U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Strategy Guideline: Proper Water Heater Selection

M. Hoeschele, D. Springer, A. German, J. Staller, and Y. Zhang
Alliance for Residential Building Innovation (ARBI)

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Prepared by:

M. Hoeschele, D. Springer, A. German, J. Staller, Y. Zhang

Alliance for Residential Building Innovation (ARBI)

Davis Energy Group, Team Lead

123 C Street

Davis, California 95616

NREL Technical Monitor: Stacey Rothgeb

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Notice

The work presented in this report does not represent performance of any product relative to regulated minimum efficiency requirements.

The laboratory and/or field sites used for this work are not certified rating test facilities. The conditions and methods under which products were characterized for this work differ from standard rating conditions, as described.

Because the methods and conditions differ, the reported results are not comparable to rated product performance and should only be used to estimate performance under the measured conditions.

Acknowledgments

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Contents

List of Figures

Unless otherwise noted, all figures were created by the ARBI team.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

List of Tables

Unless otherwise noted, all tables were created by the ARBI team.

Definitions

ACEEE	American Council for an Energy Efficient Economy
AFUE	Annual Fuel Utilization Efficiency
ANSI	American National Standards Institute
ARBI	Alliance for Residential Building Innovation
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEDB	Building Energy Data Book
Btu	British thermal unit
CARB	Consortium for Advanced Residential Buildings
CEC	California Energy Commission
CEE	Center for Energy and Environment
DOE	Department of Energy
DEG	Davis Energy Group, Inc.
DHW	Domestic hot water
^{o}C	Degrees Celsius
^{o}F	Degrees Fahrenheit
EERE	Energy Efficiency and Renewable Energy
EF	Energy factor
EIA	Energy Information Administration
FSEC	Florida Solar Energy Center
EPA	Environmental Protection Agency
gpd	Gallons per day
gpm	Gallons per minute
HP	Horsepower

HPWH	Heat pump water heater
IPC	International Plumbing Code
IRC	International Residential Code
kBtu/h	Thousand British Thermal Units per hour
kWh	Kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory
MBtu	Million Btu
NAECA	National Appliance Energy Conservation Act
NO_x	Nitrogen oxide
PIER	Public Interest Energy Research
RECS	Residential Energy Consumption Survey
UPC	Uniform Plumbing Code
W	Watt

Executive Summary

This Strategy Guideline on proper water heater selection has been developed to provide step-by-step procedures for evaluating preferred cost-effective options for energy efficient water heater alternatives based on local utility rates, climate, and anticipated loads. These procedures, developed both for individual water heater applications (both single and multi-family) and multifamily central systems, provide users with projections on operating cost savings over a 10-year time horizon for retrofit applications and on a cash flow basis for new construction. The savings information, combined with installation cost estimates, allows one to determine which alternatives make sense for a particular application. The information presented in this guideline is based on latest monitoring results from residential field assessments of advanced gas water heater systems and heat pump water heater (HPWH) systems. The methodology presented here can be further refined as more data becomes available on emerging water heating technologies.

The tool is targeted at both single and multifamily new and retrofit applications. The intended audience includes:

- Builders and Building Owners
- Plumbers
- General Contractors
- Homeowners.

This guideline fills an important need because it moves beyond a simplified approach of comparing alternative water heating systems based on a single performance metric. By recognizing the load variations on equipment performance, climate differences, and retail fuel rates, one can develop a more customized performance assessment of competing technologies. This guideline represents the first step in the process of developing a comprehensive system-based evaluation of optimal water heater system design, which will hopefully be developed in the near future.

Other Building America-sponsored activities will lead to measure guidelines that focus on technology-specific implementation details related to installation issues in new and existing homes. These guidelines will address issues related to combustion air, venting requirements, space conditioning impacts, safety issues, and other implementation details. The CARB team has developed such a guideline on HPWHs, entitled "Heat Pump Water Heaters in New and Existing Homes", and IBACOS is in the process of finalizing a tankless water heater guideline.

1 Residential Water Heating Background Information

1.1 National Overview

According to the U.S. Department of Energy's (DOE) 2010 Building Energy Data Book (BEDB)[1], residential water heating consumes 2.9 quads of primary energy annually, or 13.1% of the energy delivered to residential buildings (Figure 1). In milder climates, water heating represents an even larger fraction of total household consumption. For example, the 2009 California Residential Appliance Saturation Survey[2] indicates that average household water heating gas use represents 49% of the 354 therm/year household consumption (versus 37% for space heating), in contrast to the roughly 2:1 national heating to water heating ratio shown in Figure 1.

More than 92% of U.S. households live in either single-family homes or multifamily buildings with four or less units (RECS 2009). For this segment of the population, individual water heaters represent the water heating appliance of choice. For the remaining ~8% of households, central water heaters serving multiple households represent the most common system type.

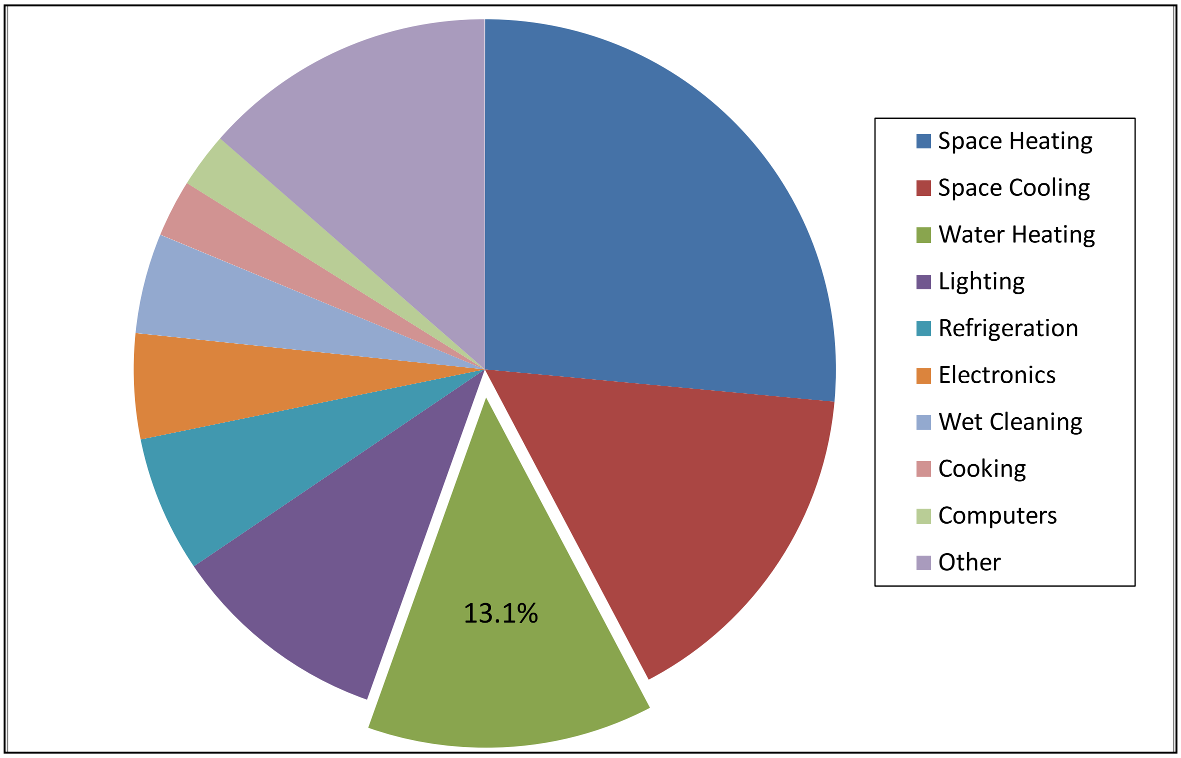

Figure 1. 2010 BEDB residential primary energy use breakdown

Over the past 70 years, storage water heaters have been the predominant water heater type in the United States, making up over 95% of the existing units installed in single and multifamily

[1] http://buildingsdatabook.eren.doe.gov/docs%5CDataBooks%5C2010_BEDB.pdf
[2] http://www.energy.ca.gov/appliances/rass/

households. Recently, gas tankless water heaters have made inroads with industry projected gas tankless sales of over 400,000 units per year (or 5% of annual sales) with near-term growth expectations significantly exceeding that of conventional storage water heaters[3]. Storage water heaters maintain a reservoir of heated water available at all times, resulting in instantaneous delivery of hot water. Maintaining the hot water reservoir comes at the expense of standby losses attributed to tank losses and pilot energy common to virtually all atmospheric gas storage water heaters. Regardless of hot water demand, standby energy losses occur with storage water heaters. In looking toward a future with more efficient water heating ***systems***, not only are efficiency improvements necessary at the heat source, but water heater recovery loads also must be reduced through a combination of improved appliances, fixtures, and showerheads, as well as improved hot water distribution systems. In this environment, conventional storage water heaters, especially center flue gas units, will look increasingly undesirable as a component of an energy efficient home.

1.2 Where Does Hot Water Energy Go?

The breakdown of hot water energy use in a single or multifamily building type is comprised of the energy consumed at the fixtures, the distribution losses resulting from delivering hot water from the water heater to the use points, the water heater combustion (or conversion) inefficiencies, and the associated standby losses (see Figure 2). Distribution losses vary widely based on factors including building type, presence (and control type) of a recirculation system, configuration of the distribution system, and use quantities and patterns. Gas water heater combustion inefficiencies typically range from 5%-25% of the recovery load, while electric inefficiencies are close to zero for electric resistance heating. Standby losses represent the energy required to maintain the system in an active mode[4]. Gas tankless water heaters eliminate this standby thermal parasitic[5], but exhibit cycling degradation as each draw requires the heat exchanger to be brought up to temperature, resulting in additional energy use, water waste, and a delay in hot water delivery. Auxiliary system inputs include energy contributions from solar systems, drain heat recovery devices, and desuperheaters.

In multifamily buildings, one finds either individual water heaters serving each apartment, or a central water heating system where multiple dwelling units are served from a single water heater system. This can encompass one or more water heating devices and/or storage tanks. The central systems generally feature a pumped recirculation loop to more quickly deliver hot water to individual dwelling units. Figure 3 shows a typical schematic of such a system in a multistory building. The key components are the heating system, the recirculating loop (denoted by hot water supply and return lines) and the non-recirculating branch lines that feed individual units. The benefit of the recirculation loop is to bring hot water in closer proximity to the use points, at the expense of added thermal and pumping energy losses. In the example shown, the distribution losses are roughly the same magnitude as the hot water energy consumed.

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[3] http://www.aceee.org/files/pdf/conferences/hwf/2011/Plenary%20-%20Mike%20Parker.pdf

[4] For gas storage water heaters this represents about 40 therms/year (Hoeschele et al, 2011), which can significantly erode overall efficiency in low-load applications.

[5] It is important to recognize that nearly all gas tankless units, HPWHs, and high efficiency gas storage products have parasitic electrical usage due to components including controls, pumps, and combustion air blowers.

