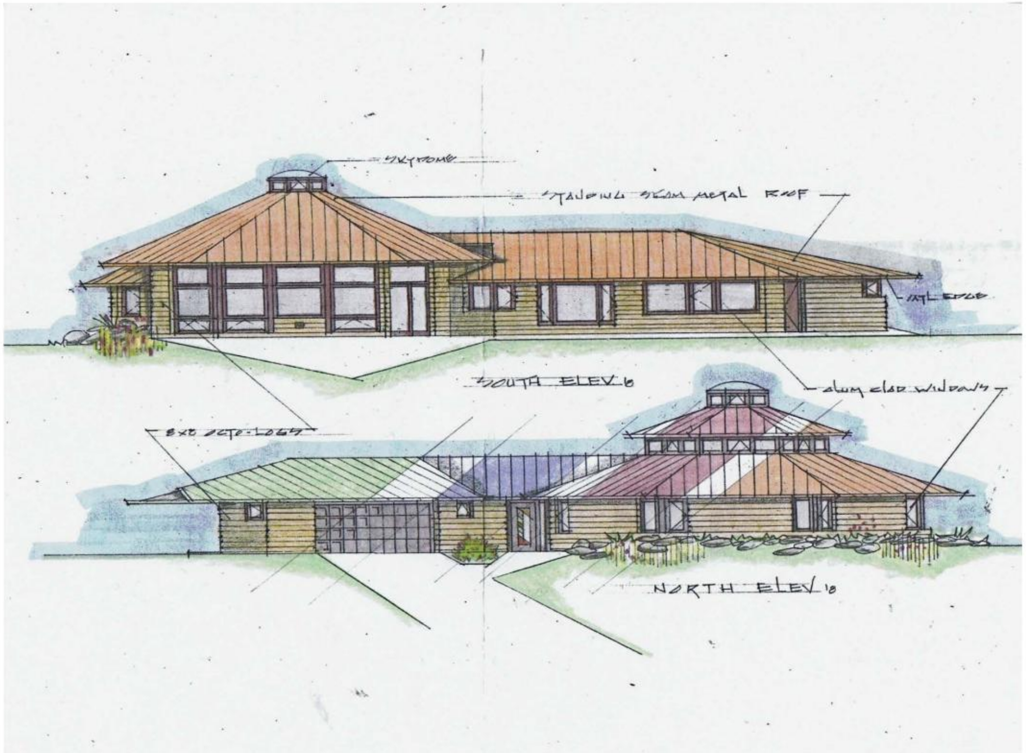
ATTACHMENTS TO PROPOSED CHANGES

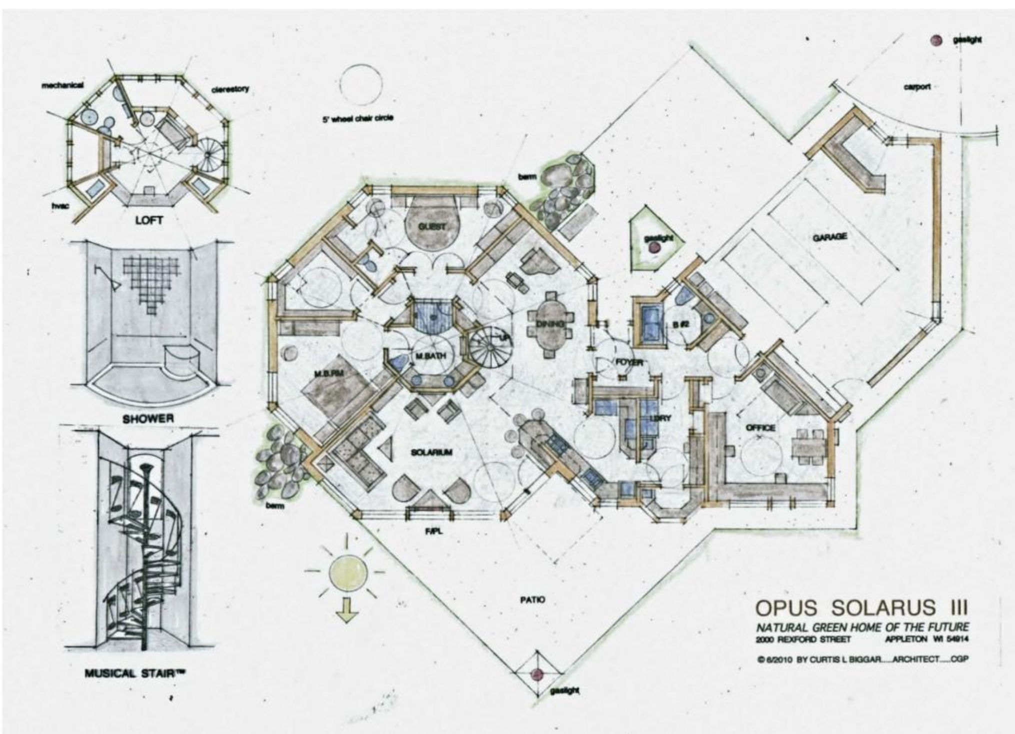
Table of Contents

Figure 1. 4400 w pine new.jpg

Figure 2. 4400 w pine int.jpg



SOUTH & NORTH ELEVATIONS



FIRST FLOOR & LOFT PLANS

OPUS SOLARUS III,1998 REXFORD DR. APPLETON WISCONSIN,NATURAL GREEN HOME OF THE FUTURE

© BY CURTIS L BIGGAR ARCHITECT/CERTIFIED GREEN PROFESSIONAL 920-716-2420 OCTOMAN80@MAC.COM

NATURAL GREEN HOME OF THE FUTURE

OPUS SOLARUS TEAM

A Work of Light

What is green architecture? What is green building? What is total green? Socrates taught his students to consider lofty porticos facing south to capture the warmth of the sun and with less important spaces facing the north to shelter from the cold wind. Frank Lloyd Wright practiced a natural architecture. He studied nature to better understand structure and built with indigenous materials, to cut transportation costs. Wright taught about truth in the use of materials. He employed the principles of passive solar heating using concrete floors in rooms with large expanses of south facing glass overlooking a garden. His floors used gravity heat under concrete floors.Most of his homes had tall kitchens with high windows to allow warm air and cooking odors to escape without a mechanical force. Many of Wright's designs were abstractions of nature forms such his snowflake design of several homes based on the hexagon. Wright was an early fan of the octagon and professed that man has an a natural tendency to walk at angles rather the military form of turning square corners as many of us are forced to do because of the design of most buildings. Orson Squire Fowler built and over twenty Octagon houses during the mid 1800s thru the United States instructing the geometrical shape was close to a circle and enclosed more interior space with less outsidewall area.The answer to the above green questions are as follows:

