards WaterSense showerheads will result in shower hot water use savings.

In addition to showerheads, WaterSense also provides a list of qualified bathroom sink faucets that can reduce sink water use by 30 percent[36]. Sink hot water use is a highly behaviorally driven usage, as different people have different methods of interacting with the fixture. Arguments can be made that single lever faucets may draw more hot water inadvertently as many users may naturally operate the faucet in the vertical position (half hot, half cold), regardless of whether they will actually wait for the hot water to arrive.

Finally appliance selection can further reduce hot water loads. Efficient clothes washers[37] and dishwashers can reduce appliance water use. These efficient units are often also eligible for water utility rebates. Providing these appliances as part of a standard builder package would demonstrate a strong commitment to water and energy efficiency.

It is important that these issues also become part of the retrofit discussion. Many existing showerheads, faucets, and appliances are inefficient in terms of flow rate or water use.

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[34] an estimated 3.8 million gallons per day.

[35] http://www.epa.gov/WaterSense/docs/showerheads_finalspec508.pdf

[36] http://www.epa.gov/WaterSense/products/bathroom_sink_faucets.html

[37] http://www.energystar.gov/index.cfm?c=clotheswash.pr_crit_clothes_washers

Homeowners and plumbers need to become familiar with various low-flow options so that they can make informed decisions on what works best for their needs.

Distribution System Design and Installation

The architectural design represents the critical first step in defining the hot water system performance, but a poorly designed and implemented plumbing layout can still ruin a fundamentally "good" architectural design. More attention needs to be paid by the plumbing designer in making sure that the intended plumbing design is properly implemented in the field. PEX is an attractive piping material, but it does facilitate the potential for a fast and sloppy installation where the piping is run where it is easiest to run, rather than in a manner conducive to efficient hot water delivery.

General rules to follow:

1. Avoid using 1" piping unless detailed pipe sizing calculations warrant its use. In virtually all residential applications, there is no need for 1" piping.
2. Minimize the use of ¾" and larger piping. For "trunk and branch" or hybrid configurations, avoid the long trunk line snaking through the attic, if a more direct route from the water heater can be achieved more directly.
3. Home run manifold systems can offer an efficient alternative, even more so if 3/8" piping is allowed by the local building jurisdiction. It is absolutely critical to keep the water heater to manifold distance at an absolute minimum to achieve good home run system performance.
4. Hybrid systems with distributed mini-manifolds should strive to keep the manifolds close to the water heater.
5. Recirculation systems are certainly appropriate for some applications or for satisfying discriminating client who demand immediate hot water delivery. Prior to selecting a recirculation system, a careful review of the plumbing design should be completed. Is a second water heater a better solution? If so, a small powder room could possibly be served by a 1 gallon electric instantaneous unit on a timer. Or a tankless water heater or HPWH may be the right solution. Consider the standby energy impacts of having two storage water heaters. If a recirculating system is to be selected, the demand recirculation system with push button control represents the best option. Careful recirculation loop sizing (to avoid pipe oversizing) and balancing of the loop layout vs. the loop proximity to the end use points is critical. If a recirculation system is still needed, use demand recirculation for best performance.
6. Installation practice should focus on avoiding excess pipe length and high quality pipe insulation installation. (A good pipe insulation job is especially critical in recirculating

systems.) Attic piping should be buried in blown ceiling insulation[38], especially PEX and CPVC due to their high radiant heat loss when uninsulated.

7. It is important to think of distribution losses and water waste in a manner similar to atmospheric water heater pilot energy (estimated to be equal to 6 percent of California residential gas consumption). Although impacts due to improvements are often not large, the cumulative statewide impact is significant.

Water Heater Selection

Numerous efficient water heater options are now available in the marketplace. Many of these new options come with a significant price premium, primarily due to current low production volumes which result in higher unit costs. High installation costs for efficient technologies are especially common in the retrofit market where transaction costs are high and some technologies (e.g. gas tankless) often require very costly infrastructure upgrades. The tool in Appendix A allows one to evaluate the cost effectiveness of various high efficiency equipment options.