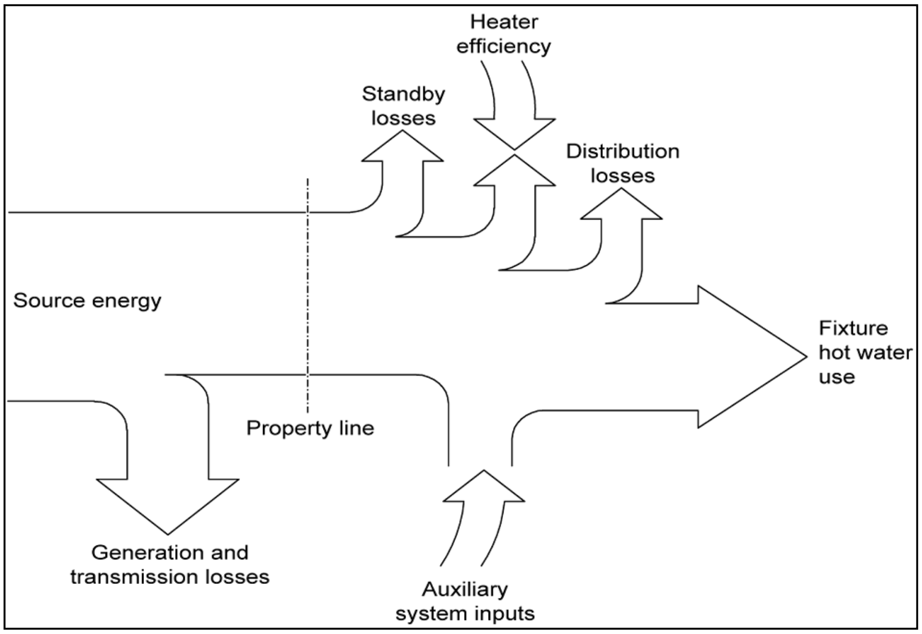


Figure 2. Typical hot water system energy flow schematic

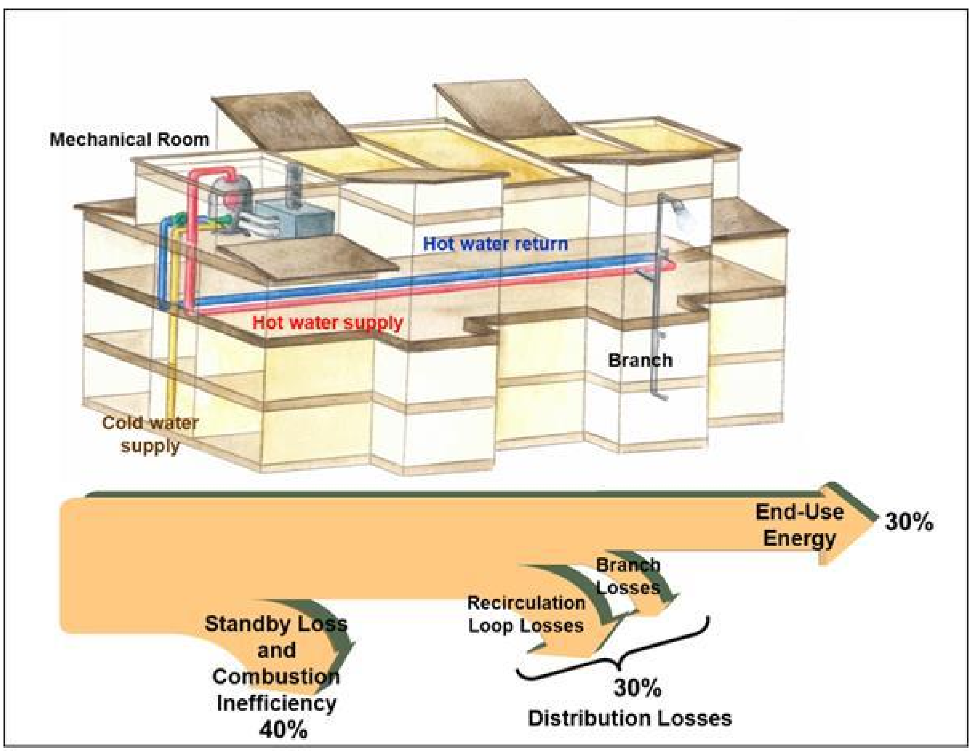
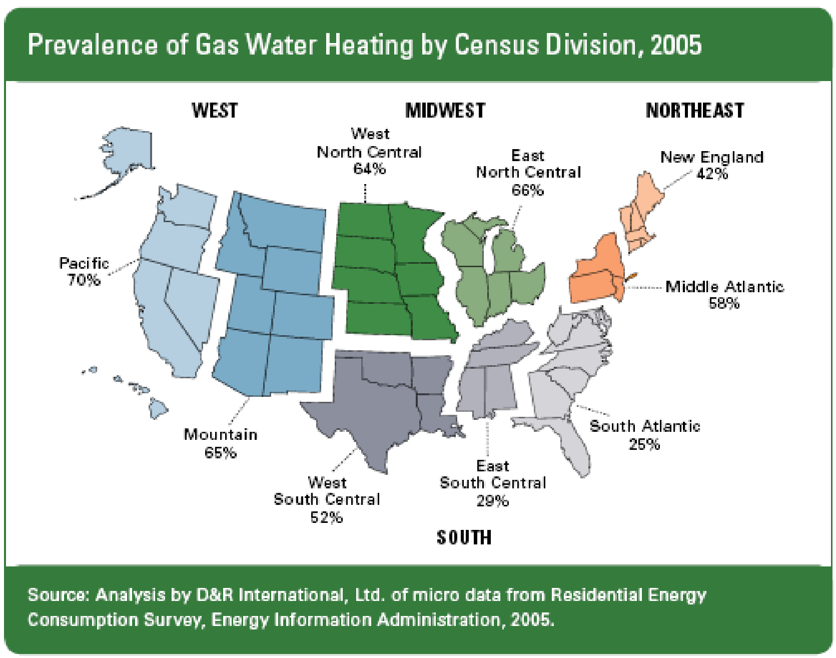


Figure 3. Example central system design with approximate energy flows

1.3 Regional Look at Water Heater Types

Nationally, 52% of homes are served with natural gas water heaters, 42% with electric water heaters, and the remainder served primarily by propane, and to a lesser extent, fuel oil. Figure 4 provides recent estimates of gas storage water heating saturation with higher percentages found in the western states and the northern tier. The southeast has the greatest saturation of electric water heaters.

These regional differences are a function of both natural gas availability and the relative cost of natural gas and electricity, per Btu. Figure 5 plots the ratio of average statewide residential electric rates to average natural gas rates (2009 EIA data) on a "per kBtu" site energy basis[6]. This plot highlights the wide range of pricing that exists throughout the United States and is informative in developing a first impression of whether conversion from gas-to-electric (i.e. HPWH) or vice versa, is appropriate for a given location. Not all states are shown, as the graph focuses on those states with the greatest range in electric/gas pricing. For areas with electric to gas ratios of 3 or higher, the economics of converting from gas to HPWH will be challenging. Conversely, for locales with ratios of <2, HPWHs should be an economically attractive alternative to gas.



Source: DRI International, 2009. Water Heater Market Profile

Figure 4. Regional gas water heating saturations

[6] 1 kWh = 3.413 Btu/hour on a site energy basis

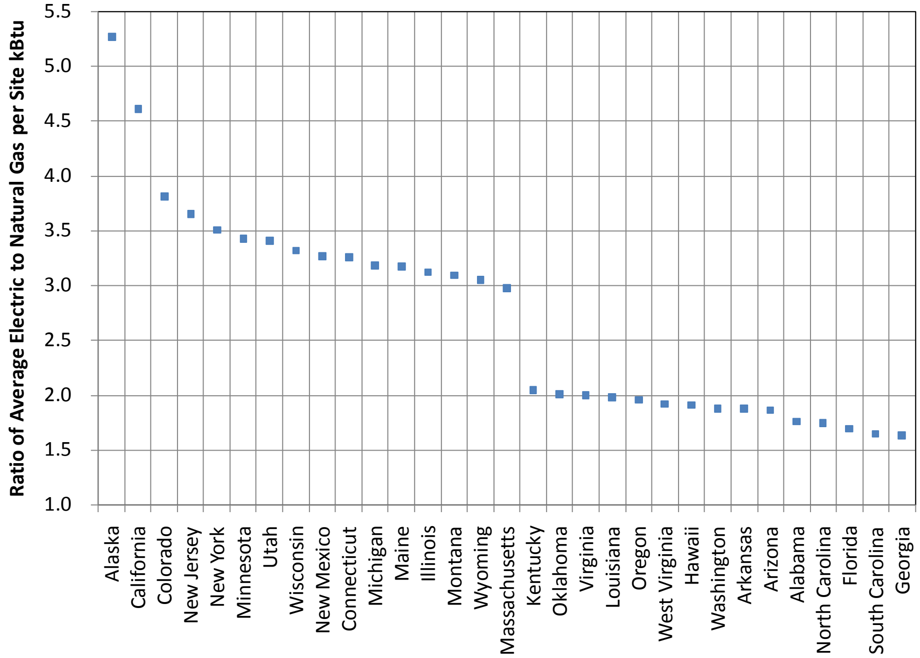


Figure 5. Relative residential pricing of electricity to natural gas (site basis)

Energy Factor Test

The EF test procedure prescribes six equal hot water draws (total of 64.3 gallons) at hourly intervals followed by 18 hours of standby. Energy output from the water heater and energy consumed are totaled during the test.

1.4 Types of Systems

There are numerous recent resources that provide an overview of advanced water heating technology options. DOE's Energy Efficiency and Renewable Energy website[7] has information and simple tools for comparing efficient water heater options. A 2011 water heating "roadmap" was developed for DOE's Building Technologies Program to assist DOE in developing a strategy for moving the marketplace towards more efficient water heating strategies[8]. In addition, the Florida Solar Energy Center (FSEC) held a webinar[9] in late 2011 providing an overview of high efficiency options, and the American Council for an Energy Efficient Economy (ACEEE) recently completed an assessment of potential savings and expected cost effectiveness of various residential water heating technologies[10].

Prepping for Future Efficiency Retrofits

California's Title 24 is proposing a requirement to provide the infrastructure for future efficient water heater retrofits, reducing some of the significant barriers. This approach would involve providing an adequate gas line to handle high capacity equipment, locating an electric outlet adjacent to the water heater location, and facilitating future alternative venting systems.

[7] http://www1.eere.energy.gov/calculators/water_heating.html
[8] http://www.ornl.gov/sci/ees/etsd/btric/pdfs/WaterHeatingTechnologiesRoadmap_9-30-2011_FINAL.pdf
[9] http://vimeo.com/29780187
[10] http://aceee.org/research-report/a112

1.4.1 Individual Water Heaters

Figure 6 compares the key components of residential electric (on the left) and gas storage water heaters. The electric water heater typically has two 4.5 kW electric elements that are interlocked to prevent simultaneous operation. The center flue gas storage water heater on the right has a burner on the bottom with hot combustion gases rising through the center flue and exiting at the top of the tank. The design is thermally less efficient than that of a storage electric water heater since the center flue design and continuously burning pilot contribute to significant standby energy consumption. This parasitic effect is clearly represented by typical Energy Factors (EFs) for conventional gas and electric storage water heaters. Energy Factor is the federally mandated performance metric for the vast majority of residential water heaters. These products include storage water heaters (gas, propane, electric resistance, or heat pump) with storage volumes between 20 and 120 gallons, and input ratings of less than 75,000 Btu/hour.Gas units with EFs of ~ 0.60 have recovery efficiencies in the neighborhood of 78%. Electric storage units, which are nearly 100% efficient at converting input energy to stored heat, demonstrate a smaller resulting standby degradation, with typical EFs of about 0.90.