Green architecture is appropriate to it's geographic location, it's particular site, it's orientation to the sun. Green buildings will now be built & certified under the NATIONAL GREEN BUILDING STANDARD, Leeds v.3, Energy Star and other emerging certifiable programs. Passive & natural energy designs will lead to near zero energy cost and allow buildings to be constructed off-grid on remote properties. Sustainability and long term cost benefits are the reward for green buildings.Total Green is about lifestyle. The size of your home; it's proximity to workplace, shopping, public facilities,etc.; the car you drive; the food you eat; the things you share. etc.

Opus Solarus is a result of 50 years in architectural practice. I have found the octagon plan, if properly developed lends itself to panoramic vistas, ease in moving within the building and admits more natural interior light. I have lived in a south facing octagon home-studio with generous areas of glass and can attest to the positive psychological effect on my life. The warmth of the sun on a cold day is just as Socrates said. The open vistas of outside landscape bring us close to nature as Mr. Wright encouraged. These buildings cost less to build because the octagon is practical in shape , uses less construction materials, and costs less to heat, cool , light or to maintain.

4 BEDROOM-2 CAR 1746 sf affordable-accessible-near zero energy cost-storm resistant-mold resistant--fire resistant & sprinklered----aquaponic greenhouse---ships ladder--passive solar---natural cooling---natural lighting---with all masonry walls. Customized modifications availabe. Interior walls are non bearing & can be modified to fit your lifestyle. Heated attic storage space is above the kitchen-Laundry.