For much of California, it appears that typical existing household water heating loads are roughly 30-40 percent lower than assumed in the Energy Factor test procedure. As loads continue to diminish in the future through improved fixtures and appliances (and potentially solar or heat recovery), economics will tend to drive the water heater selection from high standby storage units, to gas tankless or lower standby storage units. Lower water heating loads will also most likely tend to make the economics of condensing technologies less favorable, as the energy saved per $ of incremental cost is reduced. An important consideration for tankless units in retrofit applications is understanding the existing distribution system performance. A house with long hot water waiting times to the master bath will have that problem magnified by a tankless unit due to the cold start-up time delay.

The selection of advanced water heating systems should also focus on overall reliability and the need for ongoing maintenance. Many of the newer technologies need to log more field operating time before they are widely recognized as reliable water heating systems. Tankless water heaters in areas with poor quality will absolutley require some level maintenance (or water softening) to preserve the performance of the heat exchanger. Maintenance costs may exceed the value of the energy savings, resulting in poor economics, despite the fact that energy savings are realized.

Water heater selection should also look for synergies to increase the energy savings or overall cost effectiveness. An example includes indoor HPWHs in warm climates[39], where the unit

[38] In cases of attic piping and batt insulation, care should be taken to make sure that the piping installed below the batts does not lift the insulation off the ceiling drywall. In that case, the benefit of keeping the pipe out of the more extreme attic environment is more than offset by the house thermal envelope degradation caused by separating the house thermal and pressure boundaries.

serves the dual purpose of water heating and supplemental space cooling and dehumidification. Another important option to consider is combined hydronic systems whereby a single high efficiency heat source (water heater) replaces the conventional furnace and water heater. By replacing the furnace with a lower cost air handler, more favorable economics can often be achieved.

The Efficient Water Heating System Scorecard

In conclusion, we present the following scorecard, which represents a simple summary of the key items discussed in this guide, as it relates to delivering a high performance water heating system. The goal is for each installed hot water system to achieve five checks.

Attribute	Achieved	Not Achieved
Basic building design and hot water use points/ water heater intelligently located?	✓	
Hot water load reduction strategies and water efficient appliances in place?	✓	
Efficient distribution system installed and verified for compactness and low entrained volume; insulation and/or recirculation controls (if installed) properly verified/commissioned?	✓	
Efficient water heater properly installed according to manufacturer's instructions (and local code) and commissioned (take into account actual or expected loads, homeowner expectations, available fuels and rates, installed costs, climate, and incentives)?	✓	
Occupant education completed (how to maximize system efficiency)?	✓	
TOTAL SCORE	✓ 5	

[39] If natural gas is unavailable, or electric rates are low enough to make HPWH's attractive.

GLOSSARY

Term	Definition
ACEEE	American Council for an Energy Efficient Economy
AET	Applied Energy Technology
AIM	Affiliated International Management
ATS	Applied Technology Services at PG&E
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioing Engineers
Btu	British Thermal Units (measure of energy)
CARB	Consortium for Advanced Residential Buildings
CEE	Consortium for Energy Efficiency
CPVC	Chlorinate Polyvinyl Chloride (rigid plastic piping used in plumbing)
CUWCC	California Urban Water Conservation Council
DEG	Davis Energy Group
Demand Recirculation	A recirculation pumping system that responds to a signal (either push button, flow acitivated, or occupancy) to initiate pump operation.
EnergyStar	An EPA program that provides guidance and performance criteria for energy efficient products including water heaters
EF	Energy Factor; the performance rating metric for most residential scale water heaters
EPA	Environmental Protection Agency
First Hour Rating	An estimate of the maximum volume of hot water that a storage-type water heater can supply within an hour that begins with the water heater fully heated
GTI	Gas Technology Institute
HPWH	Heat pump water heater
HWDS	Hot water distribution system
HWSIM	A sub-hourly time step model for simulating the performance of hot water distribution systems and water heaters