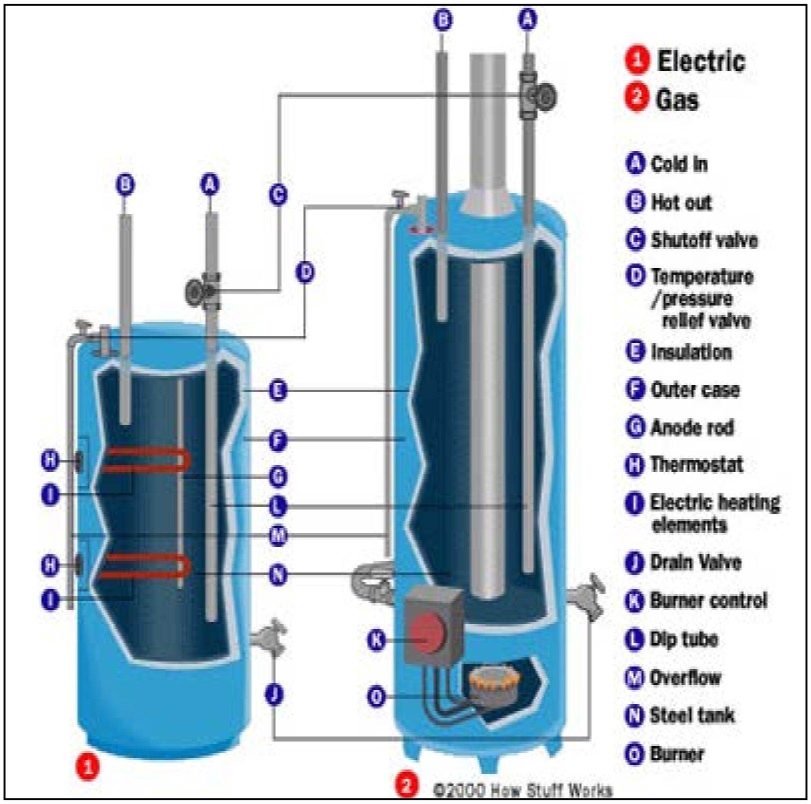


Figure 6. Electric and gas storage water heater schematics

Gas tankless water heaters, with storage volumes of less than 2 gallons, and input ratings between 50,000 and 200,000 Btu/h are also covered by the EF rating. Currently, many of the residential/small commercial condensing storage water heaters on the market are not EF rated, since their input rating exceeds the 75,000 Btu/h maximum limit. These water heaters and other larger commercial water heaters fall outside of these criteria and therefore have performance defined in terms of thermal efficiency and hourly standby loss.

Current National Appliance Energy Conservation Act (NAECA) requirements for a 40 gallon storage water heater mandate a minimum EF of 0.59 for gas water heaters and 0.92 for electric water heaters[11]. Effective April 15, 2015, new NAECA requirements will boost minimum EFs slightly for units with storage volumes < 55 gallons, but gas-fired units above 55 gallon storage volume will be required to achieve condensing efficiencies and similarly, heat pump technology will be required for electric units above 55 gallons. Table 1 summarizes the current and 2015 minimum storage water heater EFs for 40 and 60 gallon storage units.

Table 1. Current and April 2015 NAECA Storage Water Heater Requirements

	Current		April 2015	
Gallons	**Gas**	**Electric**	**Gas**	**Electric**
40	0.59	0.92	0.62	0.95
60	0.56	0.89	0.75	1.99

The advent of new technologies such as tankless heaters, HPWHs, and gas hybrid units, which combine a tankless unit with a downsized storage tank, results in changes in both performance and hot water delivery characteristics relative to the mainstay gas and electric storage water heaters. Table 2 compares the pros and cons of the various water heater types serving single family buildings and individual units in multifamily buildings.

11 Minimum efficiency is dependent on storage volume.

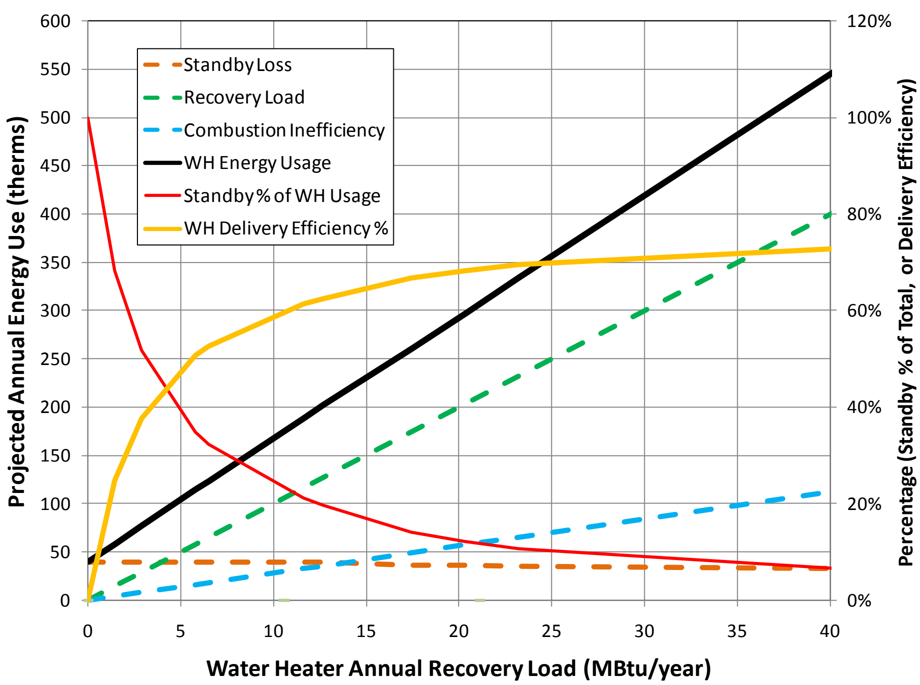
Table 2. Water Heater Comparison

	Conventional Storage		Advanced Technologies			
	Gas	**Electric**	**ENERGY STAR Gas (0.67–0.70 EF)**	**Gas Tankless**	**Condensing Storage**	**HPWH**
Typical Efficiency	0.58–0.62 EF	0.90–0.95 EF	0.67–0.70 EF	0.80–0.95 EF	≥ 90% thermal efficiency	> 2.0 EF
Installed Cost (New)	Low	Low	Moderate	Moderate-high	Moderate-high	Moderate-high
Installed Cost (Retrofit)	Low	Low	Moderate-high	High (assuming gas line must be upsized)	Moderate-high	Moderate-high
Savings Versus Standard	N/A	N/A	For moderate to high loads, typically ≥ 10%	Typically ≥ 30%	For moderate to high loads, typically ≥ 30%	Typically ≥ 40% (versus electricity) depending on climate loads, installation details
Hot Water Delivery Performance	Immediate; good recovery capacity	Immediate; moderate recovery capacity	–	Cold start delay; minimum flow rate; cold water sandwich; endless hot water	Immediate; generally high recovery capacity	Immediate; relatively low heat pump recovery capacity
Maintenance	Minimal	Minimal	Minimal	If hard water area, can be significant	Generally minimal	Some (air filter)
User Interactions	None	None	None	Generally see change in behavior from users versus standard gas storage water heater	None	Mode, set points, and hot water loads affect performance and backup heating

Supporting Research

It is important to look at conventional storage water heater performance from a context of efficiency dependence as a function of hot water recovery load. As the graph below shows, an idle standard efficiency atmospheric gas water heater will consume about 40 therms/year just to maintain a hot tank. As hot water loads increase, efficiency, defined as energy flow out of the water heater divided by energy consumed, slowly climbs upward from zero. Water heating loads are typically characterized in terms of average gallons per day. "Typical" per capita hot water consumption has generally been assumed to be ± 20 gallons per day, although variations among households are large due to behavioral factors, frequency of tub use, and water efficiency of appliances, showers, and sink faucets. A recent compilation of data from various detailed monitoring studies across the nation (Lutz, 2011) suggests average single family household usage of approximately 50.6 gallons per day, or 17.0 gallons per person per day.

A recently completed California water heater field test of eighteen single family households (with an average of 3.6 occupants) monitored average recovery loads of 27,200 Btu/day (9.9 MBtu/year). Another factor suggesting lower average water heating loads is that RECS estimates that 58% of U.S. households are single or two-person households. Future trends towards reducing shower and appliance hot water usage will further reduce usage, increasing standby parasitic as a total percentage of consumption. Multi-family central water heating systems generally see much higher loads than water heaters serving individual dwelling units, and therefore standby parasitics are a much smaller fraction of total usage.



1.4.2 Central Water Heaters Serving Multiple Dwelling Units

Compared to an individual water heating configuration, central water heating systems generally exhibit higher daily loads, with a resulting increase in daily operation (i.e. burner or heater operation) and fewer hours in standby mode. However, offsetting the decreased stand-by loss are higher distribution losses associated with central system recirculation loops. The recirculation loop distribution piping ensures a quick delivery of hot water at a consistent temperature and significantly reduces water waste due to high wait times encountered in "trunk-and-branch" systems. Central system recirculation loops can also lead to increased plumbing design complexity and significant plumbing cost. Based on our regional understanding of central system practice, and surveying of key Building America teams with knowledge of central system configurations, there appears to be a high degree of variability in how systems are laid out, with resulting implications on overall system performance.

According to information presented at the 2011 ACEEE Hot Water Forum[12], over 70% of central commercial water heating heat systems are gas-fired, with current sales approximately equally split between condensing and non-condensing gas-fired systems. Figure 7 and Figure 8 show typical layouts for the two common central gas-fired heating system configurations: boiler system with storage, and multiple storage water heaters.

Recirculation loop pumps installed with central systems may or may not be controlled. Often, controls are installed but building owners override them to address occupant complaints when they have problems getting hot water in the middle of the night. Common control options include a time clock, a temperature sensor to operate the pump based on a minimum return water temperature, a combination time clock/ temperature control, and emerging control technologies that include temperature modulating and demand recirculation systems.

Temperature modulation controls do not control the pump but instead control the water heater temperature setting. This control lowers the hot water temperature at times when demand is expected to be low, usually during the middle of the night. Both temperature modulation schedule and temperature setpoints can be tailored according to hot water demand patterns.

Demand controls switch the recirculation pump on in response to either water demand or a combination of water demand and hot water temperature drop measured at the end of the loop. Water demand can be signaled by the user manually pressing a switch or activating a motion sensor or detected by a flow meter located at the beginning of the loop. "Demand only" sensors switch the pump on whenever hot water is drawn. Those controlled on both demand and return temperature switch the pump on when there is demand and the return temperature reaches a lower threshold. Compared to the other controls, demand controls result in

Recirculation Losses

Field data from a California PIER multi-family DHW system research study (slated for completion at the end of 2011) indicates that the average monitored recirculation loop heat loss from 30 buildings was ~30% of total use, or roughly equal to the total delivered hot water energy at the fixtures. However, the range of distribution loss varied widely (5%–61% due to loop configuration and operational differences. The variability among buildings is difficult to assess without monitoring.

[12] See Slide # 4 at http://www.aceee.org/files/pdf/conferences/hwf/2011/Plenary%20-%20Mike%20Parker.pdf

an increase in total pump off cycle time, enhancing energy savings while reducing wait time for hot water.

Figure 7. Central system utilizing two circulating boilers with storage tank

Figure 8. Central system utilizing two large storage water heaters

Federal standards mandate minimum thermal efficiencies of 80% for large gas storage water heaters and hot water supply boilers manufactured after October 2003. The federal standards require that water heater thermal efficiency and standby loss must be tested according to ANSI

Z21.10.3-1998, §2.9 and ANSI Z21.10.3-1998, §2.10, respectively. Table 3 summarizes minimum efficiency requirements for large storage water heaters and boiler systems.

