Photo: Ted Cushman/JLC; illustrations by Tim Healey

Architectural Compactness and Hot-Water Delivery

To satisfy homeowners, cluster water heaters and fixtures

BY GARY KLEIN

Over the past three decades, I've canvassed thousands of people and asked them what they expect from their hot-water delivery system. The results are virtually unanimous: First, almost without exception, people want hot water to come out of their tap within a few seconds of turning the faucet. Second, people don't want to run out of hot water, ever.

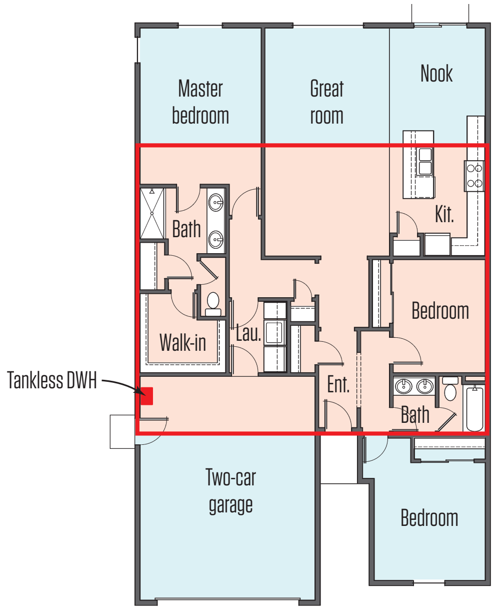
The second demand is satisfied easily enough by providing a water heater that has the capacity to supply the expected use, either through a large storage tank or through a burner (or electric element) large enough to keep up with the instantaneous hot-water demand. But the first requirement—practically instant hot water—turns out to be very difficult to achieve.

And it has only gotten harder to achieve over the past 50 years. That's because of two trends in the building industry. On the one hand, houses keep getting bigger. That means that bathrooms and kitchens are spread out over a larger and larger area. Moving hot water from the water heater to the bath or kitchen fixtures requires longer and longer runs of pipe.

At the same time, flows at fixtures have continued to be constrained by federal and state water-conservation standards. In 1980, a residential bathroom lavatory faucet had a flow rate of 3.5 gallons per minute (gpm) or more. Under current plumbing codes, that fixture can draw only 2.2 gpm. And under some stricter state codes, those faucets can draw only 1.2 gpm—a reduction of 66% since 1980.

The Hot Water System Rectangle

One Story (3 Bedrooms, 2 Baths)



Hot Water System Rectangle ~67% (1,137 sq. ft.)
of total square footage (1,697 sq. ft.)

One Story (4 Bedrooms, 2 Baths)

Hot Water System Rectangle ~81% (1,628 sq. ft.)
of total square footage (2,010 sq. ft.)

The author calculates the area of the hot water system rectangle by drawing a bounding box around the water heater and hot-water-using fixtures and dividing the occupied floor area of the home by the area of the bounding box. The result can exceed 100% because the bounding box includes unoccupied areas such as the garage.

What about showerheads? In 1980, a flow rate of 3.5 gpm or more was typical. Today, mainstream codes limit showerhead water consumption to 2.5 gpm, and advanced green codes limit the flow to 1.8 gpm, a reduction of 49%.

It's a pattern. Commercial lavatory faucets used to draw 3.5 gpm; now, they can draw no more than 0.5 gpm. Residential clothes washers used to use 51 gallons per load; now, an Energy Star–rated washer uses only 12.6 gallons. Dishwashers used to use 14 gallons per cycle; today's Energy Star appliances use only 3.5 gallons.

Have pipe diameters decreased to match these changes in draw? No, they have not. Pipe sizing rules have not been revisited since they were first written down in the 1940s. So we have pipes that are sized by 1940s standards serving fixtures and appliances with radically reduced flow and fill rates. And because the houses are larger, those pipes are longer than ever before.

When you turn on a hot-water tap, all the standing water in the pipe serving the tap has to flow out before you see hot water at the tap. In fact, it's even worse than that: It turns out that because of mixing in the pipe, you actually have to flush double the volume of the standing water out of the pipe before fully heated water reaches the tap. In a modern house, that wait is often two minutes or more.

In practice, that adds up to a waste of water, energy, and of course, time. If the person using the tap actually decides to wait for the hot water, then several gallons of water can go down the drain before hot water arrives. If they don't wait, but instead go ahead and wash or rinse using cold water from the hot-water pipe, then there's a waste of energy: Water from the water heater ends up stranded in the pipe where it cools down, letting the energy dissipate without being used. In either case, there's a dissatisfied customer.

