HOT WATER RUNS COLD

The ideal hot water distribution system wastes no water or energy. We're not even close to that ideal—yet.

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National appliance standards and aggressive building energy standards in California and other states have significantly lowered the per ft^2 energy consumption of new homes. Over the past 30 years, the advent of higher air conditioner and furnace efficiencies, high-performance windows, improved insulation standards, and low-leakage duct systems has led to real improvements in energy efficiency.

One area that is not keeping pace is domestic water heating. Although efficient instantaneous gas water heaters are slowly gaining market share, the vast majority of water heaters are tank storage units—either electric, or gas units with a center flue and continuously burning pilot light. Tank storage water heaters have seen incremental improvements in efficiency, but the basic design has changed little over the part 30 years.

Similarly, the distribution system, which delivers hot water from the water heater to the end use points, has remained essentially unchanged. Some plumbers have told me that the quality of workmanship (soldering) is not as good as it once was, making it difficult to achieve leak-free installations with copper. New materials, such as cross-linked polyethylene (PEX), have made installations more leak-free and are cheaper to install, but distribution system size is still based on an archaic plumbing code from the 1940s. Oversized piping leads to significant water and energy waste and long wait times for hot water to arrive at the use point. (For more on hot water distribution systems, see "Are You Getting into Hot Water?" *HE* Sept/Oct '03, p. 33, and "Hey, Where's the Hot Water?" *HE* Sept/Oct '04, p. 36). Inefficiencies in the distribution system are compounded by the following new construction trends:

• Houses are larger. (The average size of a new home has increased by 35% over the past 20 years.) This means that hot water fixtures are further away from the source of hot water.

• There are more hot water use points, (such as added bathrooms and dual showerheads).

• Many new homes have large whirlpool tubs. (The high design flow rate for these tubs means bigger pipes all the way back to the water heater.) This means more water and energy waste and longer wait times.

• Many new homes have low-flow fixtures. This again means longer wait times.

There are three major barriers to improving water heating distribution system design practice. These barriers involve understanding hot water use patterns; understanding how hot water is used from a behavioral perspective (occupant control); and developing a better scientific understanding of pipe heat loss characteristics in a variety of environments. Prior studies of water distribution systems have been limited in scope and have had a variety of different objectives. This makes it difficult to draw valid conclusions about improving water distribution systems based on these studies. Many studies date from the early 90s; the subsequent introduction of low-flow fixtures has changed hot water usage. What is needed is an extensive database on water use, with data collected under similar protocols to allow for statistical analysis of the data set. This article discusses the implementation of a short-interval monitoring approach using sophisticated data loggers that allows for high-resolution data collection. My colleagues and I at Davis Energy Group hope that this approach can be applied to a larger number of sites, and that the information gathered will guide changes to hot water distribution systems to bring about a significant decrease in residential water and energy use.

Project Description

In 2003, a major home builder in the Sacramento, California, area gave researchers access to a new home to field-test an advanced HVAC duct system. Monitoring of the 2,070 ft^2 single-story home was sponsored by DOE's Building America program. Since the Building America program is also very interested in residential water heating, they decided to install additional sensors to monitor hot water usage characteristics and delivery system performance.

PEX hot water piping was installed in the house. PEX has become fairly common in the Sacramento area and other regions of California because it costs less than traditional piping, takes less time to install, and is less likely to leak. Except for the drops through interior walls to the fixtures, all hot water piping was located in the attic (see Figure 1 for tubing layout). Pipe length should be minimized and the pipe should be fully covered by the loose-fill ceiling insulation (the pipe was otherwise uninsulated). But sections of the hot water piping extended above the insulation, exposing the pipe to greater heat loss (see photo, p. 28). Also, little effort was made to keep pipe lengths to a minimum.