Term	Definition
IAPMO	International Association of Plumbing and Mechanical Officials
LBNL	Lawrence Berkeley National Laboratory
PG&E	Pacific Gas and Electric
PIER	Public Interest Energy Research program at the Energy Commission
PEX	Cross linked polyethylene pipe (flexible plastic piping used in plumbing)
quad	A unit of energy equal to quadrillion Btu's
RASS	Residential Appliance Saturation Survey (an Energy Commission sponsored ongoing effort to disaggregate California residential energy use from a broad sample of households)
Recovery Load	the energy load imposed on a water heater and comprised of the hot water distribution losses and the hot water delivered at fixtures and use points
Recovery Efficiency	the ratio of energy delivered to the water to the energy content of the fuel consumed by the water heater
RECS	Residential Energy Conservation Survey (a US Department of Energy effort to disaggregate energy usage on a national level)
SCG	Southern California Gas Company
SDG&E	San Diego Gas and Electric Company
SDR	Standard dimension ratio (for PEX pipe wall thickness)
TWH	Tankless water heater
therm	Quantity of energy used for billing natural gas consumption to customers (equal to 100,000 Btu/hour)
Title 24 Standards	The energy code in California as published by the California Building Standards Commission
Uniform Plumbing Code	The UPC is a model code developed by the International Association of Plumbing and Mechanical Officials to govern the installation and inspection of plumbing systems as a means of promoting the public's health, safety and welfare.
WaterSense	A US EPA program to help consumers make smart water choices. Products and services that have earned the WaterSense label have been certified to be at least 20 percent more water efficient.

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Heat pump water heater measure guideline

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APPENDIX A:
Water Heater Selection Tool

Step 1: Determine Climate

From Table 1 below, select the climate that best characterizes your location. (Note that the selected climate influences both the performance of HPWHs and also the hot water load as cold water supply temperature is dependent on climate).

Step 2: Estimate Hot Water Load

Residential hot water loads are characterized as low, moderate, above average, or high. Realizing that inlet and outlet water temperatures strongly affect the water heater recovery (Btu) load, a rough approximation for the four load categories (in terms of gallons per day) is 20, 45, 65, and 110 gpd, respectively. For new construction, assume either Moderate or Above Average loads, unless more specific household information is available. For retrofit applications, try to assess the current occupant situation, or rely on the load suggestions presented in Table 1. In cases where two load categories are shown, red highlighting indicates the suggested selection. If neither selection is highlighted, either evaluate both load options or use your best judgment.

Table 1: Estimating Hot Water Loads Based on Number of Occupants and California Climate

	Number of Occupants in Household			
Climate Type	**1-2**	**3**	**4**	**5+**
Mountain Regions	Low / **Mod**	**Mod** / Above Avg	**Above Avg** / High	High
North Coast/ Cold Foothills	**Low** / Mod	**Mod** / Above Avg	Above Avg	Above Avg / **High**
Moderate North/Central Inland Regions, Coastal Southern CA	Low	Mod	Above Avg	Above Avg / **High**
Inland Southern California/ Hot Central Valley Regions	Low	Mod	Above Avg	**Above Avg** / High
Hot Desert Regions	Low	Mod	**Mod** / Above Avg	**Above Avg** / High

Step 3: Calculate Electric and Gas Rate Factors to Reflect Local Retail Prices

3a. Calculate Electric Rate Factor

Enter Local Average Electric Rate in the calculation below:

$$Elecfactor = \frac{Local\ Average\ Electric\ Rate(\frac{\$}{kwh})}{\frac{\$0.10}{kWh}(nominal\ Electric\ Rate)}$$

3b. Calculate Gas Rate Factor

1. For natural gas customers, enter Local Average Gas Rate:

$$Gasfactor = \frac{Local\ Average\ Gas\ Rate\ (\frac{\$}{therm})}{\frac{\$1.00}{therm}(nominal\ Gas\ Rate)}$$

2. For propane customers, enter Local Average Propane Rate:

$$Gasfactor = \frac{Local\ Average\ Propane\ Rate\ (\frac{\$}{gallon}) * \frac{gallon}{0.91\ therm}}{\frac{\$1.00}{therm}(nominal\ Gas\ Rate)}$$

Step 4: Calculate Base Case Annual Water Heating Cost

Identify the base case water heater type (gas storage or electric storage). For retrofit projects this is the existing water heater. For new construction this depends on local building code. Calculate Base Case annual costs (BC$) using Table 2 and the appropriate equation below.