Table 3. Commercial Water Heater Efficiency Standards

Standards for Large Water Heaters (Effective October 29, 2003)				
Appliance	**Input to Volume Ratio**	**Size (Volume)**	**Minimum Thermal Efficiency (%)**	**Minimum Standby Loss*,****
Gas Storage Water Heaters	< 4000 Btu/h/gal	Any	80	$Q/800 + 110(V_r)$*,** Btu/h
Gas Instantaneous Water Heaters	≥ 4000 Btu/h/gal	< 10 gal ≥ 10 gal	80 80	– $Q/800 + 110(V_r)$*,** Btu/h
Gas Hot Water Supply Boilers	≥ 4000 Btu/h/gal	< 10 gal ≥ 10 gal	80 80	– $Q/800 + 110(V_r)$*,** Btu/h
Oil Storage Water Heaters	< 4000 Btu/h/gal	Any	78	$Q/800 + 110(V_r)$*,** Btu/h
Oil Instantaneous Water Heaters	≥ 4000 Btu/h/gal	< 10 gal ≥ 10 gal	80 78	– $Q/800 + 110(V_r)$*,** Btu/h
Oil Hot Water Supply Boilers	≥ 4000 Btu/h/gal	< 10 gal ≥ 10 gal	80 78	– $Q/800 + 110(V_r)$*,** Btu/h
Electric Storage Water Heaters	< 4000 Btu/h/gal	Any	–	$0.3 + 27/V_m$%/h

* Standby loss is based on a 70°F temperature difference between stored water and ambient requirements. In the standby loss equations, V_r is the rated volume in gallons, V_m is the measured volume in gallons, and Q is the nameplate input rate in Btu/h.

** Water heaters and hot water supply boilers with > 140 gal storage capacity are not required to meet the standby loss requirement if the tank surface is thermally insulated to R-12.5, if a standing pilot light is not installed, or (for gas-or oil-fired storage water heaters), if there is a flue damper or fan-assisted combustion.

2 Water Heater Selection Process

Two tools have been developed for this guideline: one focused on water heaters serving individual dwelling units, and a second that addresses multifamily central water heater installations. Both tools present a process for selecting appropriate cost-effective water heaters based on specific information on hot water loads, climate, and utility rates. Default incremental cost assumptions are provided, but ideally, site-specific cost estimates should be used, especially in retrofit applications where implementation costs for different technologies can vary significantly based on venting requirements, electrical availability, and gas line upsizing needs.

The individual water heater tool is presented in the form of a step-by-step manual calculation. This tool relies on recent field performance data on current advanced water heater technologies to model the performance of the different technologies. The multifamily central water heater tool is more complex in terms of inputs, and therefore has been developed as a stand-alone spreadsheet tool. It focuses solely on gas water heating performance assessment, since robust field data on advanced electric (i.e. HPWH) options are not complete at this time. This guideline document describes how to use the spreadsheet tool.

2.1 System Considerations

As new higher efficiency water heating technologies have entered the market in the past few years, early adopters have generally realized energy savings, but have also in some cases experienced a change in water heating delivery characteristics. Table 2 presented some of the key attributes of the different technologies. This section explores some of the hot water performance issues associated with different technologies in more detail.

2.1.1 Gas Tankless Water Heaters

Tankless water heaters have some unique hot water delivery characteristics, which offer benefits and can also lead to undesirable user behaviors. Widely marketed as providing "endless hot water", these units, unlike storage water heaters, will provide hot water indefinitely[13] up to a maximum flow rate (defined by heating capacity, setpoint, and inlet water temperature). For large households, this provides the advantage of being able to handle sequential high demand water heating loads. A potential disadvantage is that this could contribute to longer showers, resulting in reduced energy savings.

Endless Hot Water

Two recent field studies have collected high resolution data that addresses whether tankless water heater "endless hot water" contributes to higher hot water loads. A 2010 Minnesota CEE study that converted in ten homes storage to tankless water heaters, showed there was no statistically significant change in hot water consumption. A 2011California Residential Gas Water Heating Program completed "pre" and "post" monitoring that indicated that at four of six tankless retrofit sites hot water consumption remained essentially the same. The remaining two sites showed increases, indicating more study of consumer behavior may be needed.

Tankless units also experience a time delay in delivering hot water due to start-up sequences, especially if the heat exchanger has fully cooled off from the prior draw. Most homeowners will notice the longer time delay, which may lead to a change in

[13] A more extreme high load case (typically in cold climates where winter water heating Btu needs can be high) is where the unit cannot keep up with the load as the deltaT and flow rate exceed the unit's heating capacity.

behavior in certain draws as occupants may give up on waiting for hot water to arrive. Time delays of 20 seconds or so are not uncommon, and can result in increased and unacceptable water waste and waiting times, especially in retrofit applications where homeowners have prior expectations on delivery times. Gas tankless minimum flow rates (typically 0.4 to 0.75 gpm) may also impact behavior as certain common draws, such as shaving or dish rinsing, may be impacted by the minimum flow rates.

User behavior and adaptability are key factors in how occupants respond to tankless delivery characteristics. Some occupants will seamlessly modify their behavior, while others will allow the performance changes to negatively influence their perception of the technology. Hybrid gas technologies, which marry a tankless unit with a smaller storage volume, aim to provide a middle ground performance approach while maintaining the rapid delivery characteristics associated with storage water heaters.

HPWHs and Homeowner Interactions

HPWHs represent the residential water heating technology whose performance is most sensitive to homeowner interactions. With a capability to set operating modes, as well as tank setpoints, the user has significant influence on performance. Applied loads, usage patterns, showerhead and appliance properties all factor heavily into how well the heat pump can keep up with loads and how much electric resistance heating is needed. Educating both plumbers and consumers is a critical step in achieving optimal performance.

2.1.2 Heat Pump Water Heaters

The performance of HPWHs can vary significantly depending on a number of factors. Field findings, which are not comparable to standard test procedures, suggest that resistance heating operation can be significant depending upon climate (both due to inlet water and evaporator inlet air), setpoints and load patterns. High daily loads or short duration, high intensity loads, can lead to situations where heat pump recovery capacity is insufficient to satisfy the tank thermostat, triggering inefficient electric resistance heating. Conversely, load reduction measures which reduce hot water use at showerheads, fixtures, and appliances will contribute to reduced peak and daily hot water loads, and should therefore improve HPWH efficiency. There may be other factors and sensitivities affecting HPWH field performance variations, but homeowner education is clearly an important step in achieving optimal HPWH performance.

Solar Thermal Water Heating

Although solar thermal water heating currently remains an expensive option, it can be a viable strategy in locations with significant solar availability, high gas and electric rates, and high water heating use, especially in multi-family applications. Existing Federal tax credits and state incentives (see http://www.dsireusa.org/) will improve overall economics.

2.1.3 Solar Thermal Water Heating

Solar thermal water heating is a technology that is frequently considered as a potential component of an energy efficient water heating system. A good overview of technology options can be found at the EERE website[14]. Relatively high costs make the market penetration low in

[14] http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12850

single family homes, although multifamily installations generally offer better economics due to economies of scale and consistently higher loads for the system to work against. In many cases, a solar system will have a pre-heat tank that circulates water to the collectors and provides pre-heated water to the water heater. Storage systems interface well with solar systems, although condensing appliances may not operate at expected condensing efficiencies if water temperatures are too high. The BA-PIRC team is currently testing HPWHs with solar pre-heat in the laboratory to assess the combined performance and cost effectiveness. Gas tankless water heaters coupled with solar thermal systems have been observed to experience burner modulation control issues when solar pre-heated water comes within 20°F to 30ºF of the setpoint temperature. In this situation, the system may fire, and then shut off, leading to fluctuating output temperatures as the system attempts to reach a stable condition.

2.1.4 Combined Hydronic Systems

Combined hydronic systems utilize a single heating device to deliver heated water to both a delivery device (fan coil, baseboard, or radiant floor or panel) and for potable water for domestic uses. Common heat sources include high capacity gas tankless units, storage gas water heaters, boilers, and larger commercial HPWHs. Some building jurisdictions require a heat exchanger to isolate the potable water from the space heating loop, adding cost and reducing efficiency. The benefits of combined hydronic systems lie primarily in the potential cost advantage associated with using one heating appliance versus two appliances (a water heater and a space heater). The realized cost savings from eliminating the space heater can be applied to a single high efficiency water heating device. A key performance benefit for storage water heaters in low-load combined hydronic applications is that the combined space and water heating loads will serve to improve the operating efficiency of the system. Significant research is currently underway within Building America (NorthernSTAR and BA-PIRC research projects) to identify preferred system configurations, document lab and field performance, assess customer satisfaction, and develop input for a design guide.

Minimizing Loads

Remodels or appliance replacements are the perfect opportunity to evaluate water and energy efficient alternatives in showerheads, fixtures, clothes washers, and dishwashers. Visit the EPA and EnergyStar websites listed here, as well as your local utility for potential incentives.
www.epa.gov/watersense/
www.energystar.gov/index.cfm?c=products.pr_find_es_products

2.1.5 Distribution Systems

Distribution systems are a key part of the domestic hot water system, linking the heat source and the use points. In non-recirculating systems, hot water entering a “cold” distribution system will experience a transit time proportional to the entrained pipe volume (between water heater and fixture) divided by the hot water flow rate to reach the end user. During this time, some energy is lost, and additional energy contained in the water may be fully lost for the next draw. The specifics of the distribution system layout, pipe location, fixture/appliance flow rates, and use patterns all play into determining the overall impact in terms of distribution losses, water waste, and hot water waiting time. Recirculating systems generally result in much higher distribution losses, but significantly reduce water waste and hot water wait time.

In larger homes or homes undergoing significant remodels, there are often bathrooms or other use points that are remote from the existing (or proposed) water heater location. Although every effort should be taken to optimize building design (i.e. hot water use point locations) relative to the water heater location, there are certainly cases where a second water heater or a demand recirculation system should be considered. A second water heater could make sense if the extended pipe runs are of extended length and large pipe diameter (more than a gallon of entrained pipe volume), since the incremental equipment cost would be partially offset by reduced plumbing costs and distribution losses. This could also improve customer satisfaction due to reduced hot water delivery times. Care should be taken in the selection of the second water heater, balancing the standby effects of a second storage tank versus a tankless water heater.

For central multifamily recirculating systems, a key factor affecting water heater recovery loads, and therefore the savings associated with a high efficiency system, is the configuration of the recirculation system and how the system is controlled. The ongoing PIER central water heating study has monitored more than thirty multifamily buildings in California. In addition to characterizing distribution system heat loss in these buildings, the study investigated the energy savings through recirculation loop control technologies. Data were collected under four recirculation control modes: continuous pumping, temperature modulation, timer control, and demand control. Monitoring was underway for more than a year with each applicable control strategy being implemented for at least two weeks. Table 4 presents study results from three of the projects, ranging in size from 40 to 98 housing units. The results indicate that controls reduce recirculation loop heat loss, although impacts do vary widely. Demand controls reduced heat loss more than temperature modulation and timer control strategies.

Table 4. Daily Recirculation Loop Heat Loss (kBtu) and % Savings Versus Base Case

	Site 1 (98 Units)	Site 2 (82 Units)	Site 3 (40 Units)
Continuous Pumping	640	221	202
Temperature Modulation	633 (1%)	205 (7%)	n/a
Timer Control	601 (6%)	220 (0%)	187 (7%)
Demand Recirculation	412 (36%)	178 (19%)	180 (10%)

2.1.6 Individual Water Heater Tool

The water heater selection tool presented in this guideline takes into account estimated hot water loads, local climate effects (for HPWHs), local natural gas, propane, and electric rates, and current "best" estimates of equipment performance based on hot water load sensitivities. Local rates are important, because for the homeowner, operating costs are the driver rather than relative efficiency. The performance data incorporated into the tool is based on the latest research on advanced gas water heaters and HPWHs (a more complete description of the assumptions and the modeling methodology can be found in Appendix A.) Both hot water loads and local utility rates play a primary role in determining operating cost savings relative to the existing or base case electric or gas storage water heater. The flow chart in Figure 9 outlines the calculation methodology. The last step in the process, comparing projected savings to the expected implementation costs, can be completed with default cost assumptions or with real site-specific cost estimates. The latter is clearly preferable, especially for retrofit situations, since unique site characteristics can have a significant impact on costs.