Research Home Pipe Layout

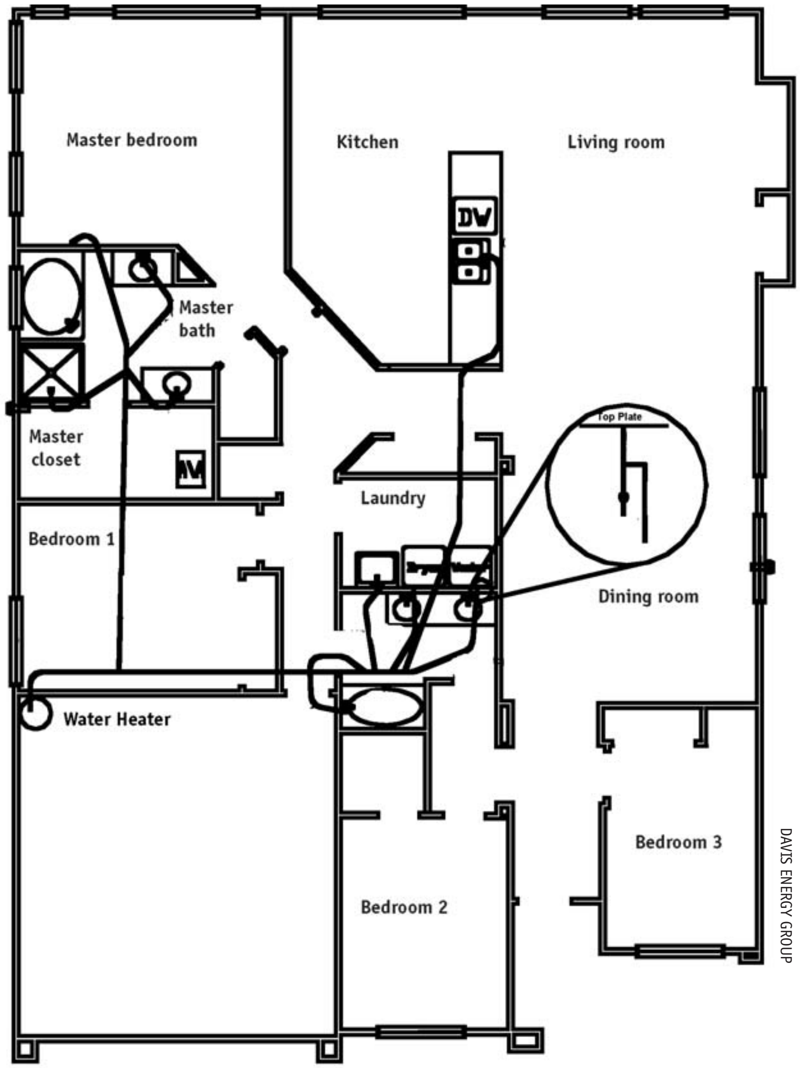

Figure 1. Unfortunately, little effort was made in building this house to minimize pipe lengths.

Monitoring Approach

The strategy used for collecting hot water usage and distribution system performance data was to monitor supply water temperatures at each hot water fixture and to measure the temperature and water flow exiting the water heater (see Figure 2 for monitoring sensor locations). The typical surface mount thermocouple installation occurred just downstream of the copper/PEX transition (see photo p. 31). This approach was used on all of the hot water use points in the house.

When the flowmeter senses a hot water draw, the data logger would immediately start logging the temperature at each use point and the hot water flow at two-second intervals. The data logger would also calculate two-second interval energy flows at the water heater and at each use point. This short-interval data collection documents

- where hot water is being used and how much is being used;
- typical hot water flow rates by fixture;
- duration of hot water draws;
- how hot water loads are distributed during the course of the day; and

• the distribution system efficiency (or what fraction of the energy leaving the water heater arrives at the fixture).

Results

The house, which had been purchased by a working couple with no children at the end of September 2003, was monitored continuously from October 2003 through August 2004. Table 1 compiles the 11 months of two-second monitoring data. Hot water draw characteristics are disaggregated by fixture to highlight variations in usage characteristics. Hot water usage during the monitoring period averaged 41.8 gallons per day. Of the total usage, nearly 45% was used at the master bath shower fixture.

The bottom two rows of Table 1 show coincident draws and draws with no end use. Coincident draws occurred when a hot water draw was initiated, but during the course of the draw, a second hot water draw was initiated. Since we were unable to precisely disaggregate a combined draw, all coincident draws were lumped in this category. (Hot water flow rate will frequently vary during the course of a draw, due to user adjustment. When a second draw overlaps the initial draw, it is no longer possible to accurately apportion flow to individual draws.) It is evident that some shower use fell into the coincident category due to the high average draw volume.

Draws with no end use occurred when hot water flow was sensed by the flow meter, but a temperature rise was not observed at any fixture. This is caused by a combination of single-lever faucets—people tend to operate single-lever faucets in the mid position, drawing both hot and cold water, while separate hot and cold water taps require a conscious effort to demand hot water—and occupant behavior—calling for hot water at the fixture, but never waiting for it to arrive. The draws with no end use averaged 0.2 minutes (10-15 seconds) in duration. This suggests that inadvertent hot water draws account for most of the draws with no end use. The 3.1-gallon per day consumption with no end use amounts to 7.5% of the total daily average consumption. This is virtually all waste, although some of the heated water in the pipes could be partially used by subsequent draws if they were taken fairly promptly, before heat from the pipes is lost.

