How Residential Water Heating is Changing

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Water heating system energy use in U.S. residences is second only to space conditioning.[1] Recent advances are changing the way water heating service is provided. This column describes hot water demand in residences, discusses new options for providing hot water and explains ASHRAE's role in the water heating industry.

Hot Water Demands

Key considerations for a building's water heating system are obtaining the needed amount of hot water rapidly and efficiently, while maintaining safe, reliable, long-life operation at reasonable installed and operating costs. A key phrase in the previous sentence is "water heating system," meaning not only the water heater, but also the hot water end uses, the distribution system and user behaviors. All four play important roles in delivering expected hot water service and providing opportunities for performance improvements.

On average, homes in North America use approximately 164 L (43 gallons) of hot water per day, but that number is highly variable depending on the number of occupants, types of appliances present, day of the week and occupant behavior. The largest hot water end uses in residences are showers, faucets, clothes washers, dishwashers and bathtubs. *Table 1* provides average daily hot water use per household from a recent field study.[2]

For human contact applications, hot water is mixed with cold water to provide the desired temperature, typically between 38°C (100°F) and 43°C (110°F). Dishwashers and clothes washers tend to use higher temperature water (49°C [120°F])—and even higher when required to sanitize (60°C [140°F]). Some appliances incorporate separate booster heaters to achieve these higher temperatures, so hot water is often provided to end uses at a temperature of approximately 49°C (120°F). Hot water temperatures are an oft-debated topic. Water should not emerge from the faucet so hot it causes scalding, but it should be heated to a sufficiently high level to minimize growth of pathogens. This issue is worthy of a complete column, and interested readers are referred to ASHRAE Standard 188-2018,[3] ASHRAE Guideline 12-2020[4] or a recent publication by the National Academy of Sciences.[5]

Water temperature entering homes varies by geographic region and time of year, but a year's average value tends to be near the average annual air temperature. Thus, energy is needed to raise water temperature from approximately 16°C (60°F) to 49°C (120°F) or more. Due to water's high heat capacity, large amounts of energy are needed to achieve this temperature increase.

End-Use Fixtures and Appliances

One key way to decrease energy consumption

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associated with water heating is to reduce the amount of hot water used. Reductions of hot water use can be achieved by several methods, depending on the end use. In some cases, providing fixtures with reduced flow rates is effective—in other cases it is not. In some cases, reducing the total volume of hot water for batch-fill operations (e.g., washing machines) is beneficial. In other cases this reduction is not possible. In some cases, changing the habits and customs of end users can save water and energy.

Some end-use fixtures and appliances serve end-use needs by providing flow rates that are adequate to achieve a desired end goal, such as the invigorating "feel" of a shower or a "scrubbing" action when washing dishes. With these types of fixtures and end uses, the total volume of hot water use is of secondary importance compared to the "velocity impact" of the flow. For these types of needs, use of lower flow fixtures that still achieve desired "velocity impact" save water and energy while not sacrificing usability.

Other types of end-use fixtures and appliances are more dependent on volume of hot water used to achieve desired end uses than they are on flow rate. These types of end uses typically involve batch-fill operations. Examples include filling bathtubs, sinks or cooking pots and using dishwashers and clothes washers. Typically no water or energy efficiency savings are associated with providing reduced flow rates to batch-fill operations, and often a decrease in user satisfaction occurs if the user must wait longer for the batch fill to complete.

If, however, end-use appliances can be designed and operated to function well while using reduced amounts of hot water in their batch fill, water and energy savings can be achieved. An example of such savings is the reduced water use of dishwashers and clothes washers in response to efficiency standards.[6]

User Behavior

Another important consideration is end user behavior. Hot water use behaviors vary with both personal preferences and cultural norms. An example of a behavior that impacts hot water consumption is the use of multiple shower heads in a shower stall to get a more "invigorating" shower. Another frequently seen behavior is for users to turn on the hot water (e.g., at a sink or shower) and walk away while waiting for hot water to arrive. This behavior often results in hot water having already reached the fixture before the person returns to use the hot water, "dumping" hot water directly down the drain without being used.

A common "fix" for the hot water delivery delay problem is equipping piping systems with pumps that circulate hot water through the piping to keep hot water immediately available at fixtures. Unfortunately, while recirculation loops save water, they can consume significant amounts of energy by keeping water in the loop hot at all times.

Distributing Hot Water

Residential water heating systems most commonly use a central water heater with storage capacity. The hot water needs to be transported to the end-use fixtures, and heat is lost along the way. While ensuring enough capacity to deliver the required amount of hot water is a key design issue with distribution systems, opportunities exist to minimize the amount of heat lost in transmission.

TABLE 1 Average daily hot water use per household.

END USE	PERCENT	GALLONS
Shower	41.1	17.8
Faucet	35.6	15.4
Clothes Washer	10.2	4.4
Bathtub	6.0	2.6
Dishwasher	5.1	2.2
Other	2.1	0.9
Total	**100.0**	**43.3**

Reducing distribution system energy losses can be accomplished in several ways. First, the layout of the plumbing system should minimize the volume of water between the water heater and the end uses. This objective can be achieved, for example, by locating fixtures closer to water heaters. Pipe sizing should also be appropriate. Many codes require large-diameter pipes based on outdated assumptions for water flows prior to the introduction of modern fixtures. However, it is likely that smaller-diameter pipes can be used to achieve desired flow rates.