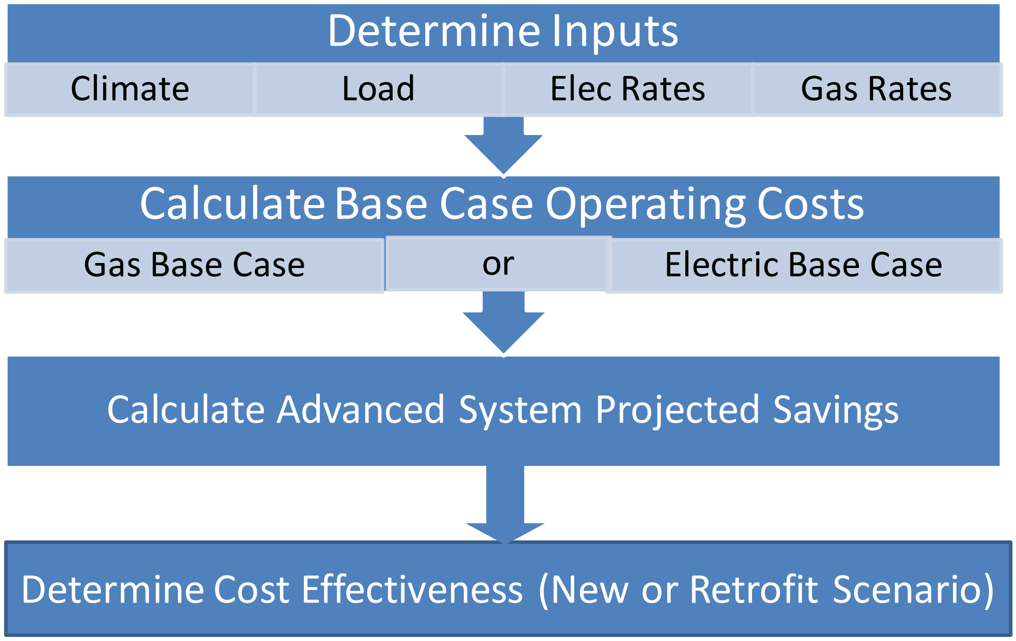


Figure 9. Individual water heater tool process flow

Step 1: Determine Climate

From Figure 10 below, select the climate that best characterizes your location. (Note that the selected climate only influences the performance of HPWHs. It also will affect 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 5 below. In cases where two load categories are shown, red highlighting denotes the recommended selection.

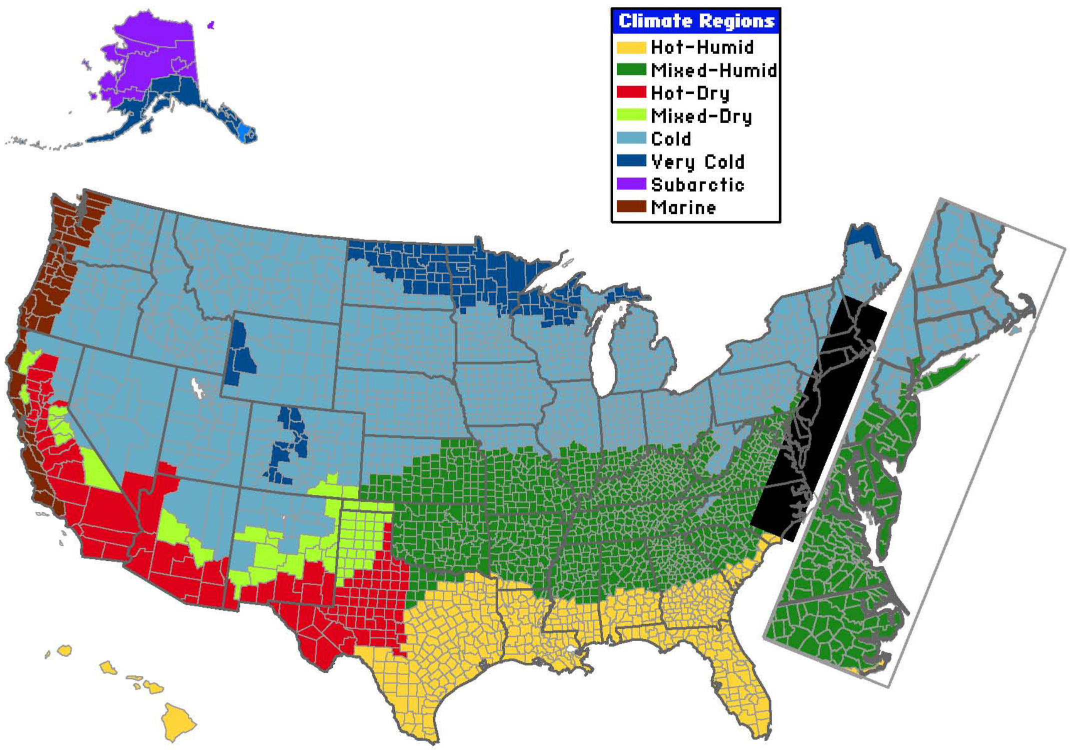


Figure 10. Climate designation for evaluating HPWH performance

Table 5. Estimating Hot Water Loads Based on Number of Occupants and Climate

	Number of Occupants in Household			
Climate Type	**1–2**	**3**	**4**	**5+**
Cold/Very Cold/Subarctic	Low/ **Moderate**	**Moderate/** above average	**Above average/** high	High
Marine	Low	**Moderate/** above average	Above average	Above average/ **high**
Mixed Humid	Low	**Moderate/** above average	Above average	Above average/**high**
Hot/Dry/Humid, Mixed/Dry	Low	Moderate	**Moderate/** above average	**Above average/** 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 practice. Calculate Base Case annual costs (BC$) using Table 6 and the appropriate equation below.

Table 6. Nominal Annual Operating Cost Versus 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 "6" Cost x $Elec_{factor}$ = ZZZZZZZZ **BC$**

For gas storage water heater base case:

Annual Base Case Cost (Gas Storage) = Table "6" Cost x Gas_{factor} = ZZZZZZZZ **BC$**

Step 5: Calculate Advanced Systems Operating Cost

5a. HPWH

Use Table 7 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), the user should consider (based on site conditions) moving 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 7. 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 "7" Cost x $Elec_{factor}$ = ZZZZZZZZ Total$

5b. Advanced Gas Water Heaters

Using Table 8, 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 based on findings from a recently completed field study (Hoeschele et al, 2011).) Apply local $Elec_{factor}$ to determine annual electric costs.

Table 8. Nominal Advanced Gas Water Heater Operating Cost (assumes $1.00/therm)

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

Advanced WH Annual Gas Cost = Table 8 Cost x Gas_{factor} = ZZZZZZZZ Gas$

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

Advanced WH Total Operating Cost = Gas$ + Elec$ = ZZZZZZZZ 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) all contribute to the final projected costs. Table 9 presents default incremental costs for each of the identified technologies, which are intended to represent the full installed cost for the advanced water heater minus the cost of a conventional replacement water heater. 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 recommended that current bids or refined estimates are used in lieu of the default costs, if possible.

Table 9. Default Incremental Installed Costs†

	New	Retrofit
HPWH	$1,000	$1,500
ENERGY STAR < 0.70 EF	$400	$800
Condensing Storage	$700	$1,600
Gas 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 30-year mortgage would represent a favorable investment option for the buyer. For retrofit, a 10-year simple payback is the assumed cost-effectiveness metric for comparing 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 10 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 10. Amortization Factor (Fixed Rate Loan Assumed)

Interest Rate	Amortization Factor (30-Year Term)	Amortization Factor (15-Year Term)
3%	0.051	0.083
4%	0.057	0.089
5%	0.064	0.095
6%	0.072	0.101
7%	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 11. In Column B, subtract base case operating costs to determine annual savings (positive value in Column B).

Table 11. New Construction Annual Savings Calculation

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

Table 12 requires information from Tables 9–11 and incorporation 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 relative cost-effectiveness.

Table 12. New Construction Cost-Effectiveness Calculation

	A	B	C	D	E
	(Table 11) Annual Savings ($)	(Table 10) Amortization Factor	(Table 9) Incremental Cost ($)	Incentives ($)	Cost-Effectiveness Ratio A/(B*(C-D))
HPWH					
ENERGY STAR < 0.70 EF					
Condensing Storage					
Gas Tankless					
Condensing Tankless					

<u>Step 7b: Calculate Projected Savings for Retrofit Case</u>

This tool presumes a 10-year simple payback as a reasonable retrofit economic criterion for assessing cost-effectiveness of competing technologies. To compute 10-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 13. In Column B, 10-year savings are calculated.

Table 13. Calculation of 10-Year Savings

System Type	[A] Annual Operating Cost $	[B] 10-Year Projected Savings $
Base Case	BC = $	n/a
HPWH	A1: $	= 10 * (BC – A1) = $
ENERGY STAR < 0.70 EF	A2: $	= 10 * (BC – A2) = $
Condensing Storage	A3: $	= 10 * (BC - A3) = $
Gas 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 any costs associated with site-level fuel switching. Local, state, and or federal incentives or tax credits for individual technologies may be available (see http://www.dsireusa.org/). 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)[15]. Table 14 is used to compute retrofit cost-effectiveness taking into account these two factors. Incentive amounts[16] 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.

Table 14. Retrofit Cost-Effectiveness Calculation

	A	B	C	D	E
	(Table 13) 10-Year Savings	(Table 9) Estimated Incremental Cost	Incentives	Fuel Switch Cost	Calculated Savings (A+C)-(B+D)
HPWH					
ENERGY STAR < 0.70 EF					
Condensing Storage					
Gas Tankless					
Condensing Tankless					

Compare 10-year savings to incremental installation cost. If the savings are greater than incremental installation cost, the measure is deemed cost effective over a 10-year time horizon.

[15] In this case, there will be a cost for running a 240V dedicated circuit to the HPWH.
[16] Visit http://www.dsireusa.org/ to determine what incentives may be available for your application.

2.1.7 Multifamily Central Water Heater Tool

The multifamily central water heating tool attempts to characterize the performance and energy use of central recirculating systems based on a limited set of input data. This is a challenging prospect given the uncertainty in trying to quantify recirculation system performance in a simplified manner. Studies have shown performance ranging from relatively low loop losses to very high losses. The PIER field monitoring suggests that 30% central system distribution losses may characterize average losses; any one particular project could deviate widely from the mean.

When evaluating multifamily central systems, it is important to realize that since the water heating recovery load is much higher than for a unit serving a single household, the economics for an energy efficient system are generally much more compelling. Although commercial water heaters and/or boilers are considerably more expensive than residential-scale products, the bang-for-the-buck is much greater. Figure 11 outlines the process for the multifamily central water heater evaluation.