Plotting the average hourly hot water consumption in terms both of percent of daily usage and average draw volume provides useful information (see Figure 3). Peak hot water usage occurs from 5:30 to 8:30 am, remains fairly consistent from 10 am to 10 pm, and then tapers to a very low level from 10 pm to 5 am. Average draw volume is highest during the morning peak, because the occupants take morning showers. Interestingly, the average draw volume exceeds

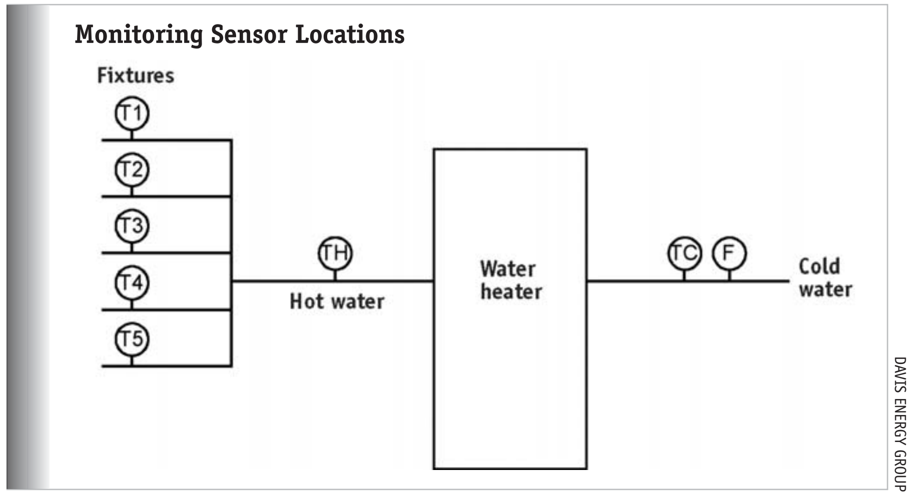

Figure 2. Surface mount thermocouples (T1–T5) were located at each hot water use point, thermocouples were located at the inlet and outlet of the water heater (TH and TC), and a high-resolution flow meter (F) was installed in the cold water line feeding the water heater.

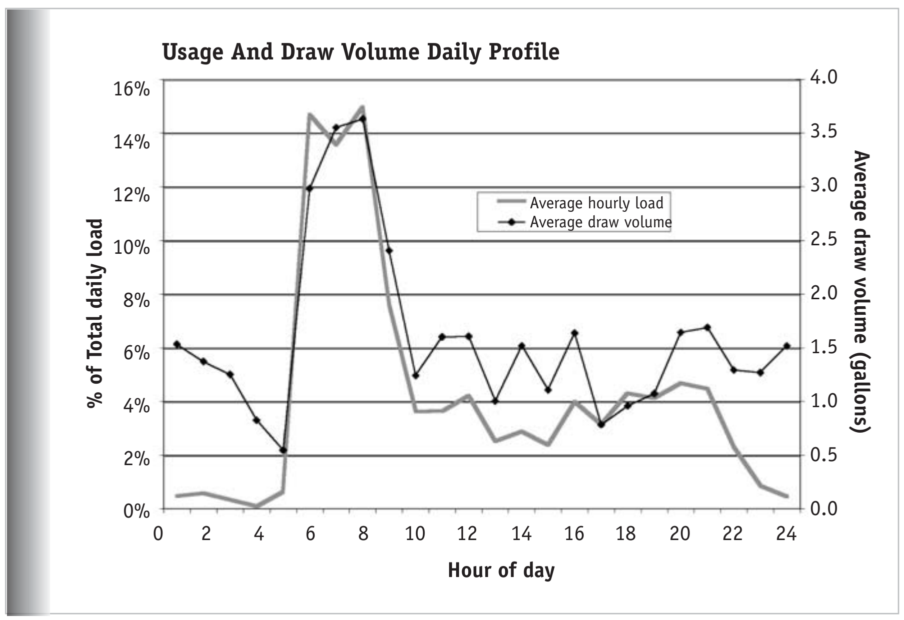

Figure 3. Peak hot water usage occurs from 5:30 to 8:30 am, remains fairly consistent from 10 am to 10 pm, and then tapers to a very low level from 10 pm to 5 am. Average draw volume is highest during the morning peak, because the occupants take morning showers.