What can be done about it? That question is at the heart of a research program I was involved in for the California Energy Commission. We looked for ways to significantly increase efficiency of hot-water distribution systems. We examined many aspects of the problem, but the one I want to focus on here is architectural compactness: What happens if you cluster wet rooms closer to each other and locate the water heater close to (or inside) the cluster?

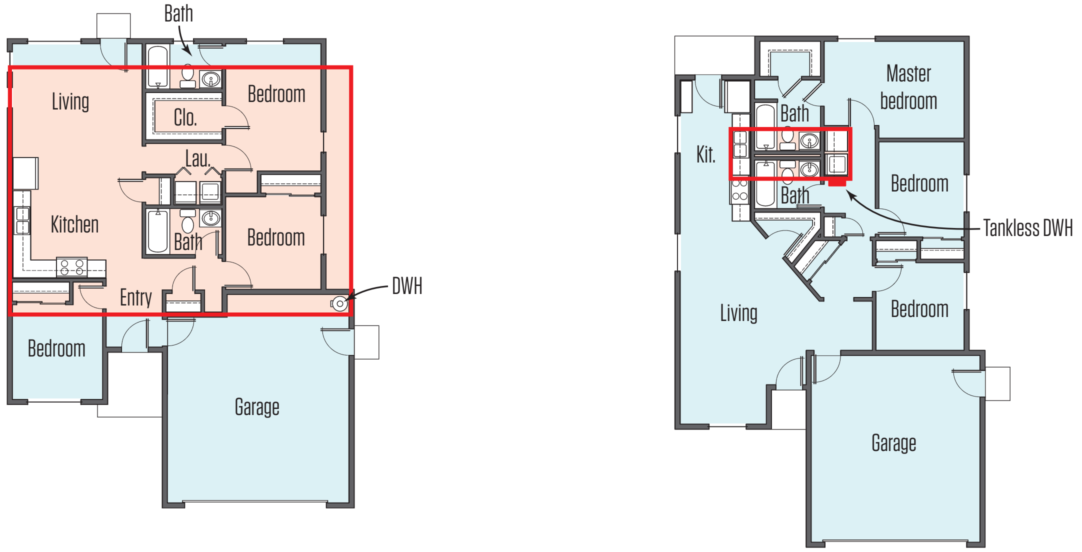
THE HOT WATER RECTANGLE

To start with, we looked at the existing layout of floor plans in the industry. We collected a sample of floor plans from the internet and

Success Story (Habitat for Humanity House)

Initial Design:
One Story (3 Bedrooms, 2 Baths)

Revised Plan:
One Story (3 Bedrooms, 2 Baths)



Hot Water System Rectangle ~79% (1,279 sq. ft.)
of total square footage (1,619 sq. ft.)

Hot Water System Rectangle ~2.5% (30 sq. ft.)
of total square footage (1,223 sq. ft.)

As a cost-saving measure, Habitat for Humanity construction manager George Koertzen was able to shrink the footprint of the hot water system in his home designs to a tiny fraction of the building floor area. Koertzen achieved this by placing bathrooms back to back and locating the washer and the kitchen sink at opposite ends of his main plumbing chase.

looked at how spread out their wet rooms were within the home's footprint. Over the existing plan, we superimposed a rectangle that bounded all the fixtures in all the wet rooms. This we called the "wet room rectangle." We also drew a rectangle that included the water heater as well as the hot-water fixtures; this we called the "hot water system rectangle." (In many cases, the two rectangles were the same.) Then we calculated the ratio of each rectangle to the total floor area in each of the houses, expressed as a percentage. The larger the percentage of the total floor area taken up by the hot water system rectangle, the more lineal feet of plumbing pipe required to reach the fixtures from the water heater. In the logical worst-case scenario, the water heater is at one corner of the house and the kitchen, laundry room, and baths are at opposite corners. It turns out that you can do worse than this!