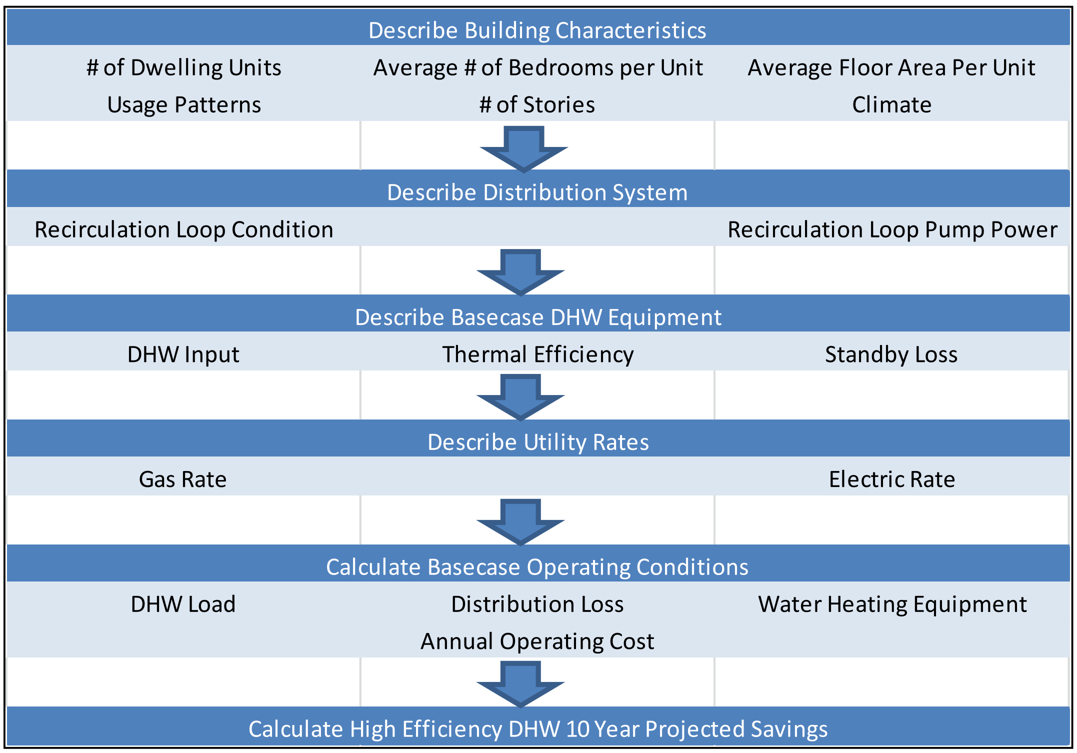


Figure 11. Central water heater tool process flow

Click MultiFamily_Central_DHW_EvaluationTool_v1.0.xlsx to access the central water heater spreadsheet tool.

Step 1: Describe Building Characteristics (Table 15)

1a: Enter the number of dwelling units in the apartment building in row five. The number of dwelling units in the building is a metric to describe if the building is considered a small, medium, or large building.

1b: Enter the average number of bedrooms per dwelling unit in row 6.

1c: Enter the average floor area per dwelling unit in row 7.

1d: Enter the number of stories in building in row 8.

1e: Enter the hot water usage pattern in row 9 based on the estimated gallon per day hot water consumption per occupant listed below in Table 16.

1f: Enter the estimated average annual water temperature in row 10 of the tool. Use Figure 12 as a resource, if needed. Based on field monitoring of water heater inlet water temperatures, 5°F should be added to the Figure 12 value to reflect increased inlet water temperature due to passive heating in garages and or basements.

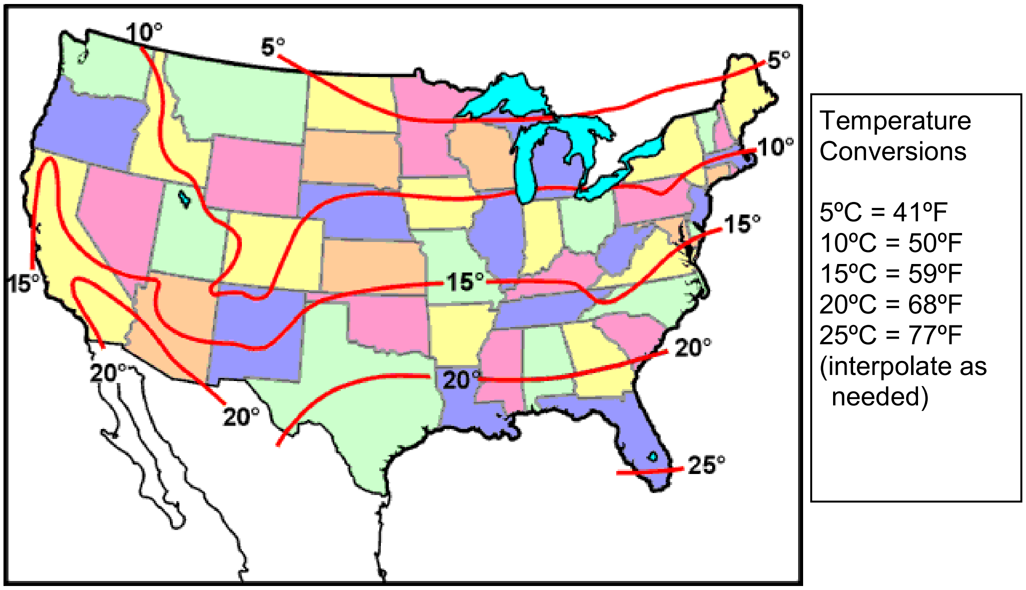
Example for Los Angeles: Inlet temperature = (20°C) 68°F + 5°F = 73°F.

Table 15. Building Characteristics

4	Input		
5	Building	Number of apartment units	30
6		Average number of bedrooms per unit	2
7		Average floor area per unit (ft^2)	700
8		Number of stories	3
9	Occupancy	Use quantity	High use
10	Climate	Average annual groundwater temperature (°F)	65

Table 16. Hot Water Use Assumptions

Multifamily Load Assumptions			
	Low Use	Medium Use	High Use
Gallons per Day per Occupant	11.52	14.40	17.28



Source: Environmental Protection Agency

Figure 12. Average annual groundwater temperature (ºC)

<u>Step 2: Describe Distribution System (Table 17)</u>

2a: Using the pull-down menus in row 11, describe the DHW distribution system condition as "poor", "normal", or "good". The calculation tool assumes a distribution system heat loss equal to 30% of the end use load for a "normal" system, based on California PIER field research[17]. The "normal" heat loss is increased by an additional 30% if the distribution system can be characterized as poor, and decreased by 30% if characterized as good[18]. Realizing that this input is somewhat qualitative, the general recommendation for all new construction and most retrofit applications is to specify "normal".

2b: Specify pump size, in horsepower, in row 12.

Table 17. Characterize Distribution System Performance

11	**Distribution**	Recirculation loop condition	Poor
12		Recirculation loop pump size	0.25

[17] Preliminary findings under California Energy Commission PIER project (contract number 500-06-029)
[18] There are multiple qualitative factors that need to be assessed to determine the condition of the distribution system. Pipes could be located in unconditioned space or located in the conditioned space. What is the level of pipe insulation on the hot water supply and recirculation lines? Is the insulation securely wrapped or is it falling off in sections?

Step 3: Describe Base Case Primary DHW Equipment (Table 18)

Identify the base case water heater type and characteristics. For retrofit projects this is the existing water heater. For new construction this will depend on local practices and the local building code.

3a: Input Total DHW Input Rate (Btu/hr) in row 13.
3b: Input DHW thermal efficiency (%) in row 14.

3c: For systems consisting of large DHW storage tank type water heaters, or boilers coupled with storage tanks, input DHW system storage tank standby loss (Btu/hr) in row 15. Manufacturer specifications and the AHRI Primenet on-line directory[19] will report standby loss for specific manufacturer and model number. (For existing water heaters not listed, assumed standby loss is equal to 2.5% of input capacity.)

Input DHW system standby loss (Btu/hr) in row 15.

3d: Input setpoint temperature in row 16.

Table 18. Characterize Heating Equipment

13	**Heating Equipment**	Total heating capacity (Btu/hr)	600,000
14		Thermal efficiency (%)	80%
15		Standby loss (Btu/hr)	15,000
16		Setpoint temperature (°F)	135

Step 4: Input Utility Rates (Table 19)

4a: Average electric rate in $/kWh in row 17.

4b: Average natural gas rate in $/therm in row 18.

Table 19. Local Utility Rates

17	**Fuel Prices**	Natural gas cost ($Therm)	$1.00
14		Electricity cost ($/kWh)	$0.14

Step 5: Tool Outputs (Table 20)

Outputs from the tool are shown in Table 20 and can be found in rows 20-33 of the tool.

[19] http://cafs.ahrinet.org/gama_cafs/sdpsearch/search.jsp

Table 20. Central Water Heater Spreadsheet Tool Outputs

20	Output		
21	Load	Daily dwelling unit hot water draws (gal/day)	51.8
22		Daily building hot water draws (gal/day)	1555
23		Temperature rise (°F)	70
24		Annual hot water Btu demand (therm/yr)	3298
25	Distribution	Normal recirculation loop heat loss (therm/yr)	2807
26		Recirculation loop heat loss correction factor	1.0
27		Annual recirculation loop heat loss (therm/yr)	2807
28		Annual recirculation pump power consumption (kWh/yr)	1634
29	Heating Equipment	Annual boiler Btu consumption (therm/yr)	8793
30		Standby loss (therm/yr)	1161
31		Peak hour demand (Btu/h)	481,807
32	Costs	Annual boiler Btu consumption ($/yr)	$8,793
33		Annual pump electricity consumption ($/yr)	$229

Record the *Annual boiler Btu consumption ($/yr)* (Row 32) in Column A for BC$. Complete spreadsheet evaluation of high efficiency option and enter *Annual boiler Btu consumption ($/yr)* in the Advanced Case row in Table 21.

Table 21. Calculation of Central System 10-Year Operating Cost Savings

System Type	[A] Annual Operating Cost $	10-Year Projected Savings $
Base Case	BC = $	n/a
Advanced Case	A1: $	= 10 * (BC – A1) = $
Advanced Case	A2: $	= 10 * (BC – A2) = $
Advanced Case	A3: $	= 10 * (BC – A3) = $

Step 6: Estimate Costs and Determine Cost Effectiveness (Table 22)

Costs for commercial water heaters and boilers for various efficiency levels were estimated based on the NREL National Residential Efficiency Measures Database[20], as well as vendors that Davis Energy Group is involved with for retrofit project activities. Condensing storage water heaters are estimated to cost an additional $9.35 per kBtuh of input capacity. Boiler costs from the NREL database, as a function of efficiency, are shown in Figure 13. Since the slopes for both regression fits are approximately the same, an incremental cost of $1.60 per kBtu is assumed for

[20] http://www.nrel.gov/ap/retrofits/group_listing.cfm?gId=2

each AFUE point above 80%. These estimated costs are generic and should only be used if site-specific costs, which fully address unique site issues, are unavailable.
Incremental costs are calculated as shown below:

$$Condensing\ Storage\ Cost = \$9.35\ per\ kBtuh * Input\ Rating\ (kBtuh)$$

or

$$Efficient\ Boiler\ Cost = \$1.60 * (AFUE - 80) * Input\ Rating\ (kBtuh)$$

Enter actual or above calculated incremental costs in Table 22, as well as the 10-Year Savings summarized in Table 21. Advanced system options with savings > incremental costs should be considered for implementation.