Table 1. Hot Water Draw Characteristics

			Average Draw Characteristics*		
Draw Description	**Draws/Day**	**Gals/Day**	**Rate (Gpm)**	**Vol (Gals)**	**Time (Min)**
Master bath shower	1.5	18.7	1.4	13.3	9.5
Master bath sink 1	1.1	1.2	1.4	1.1	0.8
Master bath sink 2	1.5	2.3	0.9	1.6	1.7
Master bath tub	0.0	0.3	5.4	16.6	3.1
Guest bath shower	0.2	0.9	1.4	4.5	3.2
Guest bath sink 1	0.1	0.0	1.0	0.3	0.3
Guest bath sink 2	0.1	0.0	0.6	0.3	0.6
Laundry room sink	0.0	0.0	3.2	2.0	0.6
Clothes washer	0.7	4.9	3.1	7.0	2.2
Kitchen sink	0.6	0.4	1.2	0.6	0.5
Dishwasher	0.7	1.1	1.3	1.7	1.3
Coincident draws	2.8	8.9	1.4	3.2	2.3
Draws w/ no enduse	13.7	3.1	1.2	0.2	0.2

* rounded to the nearest tenth

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The thermocouple is located under the pipe insulation just downstream from the copper/PEX transition.

1.6 gallons per draw in only four hours per day. Based on the installed piping layouts, the volume of water entrained in the piping between the water heater and the fixture averages 1.08 gallons. If the hot water sits in the pipe long enough to cool below a useful temperature, most of the 1.6-gallon average draw will be wasted. For all the monitored draws during the 11 months, 25% occurred within ten minutes of a prior draw and nearly 60% at an interval greater than one hour. On average, 59% of the energy leaving the water heater arrived at a hot water fixture. Combining the 59% distribution efficiency with a 0.60 Energy Factor for a typical gas storage water heater results in an overall system efficiency of approximately 35% for this particular application. Overall efficiency will vary depending on the total hot water load, the distribution system configuration, water heater standby losses, and the heater combustion efficiency.

As discussed in the articles cited above, there are several ways to improve on the low distribution efficiency found in the test house. One is to design the building with the water heater as close to the fixtures as possible. Another is to install a home run parallel piping system that utilizes a distribution manifold close to the water heater to feed individual small-diameter PEX pipes running to each fixture (see Figure 4). For the monitored house, installing 3/8-inch PEX tubing to all use points would reduce the average entrained pipe volume from 1.08 gallons to 0.26 gallons. (The large tub would require a 1/2-inch line, due to its high flow rate requirement.)

A third option is to install a recirculation system (see Figure 5). Recirculation systems are most commonly installed on large houses, where either a recirculation system or several water heaters are needed to avoid excessive hot water waiting times. Although recirculation systems save water by bringing hot water close to the use points, many of the available control options are wasteful from an energy perspective. The demand recirculation system, the best energy performer of the available options, uses a high-capacity circulation pump and a push button control to quickly circulate hot water from the water heater to the use point.

Since the shower fixture is the primary hot-water-consuming end use in this, and most, houses, further analysis of the shower data is of particular interest. Based on a review of the monitoring data, a minimum hot water temperature at the shower valve of 100°F was deemed the comfort threshold for these occupants. Multiplying the average elapsed time to reach 100°F by the average hot water flow rate resulted in a determination of hot water wasted at the shower (see Figure 6, p. 33). As one might expect, more hot water is wasted in winter months than in summer months, due to greater pipe heat loss and more energy needed to warm the pipe mass.

For the 11 months monitored, we found that the average hot water wasted per shower was 1.9 gallons (ranging from 1.5 gallons in July to 2.3 gallons in February). The 1.9 gallons is nearly twice the volume of water contained in the piping between the water heater and the shower fixture. In a household with more occupants and therefore more shower events, the magnitude of this energy and water waste becomes increasingly significant. (If the showers are taken close together in time, the waste per shower would decrease, depending on the length of time between draws.)

What We Learned

The higher than expected hot water distribution losses reinforce the two key principles of good hot water system design: first, bring the water heater closer to the fixtures, and second, pay close attention to pipe sizing and pipe location. This can be done in a variety of ways, including grouping hot water use points together, utilizing a home run parallel piping approach or installing a demand recirculation system, and keeping pipe buried in attic insulation, not under the slab.