Oversizing hot water pipe diameters is a common error, in the mistaken belief that larger diameter pipes allow hot water to arrive quicker, when the opposite is true because of the greater volume of water in those pipes. Smaller pipe diameters and shorter piping runs are being implemented as parts of so-called "home-run" piping systems, in which a manifold near the water heater distributes hot water in smaller-diameter dedicated lines to end uses instead of using a trunk and branch system.

Another hot water system design approach that can minimize wait time is using more than one water heater. Some types of water heaters are optimized for installation near points of use, such as small storage water heaters (e.g., 8 L to 22 L [2 gallons to 6 gallons]) and tankless water heaters designed to be located under sinks. A combination of multiple large and small water heaters in a single residence is becoming more commonplace as designers begin to recognize potential performance and cost benefits. These actions decrease the amount of hot water sitting in pipes between uses, minimizing heat loss to the surroundings. These energy savings often exceed the added heat loss from additional water heaters installed near the end use.[7] These steps have the added benefit of reducing wait time for hot water and of reducing initial costs of piping. Finally, insulating the distribution system will cut down on heat losses.

Making Hot Water

That brings us to the final part of the system, the water heater. For many years, consumers primarily had one of two options: a storage tank fired by fossil fuel (natural gas, propane or oil) or one heated with electric resistance elements. Approximately half the U.S. uses electricity to heat water, while the other half uses combustion water heaters.[8] Recent years, however, have brought a wider range of water heating options.

On the electric side, heat pump water heaters (HPWH) have emerged as a viable method of heating water. These units, which use a refrigeration cycle to move heat from the surroundings or outdoors to heat the water, achieve significantly higher energy efficiencies than resistance water heaters. The efficiency rating metric in the U.S. and Canada, the uniform energy factor (UEF), measures the efficiency under a standard draw pattern and set of environmental conditions.

The best 189 L (50 gallon) electric resistance water heater achieves a UEF of 0.93, whereas a HPWH is listed with a UEF as high as 3.55.[9] Hence, the HPWH will tend to use approximately one-quarter as much energy as the resistance water heater, albeit with the penalty of a higher first cost. In the U.S., electric water heaters that are sold with storage volumes above 208 L (55 gallons) are required to have UEFs greater than 1.86, which can currently be met only through the use of HPWHs.[*9]

For gas water heaters, several technologies have emerged that reduce energy consumption. First, condensing water heaters offer higher combustion efficiency. While standard natural draft (atmospheric) combustion water heaters with a storage volume of 189 L (50 gallons) achieve UEFs of approximately 0.60, condensing water heaters can achieve UEFs approaching 0.90.

A technology for the future is the gas-fired heat pump water heater. While not yet commercially available, significant research and development has occurred in recent years. Coefficients of performance in field tests have exceeded 1.5,[10] which would decrease energy use by approximately 60% compared to conventional atmospherically vented products and by about 40% compared to condensing water heaters.

For both electric and gas, another increasingly popular option has been tankless water heaters. While storage water heaters maintain a volume of hot water for use, tankless water heaters only heat water when it is needed, passing the incoming mains water through heat exchangers. Several advantages exist for tankless water heaters. First, they take up less space than storage water heaters of equal capability, which allows them to be more easily located closer to end uses. From an efficiency viewpoint these units do not lose heat continuously to the environment (storage losses) because they are only kept hot when water is flowing.

Tankless water heaters require much larger heat input rates compared to storage water heaters since there is no stored energy waiting to be delivered. For fossil fuel-fired units, firing rates tend to be above 29 kW (100,000 Btu/h), whereas gas storage water heaters typically fire at about 12 kW (40,000 Btu/h). At high enough flow rates, required heating rates could be so high to necessitate changes to inlet gas piping or exhaust flues, an issue that would increase labor costs for installation.

Electrically powered tankless water heaters are also available. Versions are available from those with heating rates large enough to serve "whole-house" hot water loads, down to small units intended for single sink applications. For whole-house applications with relatively cold incoming water at the main, a high current draw may be required to raise the temperature to a usable level. These units, however, could be installed in a distributed manner under sinks to provide more localized heating, reducing water and energy waste due to lengthy hot water distribution piping. In general, the first costs of tankless units tend to be higher than conventional storage water heaters of similar delivery capability.

*Minimum efficiency standards for water heaters are based upon storage volume and delivery capacity as measured by the first hour rating.

ASHRAE's Water Heating Related Activities

ASHRAE Technical Committee (TC) 6.6, Service Water Heating Systems, provides information and content related to water heating systems. Among the key products of this committee, Chapter 51 of the *2019 ASHRAE Handbook—HVAC Applications*, "Service Water Heating," provides a wealth of information on water heating systems.

Another key area where ASHRAE assists the residential water heating community is through standards and guidelines. In particular, methods of testing for residential water heaters (ASHRAE Standard 118.2-2006, reaffirmed in 2015), combination space heating and water heating appliances (Standard 124-2007, reaffirmed in 2016), multipurpose heat pumps (ASHRAE Standard 206-2013, reaffirmed in 2017), and pool heaters (ASHRAE Standard 146-2020) provide the industry sound ways to assess performance.

Additionally, TC 6.6 regularly hosts technical sessions at ASHRAE Conferences, providing new information on modern water heating systems. With the changing landscape of water heating for residential applications, ASHRAE is well-positioned to help industry and consumers assess best approaches for their needs.

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