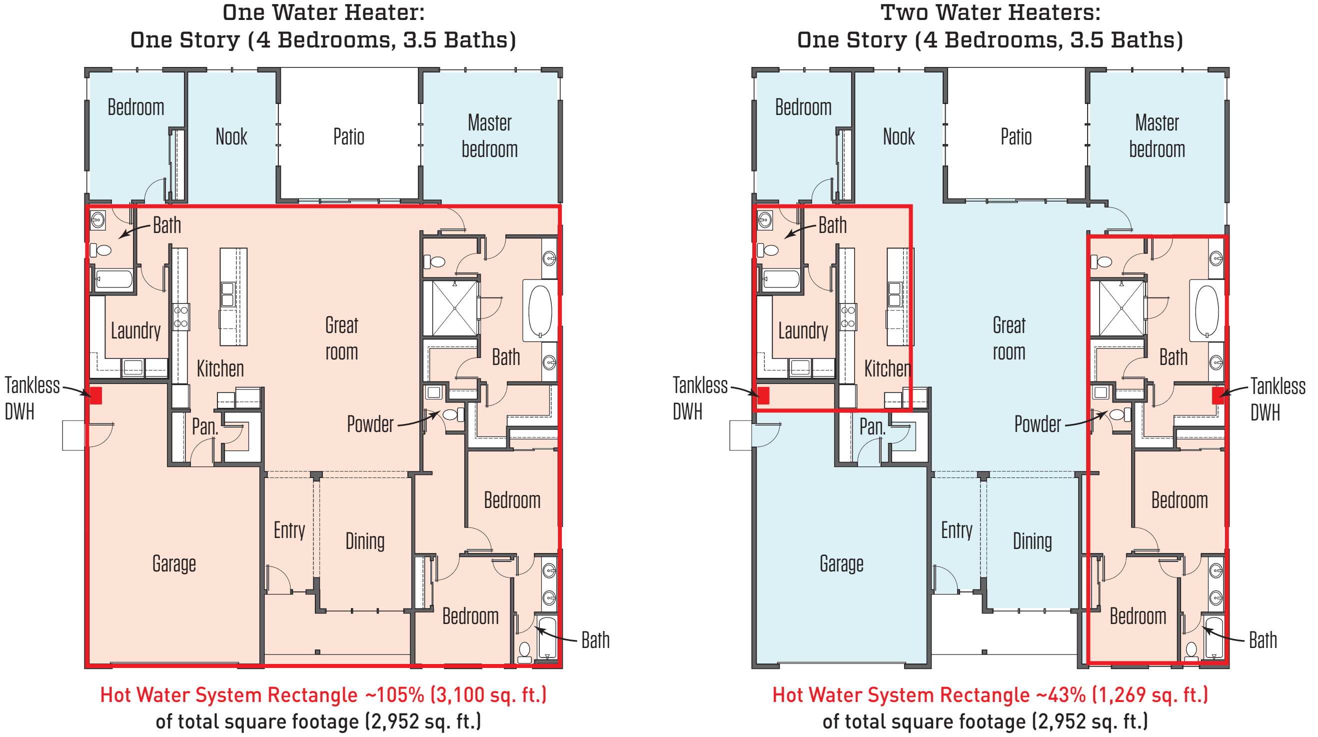
Shown here are a few examples. In all these cases, the water heater is within the wet room rectangle. The ratios range from a low of 67% to a high of 155% (the ratio can exceed 100% when the rectangle encompasses some garage and patio areas that are outside the occupied floor area of the house). The numbers show that house designers rarely design compact plumbing layouts. There's a range, but generally speaking, wet room rectangles and hot water system rectangles take up a large fraction of the floor area of houses.

SUCCESS STORY

It doesn't have to be that way. Proof of this comes from the Habitat for Humanity affiliate in San Joaquin County, Calif. George Koertzen, the construction manager for the affiliate, came to hear one of my presentations at a building industry conference. We had a short conversation that evening, and he went away and redrew the plans for his Habitat houses. Over several years, Koertzen was able to shrink the hot water system rectangle for these affordable houses from about 79% of the total footprint down to 15%, then 4%, then 2.5%, and finally down to 0.8% of the floor area.

Koertzen achieves these small rectangles by placing two bathrooms back to back, separated by a double-wall plumbing chase. At one end of the chase is the kitchen sink, and at the other end is the laundry room. The plumbing system is a ManaBloc manifold serving PEX hot and cold water lines, with a separate line for each fixture's hot and cold supply. Originally, Koertzen put the on-demand water heater for the house in one of the bathrooms,

Locating Water Heaters Closer to Fixtures



One effective way to reduce the building area required by the plumbing system is to add a second or third water heater to the plan. In this example, adding a second water heater would shrink the hot water system rectangle by more than half, reducing the required piping by a comparable amount.

but that choice proved unpopular, so he moved the water heater to the laundry room.