The monitoring methodology used in this project generated valuable data on hot water usage characteristics and distribution system performance. Replicating this methodology on more houses would provide a useful database of information.

Another interesting aspect of the monitoring was quantifying the number of draws with no end use. More monitoring should be performed to determine how much of this waste can be attributed to operation, and how much to single-lever faucets.

Next Steps

Where do we go from here? Here are some possible next steps:

• Develop a how to guide for architects, builders, and plumbers to educate the industry on the benefits of intelligent design and installation of hot water systems.

• Replicate the monitoring approach on a wider sample of houses (new versus retrofit, one- versus two-story, parallel piping and recirculation versus conventional main and branch, houses with different pipe locations, houses in different regions, and so on) to gain insights on the key factors affecting distribution system performance. The monitoring approach presented here is not too expensive or difficult to install (it requires approximately $2,500 worth of hardware, sensors, and wiring), and the incremental cost is further reduced if other monitoring is already planned for that house.

• Use available data to calibrate hot water distribution system simulation models. (Data can include field studies and controlled lab tests of hot water distribution system performance.) With calibrated tools, designers can better evaluate distribution system alternatives.

• Initiate discussion with appropriate code bodies to modify the technical basis for pipe sizing in the plumbing code. With the advent of low-flow fixtures, pipes are regularly oversized, resulting in energy and water waste, and longer hot water waiting times.

Many factors are conspiring to reduce the efficiency of hot water dis-

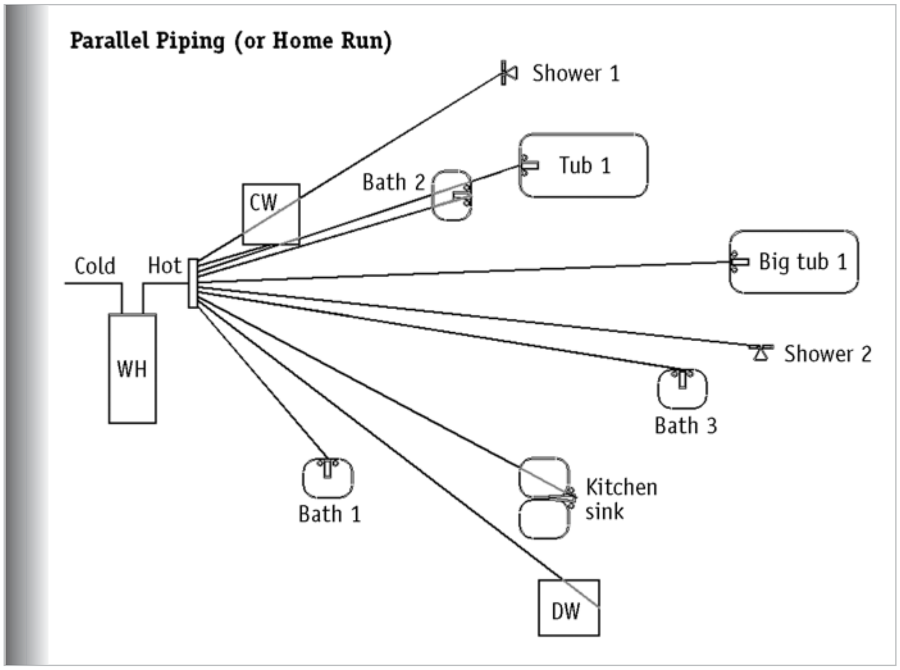

Figure 4. A parallel piping system uses a distribution manifold close to the water heater to feed individual small-diameter PEX pipes running to each fixture.