Table 2: Nominal Annual Operating Cost vs. Load (based on $0.10/kWh and $1.00/therm)

	Low	Moderate	Above Average	High
Electric Storage	$135	$344	$486	$785
Gas Storage	$95	$190	$258	$412

For electric storage water heater base case:

Annual Base Case Cost (Electric Storage) = Table "X" Cost x $Elec_{factor}$ = **BC$**

For gas storage water heater base case:

Annual Base Case Cost (Gas Storage) = Table "X" Cost x Gas_{factor} = **BC$**

Step 5: Calculate Advanced Systems Operating Cost

5a. HPWH

Use Table 3 to determine nominal annual HPWH operating costs. Note, if the HPWH location is not in unconditioned space (e.g. in a basement or inside conditioned space), move one climate down in the table to approximate improved performance due to more favorable operating conditions (i.e. assuming a HPWH in conditioned space in a cold climate, the operating costs for a marine climate should be used for calculations). Keep in mind that an indoor HPWH will affect space heating and cooling loads; this effect has not been considered in this evaluation process.

Table 3: Nominal Annual HPWH Operating Cost (based on $0.10/kWh)

	Low	Moderate	Above Average	High
Cold/Very Cold/Subarctic	$102	$194	$290	$574
Marine	$84	$157	$230	$437
Mixed Humid	$71	$132	$191	$352
Hot/Dry/Humid, Mixed/Dry	$62	$114	$163	$295

Annual HPWH Operating Cost = Table "Y" Cost x $Elec_{factor}$ = Total$

5b. Advanced Gas Water Heaters

Using Table 4 determine projected annual advanced gas water heating cost for technologies that are being considered. Calculate actual annual gas cost for each technology using the local Gas_{factor}. Electric usage is estimated at 80 kWh/year for all of the advanced gas technologies. Apply local $Elec_{factor}$ to determine annual electric costs.

Table 4: Nominal Advanced Gas Water Heater Operating Cost (assumes $1.00/therm)

	Low	Moderate	Above Average	High
EnergyStar < 0.70 EF	$77	$166	$231	$376
Condensing Storage	$70	$144	$197	$317
Tankless	$49	$133	$193	$329
Condensing Tankless	$41	$116	$169	$290

Advanced WH Annual Gas Cost =

Table Cost x Gas_{factor} = [ ] Gas$

Advanced WH Annual Electrical Cost =80 kWh x $.10/kWh x $Elec_{factor}$ = [ ] Elec$

Advanced WH Total Operating Cost = Gas$ + Elec$ = [ ] Total$

Evaluate annual operating costs for all gas water heaters of interest.

Step 6: Estimate Incremental Costs and Define Viable Options

Incremental costs for a specific technology in a specific application will vary based on many factors, especially in retrofit situations where site factors will significantly affect the implementation costs for a given technology. Equipment make and model, product pricing through existing distribution channels, plumber familiarity with the technology, and site factors (gas line upsizing, electrical circuit upgrade, venting issues, etc) are a few of the factors that will influence final project costs. Table 5 presents default incremental costs for each of the identified technologies. The costs were developed from a variety of sources including recent vendor surveys as part of Davis Energy Group's ongoing retrofit program activities, the NREL cost database, and online price quotes. It is highly recommended that current bids or refined estimates are used in lieu of the default costs, if possible.

Table 5: Default Incremental Installed Costs†

	New	Retrofit
HPWH	$1,000	$1,500
EnergyStar < 0.70 EF	$400	$800
Condensing Storage	$700	$1,600
Tankless	$600	$2,000
Condensing Tankless	$900	$2,300

† Ideally use site-specific cost estimates in lieu of default values

Step 7: Calculate Projected Savings for All Alternatives

New construction and retrofit applications are deemed to have different economic drivers. For new construction, the presumption is that a positive cash flow on a fixed rate thirty year mortgage would be a favorable investment. For retrofit, a ten year simple payback is the metric for determining the cost-effectiveness of various efficiency alternatives. For simplicity the calculation does not take into account the impact of gas/electric rate escalations or mortgage tax deduction benefits, although one could perform such a calculation, if desired.