According to Koertzen, the wait time for hot water in the kitchen is 12 seconds—not quite instant, but a far sight better than the several-minute wait time experienced in some large houses. And after one of the fixtures has been used, the manifold is charged with hot water, so that any subsequent draw on other fixtures in the array results in hot water delivery within five seconds—the target time of thousands of consumers.

THE COST OF CONSTRUCTION

Koertzen's Habitat houses rely on volunteer labor, so he has no information on the labor cost savings to be gained by using so much less pipe and fewer hangers. But there's no doubt that the construction cost involved in a compact layout is less than in a widely distributed layout. Our research team analyzed that comparison for a typical mid-market house.

Our analysis is based on the California Energy Commission's Title 24 prototype house for energy mathematics and modeling, a 2,100-square-foot single-story slab-on-grade home. We used this house for several modeling efforts. One thing we did was compare two wet-room layouts: one where the baths and kitchen were spread around the building, and one in which they were clustered together.

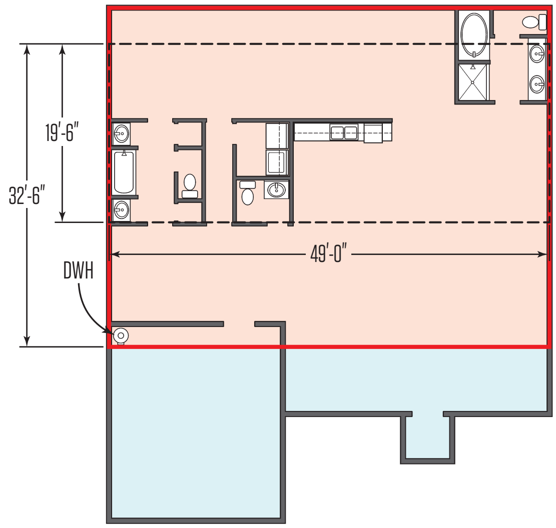
We asked one of California's largest plumbing contractors to estimate the cost of the supply, waste, and vent piping in the two scenarios. The result (see tables, facing page) indicates that clustering the wet rooms together and placing the water heater in close proximity to the cluster results in a savings of more than $2,000 in the cost of the plumbing system. Most of this cost savings is the result of labor savings. By reducing the amount of pipe and fittings to be installed in only the horizontal portions of the hot, cold, drain, and vent piping, the compact layout saves a week of labor hours.

MOVING THE WATER HEATER

Without radically rearranging the locations of the wet rooms, some house plans can be improved simply by moving the water heater or by adding a second or even a third water heater. When you add water heaters, you can break the hot water system rectangle up into two or more separate rectangles. This cuts down on the pipe lengths between the water heaters and the fixtures, reducing the time to

Compact Core

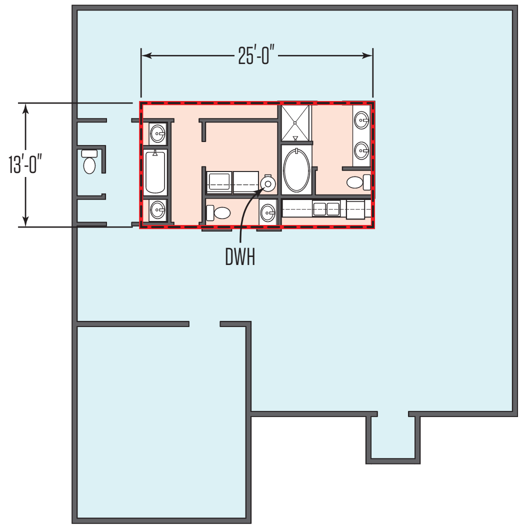
Baseline Case



Wet Room Rectangle:
- 19.5 feet x 49 feet
- 956 square feet
- 45.5% of floor area

Hot Water System Rectangle:
- 32.5 feet x 49 feet
- 1,592 square feet
- 76% of floor area

Compact Core



Wet Room Rectangle:
- 13 feet x 25 feet
- 325 square feet
- 15.5% of floor area

Hot Water System Rectangle:
- 13 feet x 25 feet
- 325 square feet
- 15.5% of floor area

The two plans above represent two hypothetical cases that formed the basis for the construction cost comparison below. The more compact plan saves more than $2,000 in estimated construction cost, mostly by saving labor.