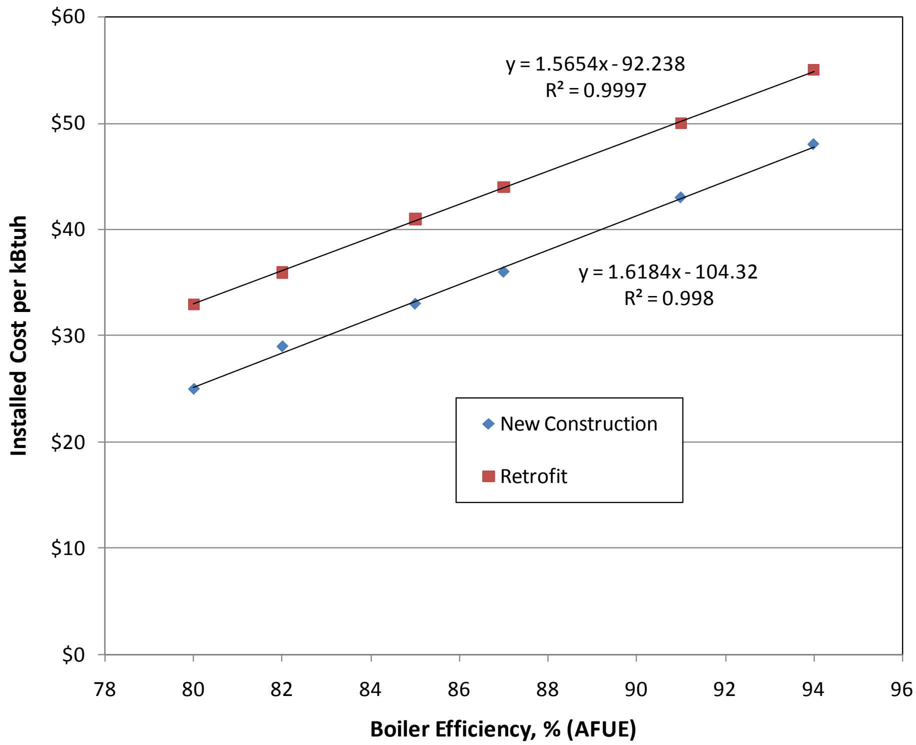


Figure 13. Estimated boiler costs as a function of AFUE

Table 22. Advanced System Cost Effectiveness Calculation †

Efficiency Option	(Table 21) 10-Year Savings	Incremental Cost
Option 1		
Option 2		
Option 3		
Option 4		

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

3 General Water Heater Implementation Details

This guideline broadly addresses key implementation details that apply to water heater installation issues. Individual Building America Measure Guidelines addressing various advanced technologies are intended to focus in more detail on the issues specific to that technology.

3.1 Applicable Health, Safety, and Energy Codes

Provided below is essential information from various building codes that must be considered when inspecting, servicing, or replacing an existing water heater or installing a new one. This is not intended to be a complete list nor a direct citation of applicable codes. It is the responsibility of the installing contractor to insure that all national and local codes and manufacturer installation instructions are complied with.

3.1.1 Temperature Control

The temperature of water from tankless water heaters shall be a maximum of 140°F (IPC 1995, 501.6). Serious burns can result from exposure to a water temperature of 140°F for only 5 seconds.

For water heaters used as a heat source for a space heating system ("combined system") the water heater shall have a maximum outlet temperature of 160°F (IPC 1995, 501.2). Even if not required by code, a tempering valve or mixing valve should be provided if the space heating system requires water temperatures higher than 125°F.

A draft ASHRAE standard, *Prevention of Legionellosis Associated with Building Water Systems* (ASHRAE 188P) was available for public review in 2010 and will likely be published in 2012. The standard covers housing units supplied by one or more centralized hot water heaters, and specifies that in non-healthcare building facilities or when local regulations prohibit use of the temperatures of 51°C (124°F) and higher, hot water shall be stored at 49°C (120°F) or above. The standard also requires annual inspection and maintenance to include verification of thermostat function and twice per year draining to remove scale and sediment. Higher water temperature settings can accelerate the accumulation of sediment, which harbors Legionella bacterium.

3.1.2 Pressure Relief Valves and Expansion Tanks

All water heaters shall be provided with approved pressure and temperature relief valves. They shall be set to open only at pressures below 150 psi and at temperatures below 210°F (UPC 2006, 608.4; IRC 2003, P2802.2; IPC 1995, 505.5).

Where a backflow prevention device or check valve is installed on the water supply to a water heater, an expansion tank must be installed to prevent an increase in pressure (UPC 2006, 608.3; IPC 1995, 608.3.2).

3.1.3 Drain Pans and Seismic Strapping

Where water heaters or storage tanks are installed in locations where leakage will cause damage, they must be installed in a pan that is not less than 1½" deep that is connected to a drain that is the same size or larger as the pressure-temperature relief valve. The drain must be terminated in an indirect waste receptor, or to the exterior of the building and not less than 6” nor more than 24” above grade (IPC 1995, 505.5) (IRC 2003, P2803).

In seismic design categories C, D, E, and F, storage type water heaters shall be anchored or strapped to resist horizontal displacement due to earthquake motion. Strapping shall be applied within the upper 1/3rd and lower 1/3rd of the tank’s vertical dimension(UPC 2006, 508.2)

3.1.4 Piping and Insulation

Piping and components connected to a water heater for space heating applications shall be suitable for use with potable water (IRC 2003, 2802.2).

PEX-AL-PEX cannot be installed within the first 18” of piping connected to a water heater. (UPC 2006, 604.13.2)

Recirculating hot water lines must be insulated to at least R-2 (IRC 2006, 403.4), or in accordance with the formula below (IPC 1995, 608.2.1):

$R = (t_i - t_o)/25)$ where:

R = resistance of insulation in hr-ft²-°F/Btu
t_i = temperature in water pipe (°F);
t_o = design temperature of surrounding air (°F)

3.1.5 Recirculation Controls

Recirculating pumps shall include controls to shut them off automatically or be provided with a manual shut-off (IPC 2009, 608.3).

3.1.6 Combustion Safety, Combustion Air, and Venting

All burners and ignition devices for water heaters installed in garages must be a minimum of 18” above the floor (UPC 2006, 508.14).

Code allows the use of indoor combustion air or a combination of indoor and outdoor combustion air sources for naturally vented gas water heaters. However, this practice is highly discouraged, as installation of whole house fans or other high volume exhaust systems can cause back-drafting of the water heater and fire hazard. Equations for calculating the minimum allowable interior volume of air for naturally vented and fan assisted appliances are given in UPC 2006, 507.2.

Existing indoor gas water heater closets that are vented to indoor space through a louvered door can be converted to outside combustion air by sealing off the louvers, gasketing the closet door, and providing combustion air openings to the crawlspace and/or attic. Permanent combustion air ducts must be provided that each have a minimum free area of 1 in^2 per 4,000 Btuh of rated water heater input if the ducts are vertical, and 1 in^2 per 2,000 Btuh of rated input if the ducts are horizontal. They must terminate within 12” of the top of the closet and within 12” of the bottom of the closet. See UPC 2006, 505 & 507 for other requirements and options.

Figure 14 provides clearance requirements for venting of mechanical draft and direct vent water heaters.

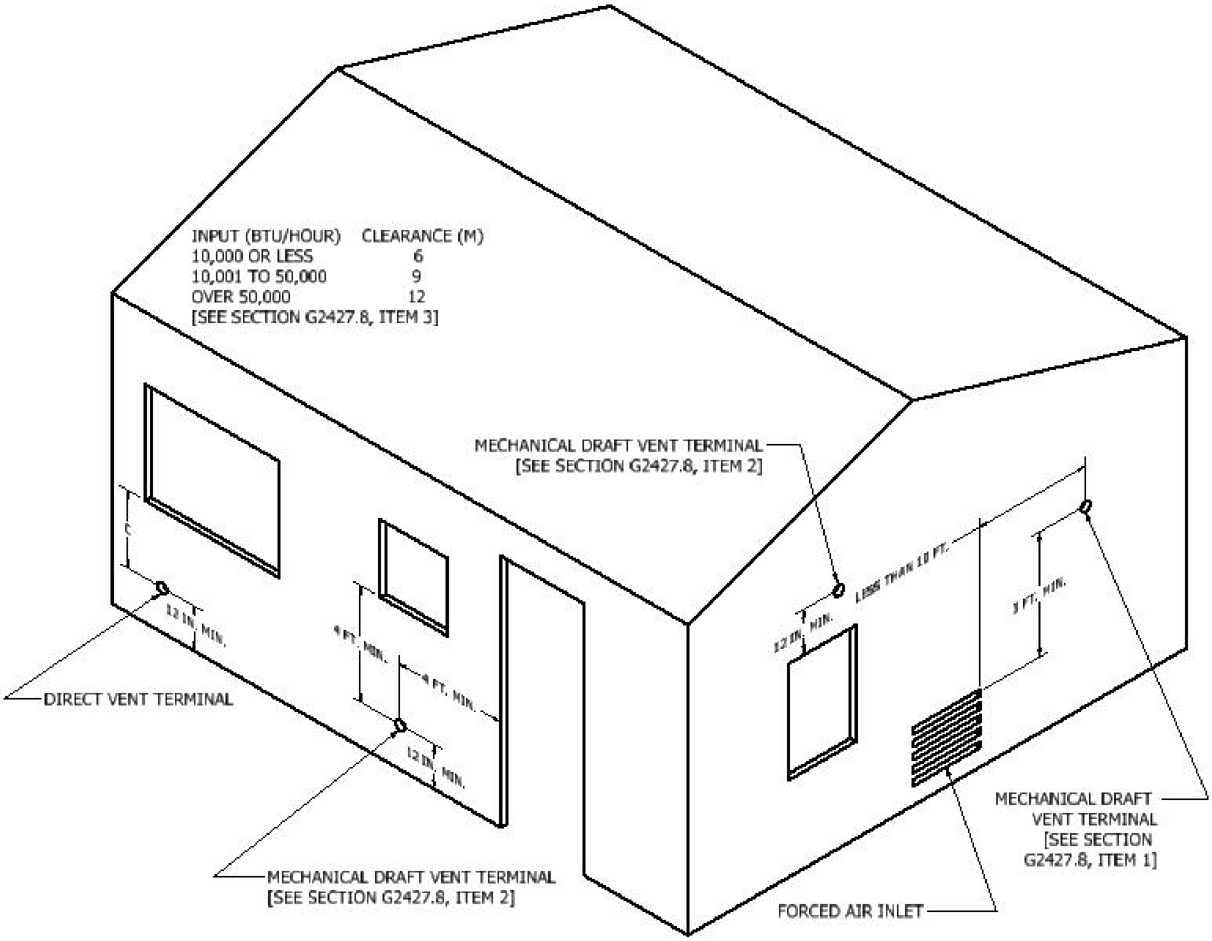


Figure 14. Gas water heater clearance requirements

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Attachment A: Supporting Information for Individual Water Heater Tool

The performance assumptions built into the Water Heater Selection Criteria Strategy Guideline for water heaters serving individual users is based on recent field research into the performance of conventional and advanced water heaters. This field research was utilized to better represent the performance of emerging gas technologies, instead of relying on nominal efficiency ratings.

The CEC PIER Residential Water Heating Program included an 18-home California field monitoring effort involving pre-monitoring of existing gas storage water heaters and post-monitoring of advanced gas water heaters, including ENERGY STAR® storage water heaters (0.67 to 0.70 EF), condensing storage units, and tankless water heaters (both condensing and non-condensing). HPWH performance was based on detailed monitoring data provided by the CARB team's ongoing monitoring of fourteen HPWHs in New England. This Building America work has been underway since late 2010 with data collection continuing into early 2012. The CARB team completed a HPWH measure guideline in November 2011.