For new construction cases, go to step 7a, and for retrofit proceed to step 7b.

Step 7a: Calculate Projected Cost Effectiveness for New Construction Case

Table 6 presents amortization factors for both 15 and 30 year fixed rate loans. Select the appropriate Amortization Factor (**AF**), with interpolation between values allowed, if needed.

Table 6: Amortization Factor (Fixed Rate Loan Assumed)

Interest Rate	Amortization Factor (30 year term)	Amortization Factor (15 year term)
3 percent	0.051	0.083
4 percent	0.057	0.089
5 percent	0.064	0.095
6 percent	0.072	0.101
7 percent	0.080	0.108

To compute cost effectiveness, enter **BC$** from Step 4 in the Base Case row and **Total$** for alternative system options from Steps 5a and 5b into column A of Table 7. In Column B, subtract base case operating costs to determine annual savings (positive value in Column B).

Table 7: New Construction Annual Savings Calculation

System Type	[A] Annual Operating Cost ($)	[B] Projected Annual Savings ($)
Base Case	BC= $	n/a
HPWH	A1: $	= BC – A1 = $
EnergyStar < 0.70 EF	A2: $	= BC – A2 = $
Condensing Storage	A3: $	= BC – A3 = $
Tankless	A4: $	= BC – A4 = $
Condensing Tankless	A5: $	= BC – A5 = $

Table 8 requires the entry of information from Tables 5-7 and also the existence of any local incentives that would reduce the cost of the advanced measure. A cost effectiveness ratio is calculated as shown in Column E. Any measure with a value greater than one is deemed cost-effective, with larger values indicating greater cost-effectiveness.

Table 8: New Construction Cost Effectiveness Calculation

	A	B	C	D	E
	(Table) Annual Savings ($)	(Table) Amortization Factor	(Table) Incremental Cost ($)	Incentives ($)	Cost Eff Ratio A/(B*(C-D))
HPWH					
EnergyStar < 0.70 EF					
Condensing Storage					
Tankless					
Condensing Tankless					

Step 7b: Calculate Projected Savings for Retrofit Case

This tool presumes a ten year simple payback as a reasonable retrofit economic criterion for assessing cost-effectiveness of competing technologies. To compute ten year savings enter **BC$** from Step 4 in the Base Case row and **Total$** from Steps 5a and 5b for alternative system options into column A of Table 9. In Column B, ten year savings are calculated.

Table 9: Calculation of Ten Year Savings

System Type	[A] Annual Operating Cost $	[B] Ten Year
Base Case	BC= $	n/a
HPWH	A1: $	= 10 * (BC – A1) = $
EnergyStar < 0.70 EF	A2: $	= 10 * (BC – A2) = $
Condensing Storage	A3: $	= 10 * (BC - A3) = $
Tankless	A4: $	= 10 * (BC - A4) = $
Condensing Tankless	A5: $	= 10 * (BC - A5) = $

Two final factors affecting cost may come into play before completing a final determination of alternative system cost-effectiveness: incentives or tax credits and costs associated with site-level fuel switching. Local, state, and or federal incentives or tax credits for individual technologies may be available. Fuel switching costs include those associated with converting a site from electric-to-gas (in areas where gas service is new to the area) or from gas/propane to electric (where electric rates are low and HPWHs may be attractive)[40]. Table 10 is used to compute retrofit cost effectiveness taking into account these two factors. Incentive amounts are entered into Column C and Column D is designed to include costs associated with fuel switching. Column E performs the final calculation for determination of savings for a specific technology.

[40] In this case, there will be a cost for running a 240V dedicated circuit to the HPWH.

Table 10: Retrofit Cost Effectiveness Calculation

	A	B	C	D	E
	(Table) Ten Year Savings	(Table) Est. Incr. Cost	Incentives	Fuel Switch Cost	Calculated Savings (A+C)-(B+D)
HPWH					
EnergyStar < 0.70 EF					
Condensing Storage					
Tankless					
Condensing Tankless					

Compare ten year savings to incremental installation cost. If the savings are > than incremental installation cost, then the measure is deemed cost-effective over a ten year time horizon.