Cost Savings Breakdown for Baseline Case

	Materials		Labor		
Item	**Quantity**	**Cost**	**Rate**	**Hours**	**Total**
Supply Piping (PEX)	297	$180.91	$43.45	15	$653.49
Supply Fittings (PEX)	28	$162.45	$43.45	15.5	$672.17
Supply Joints (PEX)	60	$25	$43.45	0	$0.00
Supply Hangers (PEX)	137	$16.14	$43.45	35.6	$1,547.69
Drain Piping (ABS)	182	$201.34	$43.45	19.5	$849.01
Drain Fittings (ABS)	40	$120.05	$43.45	17.4	$756.46
Steel Pipe	132	$146.08	$43.45	7.9	$341.95
Steel Fittings	14	$31.16	$43.45	8.9	$385.84
Miscellaneous Joints	122	$27.08	$43.45	0	$0.00
Pipe Insulation	111	$135.70	$43.45	3.2	$139.00
Subtotal		$1,046		123	$5,346
Materials + Labor					$6,392
Sales Tax					$65
					$6,457
Overhead			10%		$645.74
Profit			10%		$710
Total					$7,813

Cost Savings Breakdown for Compact Core

	Materials		Labor		
Item	**Quantity**	**Cost**	**Rate**	**Hours**	**Total**
Supply Piping (PEX)	170	$118.04	$43.45	8.8	$381.93
Supply Fittings (PEX)	27	$171.55	$43.45	15	$652.18
Supply Joints (PEX)	57	$25.00	$43.45	0	$0.00
Supply Hangers (PEX)	46	$5.36	$43.45	12	$519.66
Drain Piping (ABS)	150	$147.11	$43.45	15.1	$656.10
Drain Fittings (ABS)	40	$119.42	$43.45	17.4	$756.46
Steel Pipe	118	$152.15	$43.45	7.4	$321.53
Steel Fittings	16	$34.56	$43.45	8.9	$385.84
Miscellaneous Joints	128	$28.13	$43.45	0	$0.00
Pipe Insulation	56	$64.30	$43.45	1.6	$70.50
Subtotal		$866		86	$3,744
Materials + Labor					$4,610
Sales Tax					$54
					$4,664
Overhead			10%		$466
Profit			10%		$513
Total					$5,643

A view of the rough plumbing in a house under construction by the Habitat for Humanity affiliate in San Joaquin County, Calif. A short plumbing chase located in the double-wall partition between back-to-back bathrooms serves baths, toilets, and sinks in both bathrooms, as well as a kitchen sink at one end and a laundry at the other. Hot water is delivered to fixtures in seconds.

Photo: George Koertzen

tap of the fixtures. This would be a strain on the budget for a small house, but in large houses, where the strategy is most effective, adding a second or third water heater isn't going to break the bank.

The challenge lies in locating the water heater close enough to the fixtures. Six feet of pipe holds about one cup of water. In simple terms, one strategy is to locate the water heater within 6 feet of the fixture—that is, no more than one cup away.

That is very hard to do. In a bathroom, it might mean putting the water heater over a toilet between the sink and the shower. If you're lucky, you would have two bathrooms back to back and you could serve them both with one water heater. In practice, two cups away turns out to be much more buildable than one cup. That is, locating the water heater 12 feet from a fixture is more practical than putting it just 6 feet away.

Interestingly, if we allow 3/8-inch tubing instead of 1/2-inch tubing, 12 feet of pipe would hold one cup of water. So reducing the allowable tubing diameter would help solve the problem. Plumbing codes generally don't allow this without an engineered design. But in reality, physics tells us that dropping down to 3/8-inch pipe with modern fixtures does not impact the performance of the fixture—at least, not for showers and sinks (filling a large tub still works better with 1/2-inch or 3/4-inch pipe). So, a long-term solution to the hot-water problem may have to wait on a revision of the plumbing code to bring it into conformance with the physics of the situation.

COLD-START FUNCTION FAUCETS

Our research indicates that a lot of energy is wasted by short-duration draws at sinks. What happens is that the user turns on the hot water, but doesn't wait for hot water to arrive. Instead, they rinse or wash with cold water from the pipe and turn the tap off. There is a hardware fix that will help reduce the energy waste associated with those short draws: We call it a cold-start function faucet.

These faucets take advantage of the fact that people tend to center the lever on the faucet and keep it centered. With cold-start function faucets, the center position is cold water; you have to pull the lever to the far left to draw hot water. If you lift the lever straight up, only cold water is released. In essence, the faucet defaults to cold instead of to a mix of hot and cold. With this faucet, we avoid wasting hot-water energy for those events where hot water isn't going to arrive at the tap anyway.

Gary Klein is the president of Gary Klein & Associates. *The author wishes to acknowledge the California Energy Commission for support of the research that led to this article.*