Figure A-1 below provides an example of the data used to generate the performance curves for the gas water heaters. The data is plotted with daily input gas energy on the Y-axis and daily output thermal energy on the X-axis. The data in Figure A-1 represents gas water heater performance for both existing gas storage and advanced gas water heater modes (in the example provided, CTWH indicates a condensing tankless water heater). Base case input-output data, defined by the linear regression relationships shown, were averaged over all the base case sites, and likewise all advanced site data were averaged over the four different advanced water heater system types (ENERGY STAR- six sites, condensing storage- three sites, non-condensing tankless – three sites, and condensing tankless – five sites).

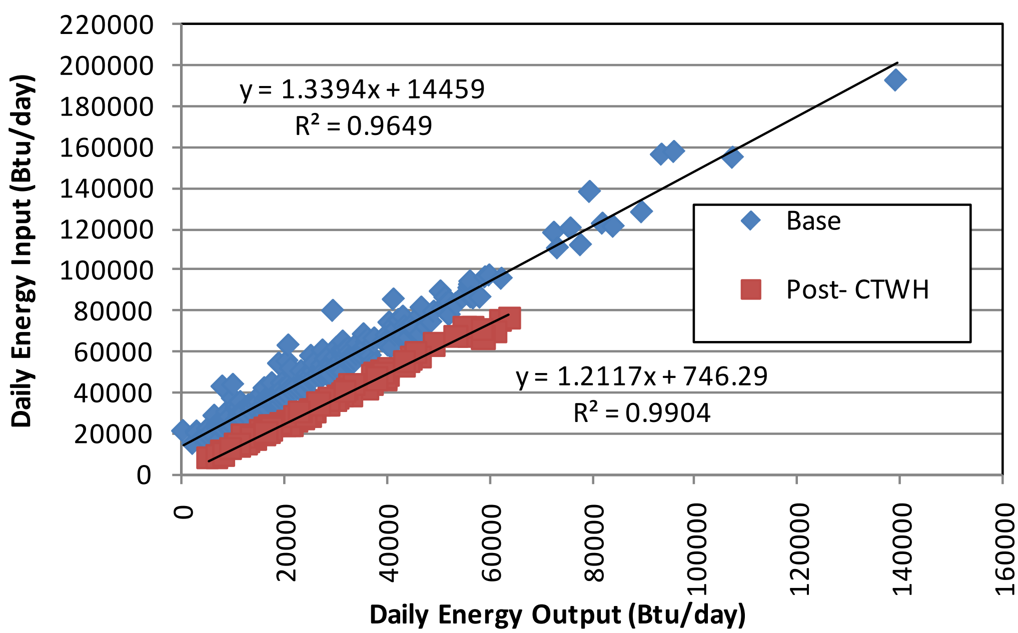

Figure A-1. Sample input-output curve for individual field site

Figure A-2 represents the average performance of each gas water heater product type. The data is plotted in the format of daily efficiency versus output energy (or recovery load). This format of plotting efficiency more clearly highlights the degradation in storage water heater efficiency at very low usage levels. (The average monitored recovery load at the 18 California sites over a 12-month period was ~ 27,200 Btu/day, or 1/3 less than the recovery load required in the Energy Factor test procedure.)

Recovery load is used as the X-axis in Figure A-2, as opposed to hot water gallons per day, since it is a better reflection of what drives the overall efficiency of a water heater. A gallon of hot water in Minnesota in December has considerably higher energy content (relative to the cold water inlet temperature) than a gallon of hot water in Palm Springs in July. With the recovery load approach, one can highlight differences in usage due to both hot water volume and climate (i.e. inlet water temperature) effects.

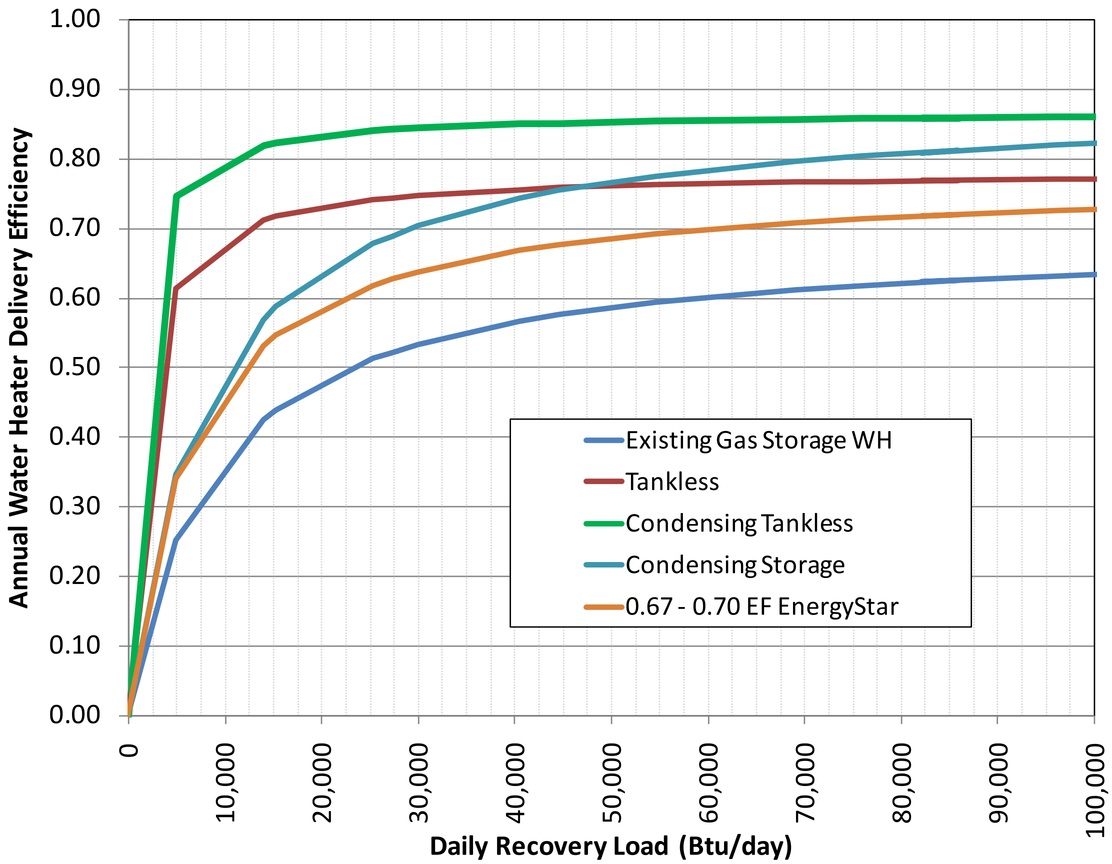

Figure A-2. Gas water heater efficiency versus recovery load

Preliminary HPWH field performance data has suggested that significant performance variations are found to exist when units are installed in real households. Current HPWH design features fairly low capacity compressors (0.5 to 1 ton nominal capacity) with second stage electric backup (typically 4.5 kW). Control strategies vary widely among the major manufacturers. Therefore, occupant behavior, tank setpoint, load pattern, and climate all potentially play significant roles in determining the operating efficiency. The CARB team graciously provided interim performance data from their 14-home HPWH field monitoring project that has been underway since late 2010. Data from the three monitored HPWH products were averaged to provide a relationship of COP versus inlet air temperature. (The performance assumptions should be reviewed in the future as more data become available). Preliminary findings also show an improvement in efficiency as loads increase, up to a point, at which time the combined effects of higher loads contribute to increased second stage heating operation. This effect was added to the simplified performance model, by degrading the calculated "heat pump only" (i.e. no second stage electric heat) COP by 0.09 for each 10,000 Btu of additional recovery load beyond 27,000 Btu/day. The net impact of the performance degradation at higher loads is reflected in the average annual COP values shown in Table A-1. Non-climate dependent electric storage water heater efficiency values are also shown as per current California Title 24 modeling rules listed in Appendix RE (Table RE-7)[21].

Table A-1. Projected Annual Efficiency Versus Load and Climate for Electric Storage and HPWHs

	Low	Moderate	Above Average	High
Storage Electric	0.72	0.84	0.88	0.94
HPWH (climate dependent)				
Cold/Very Cold (40°F)	0.95	1.49	1.48	1.28
Marine (50°F)	1.16	1.84	1.86	1.69
Mixed Humid (60°F)	1.37	2.19	2.24	2.10
Hot/Dry/Humid, Mixed/Dry (70°F)	1.58	2.54	2.62	2.50

The four hot water recovery load options available in the calculation tool are based on estimate of representative hot water loads, based on household size and climate effects. According to RECS[22], a surprising 58% of US households have two or less occupants, with nearly 27% of households having just one occupant. With best estimates of hot water loads averaging roughly 16-19 gallons per day (Lutz et al, 2011), the ARBI team developed four usage categories—Low, Moderate, Above Average, and High. Since recovery load takes into account both gallons of hot water and the inlet to outlet "delta T", we have listed a few "volume and deltaT" examples to demonstrate equivalency to the recovery load assumptions.

Low Usage (9,100 Btu/day) = 21 gal/day at a "hot climate" deltaT of 52°F , or
= 16 gal/day at a "cold climate" deltaT of 77°F

Moderate Usage (27,000 Btu/day) = 42 gal/day at a typical "cold climate" deltaT of 77°F, or
= 52 gal/day at a typical mid-range deltaT of 67°F

Above average Usage (40,000 Btu/day) = approximately equal to Energy Factor recovery load, or

[21] http://energy.ca.gov/2008publications/CEC-400-2008-002/CEC-400-2008-002-CMF.PDF
[22] http://205.254.135.24/emeu/recs/recs2005/hc2005_tables/detailed_tables2005.html

	= 72 gal/day at a typical mid-range deltaT of 67°F, or
	= 60 gal/day at a "cold climate" deltaT of 77°F
High Usage (69,000 Btu/day)	= 124 gal/day at a typical mid-range deltaT of 67°F, or
	= 100 gal/day at a "very cold climate" deltaT of 83°F

With the four recovery load levels defined, annual gas water heater energy use (both base case and advanced) can be calculated using the relationship shown in Equation A-1:

Equation A-1:

$$Annual\ Gas\ Use\ (therms) = \frac{365\ days/year}{100\ 000\ Btus/therm} * \frac{Daily\ Recovery\ Load\ (\frac{Btu}{day})}{Load\ Dependent\ Efficiency}$$

where the Load Dependent Efficiency is determined from the plot shown in Figure A-2.

Parasitic electrical use associated with the advanced gas water heaters is also addressed in this analysis. The GTI PIER field monitoring project found an average advanced water heater electrical consumption of 80 kWh/year (58 kWh/year for tankless), less than the ~ 102 kWh/year observed in the Minnesota CEE tankless study (Schoenbauer et al, 2011), where recovery load is higher and anti-freeze usage occurred with some installations. For this study, 80 kWh/year was used as proxy for the parasitic energy assumed for all advanced gas storage water heaters.

Electric water heater energy consumption is handled in a similar fashion as shown in Equation A-2. The load-dependent efficiency is taken from Table B-2.

Equation A-2:

$$Annual\ Electric\ Use\ (kWh) = \frac{365\ days/year}{3\ 413\ Btus/kWh} * \frac{Daily\ Recovery\ Load\ (\frac{Btu}{day})}{Load\ Dependent\ Efficiency}$$

Energy use for both the base case scenario and the alternative cases are then converted to annual costs using nominal energy rates of $1.00 per therm and $.10 per kWh. Final site-specific cost adjustments can then be made using local retail rate factors, as outlined in the tool.

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