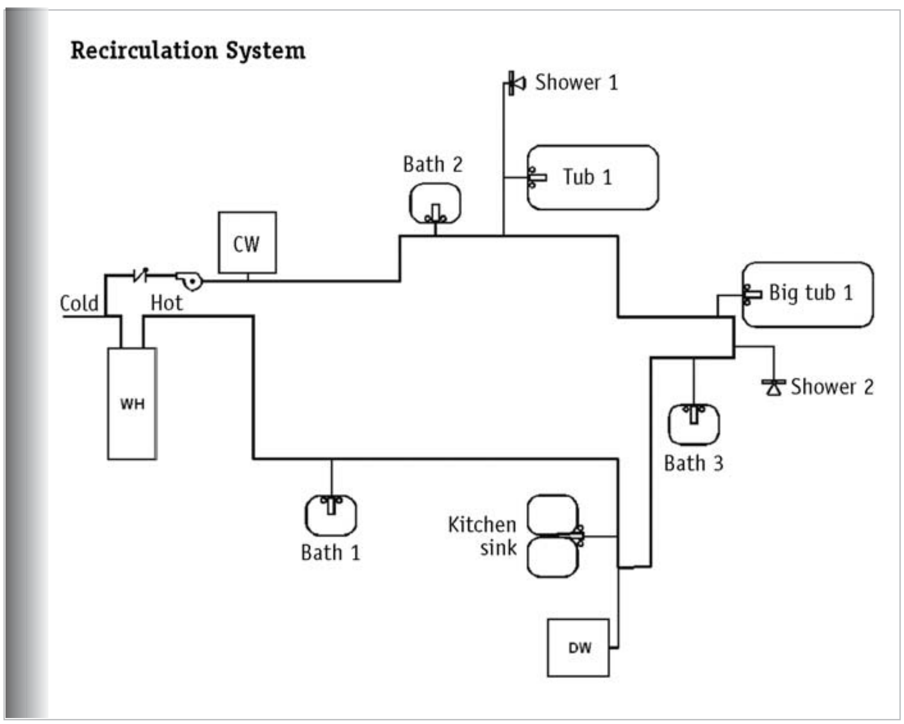

Figure 5. Although recirculation systems save water by bringing hot water close to the use points, many of the available control options are wasteful from an energy perspective.

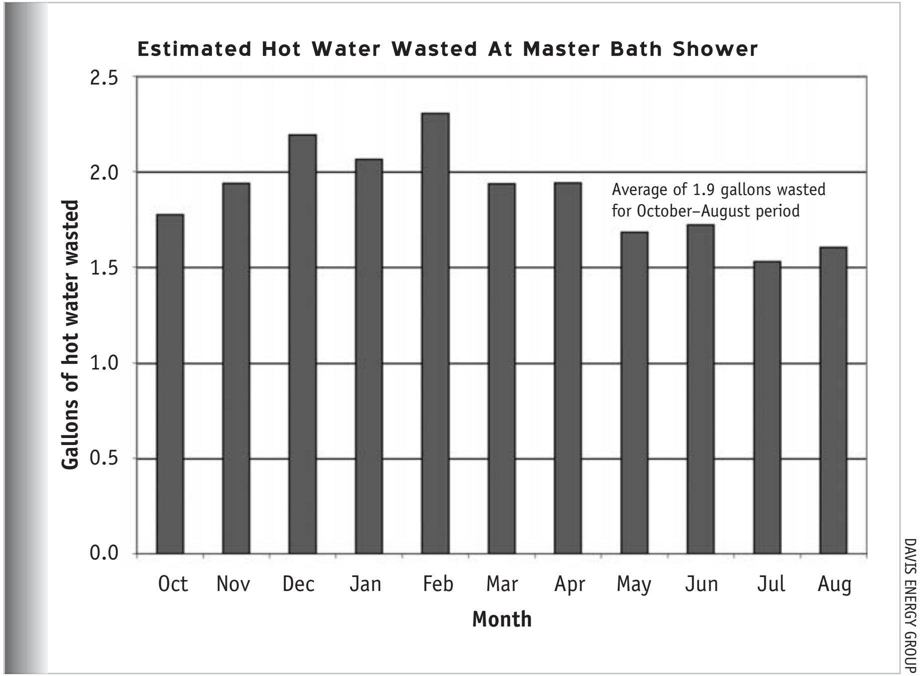

Figure 6. For the 11 months monitored, we found that the average hot water wasted per shower was 1.9 gallons (ranging from 1.5 gallons in July to 2.3 gallons in February).

tribution systems, including increasingly larger houses, more hot water use points (which leads to increased pipe sizing), and architectural designs that deemphasize the clustering of hot water use points. All these factors lead to increased hot water energy use and to aggravation for homeowners forced to wait for hot water. Validated design models and a basic understanding of hot water usage characteristics are needed to develop a best-practices guide for builders.

Marc Hoeschele is a senior engineer at Davis Energy Group in Davis, California. He has extensive experience in residential water heating and was the lead analyst on single-family water heating revisions for the 2005 California Title 24 building energy standards. He is also actively involved in water heating research under DOE's Building America program.