.....BUILDING FOR THE ENVIRONMENT....

4 BEDROOM-2 CAR 1746 sf affordable-accessible-near zero energy cost-storm resistant-mold resistant-fire resistant & sprinklered-aquaponic greenhouse-spiral stair-passive solar-natural cooling-natural lighting--------built with OCTO-LOG wall panels.. Most interior walls are non-bearing . Customized modifications available to fit your lifestyle. A loft is available above the center bath overlooking the sunroom that can be used as a den or guest area.

AVAILABLE ON YOUR IMPROVED LOT FOR ABOUT $200,000.00

Contact: Curtis L.Biggar Architect 4400 West Pine Street

SOUTH ELEVATION 2 car all masonry model (8" split face or 4"jumbo brick) available with 3 car garage . Green House window can be 45 degree or full 8' box bay. Customized modifications available. Thin solar photovoltaivs availble for off-grid buildings. ALL OPUS SOLARUS HOMES ACCOMMODATE AGING IN PLACE WITH LITTLE IF ANY MODIFICATIONS.

...FOR THE FUTURE.....FOR YOU...

ISOMETRIC DESIGN south cut-away view of log model showing solar apperature, thermal floor storage mass with radiant floor tubing, ridge beams with hollow interiors to accommodate air ducts, electrical wiring & fire sprinklers; clerestory windows above hallway for natural light, ventilation & thermal siphoning; spiral stair to den-loft overlooking sunroom. (above the central bathroom which serves as a safe-room within the storm-resistant octagonal shaped building). The laundry-craft room between the kitchen & garage has a aquaponic greenhouse at the south end. Adequate storage is provided in the walk-in closet next to the garage, in the heated attic above the kitchen-laundry room and in the upperloft equipment room...... Additional storage and a third car stall can be added to the 22' x 26' garage space.

NORTH ELEVATION 2 car all log model. Customized modifications available. Choice of asphalt/standing seam metal/colored liquid rubber available. Low eaves & wide overhangs contribute to low maintenance & reduced cooling costs. Venting clerestory windows infuse the interior with natural light & ventilation.

UP TO 75 % PASSIVE ENERGY SAVINGS............. NATURALLY

OPUS SOLARUS.. is a team of NAHB Certified Building Professionals, led by an Architect, with a mission to build homes and associated buildings in accordance with the NATIONAL GREEN BUILDING STANDARDS ICC-2008......... The new standard assures credibility to the "green movement" by complying with ANSI & International Code Council endorsed standards.

Each home built by Opus Solarus will achieve NAHB certified GOLD, or EMERALD ratings that will be verified and inspected by independent certified professionals. These new standards are a reward standard over and above building codes and will protect buyers, lenders, and insurers of these buildings.

Appleton Wi 54914 920-716-2420 octoman80@mac.com

"Whoever lives the truth comes to the light, so that his works may be clearly seen as done in God" John: 3:21

What Do Consumers Want from Their Hot Water Systems?

A SERIES ON HIGH PERFORMANCE HOT WATER SYSTEMS
PART ONE: CONSUMER EXPECTATIONS

About the Author:

Gary Klein has been intimately involved in energy efficiency and renewable energy since 1973. One fourth of his career was spent in the Kingdom of Lesotho, the rest in the United States. He has a passion for hot water: getting into it, getting out of it and efficiently delivering it to meet customer's needs. Recently completing 19 years with the California Energy Commission, his new firm, Affiliated International Management LLC, provides consulting on sustainability through their international team of affiliates. Klein received a BA from Cornell University in 1975 with an Independent Major in Technology and Society with an emphasis on energy conservation and renewable energy.

Story by Gary Klein

Let's talk about high performance hot water systems. We'll discuss the mechanics of making the heat for hot water and how much of it we may need in a moment, but first we'd better figure out what customers actually care about. To provide context for this discussion, since the mid-1990s I have spoken with and interviewed more than 20,000 people from all walks of life throughout the United States and from many countries around the world to learn what they want and expect from their hot water systems. In this series, I will be sharing with you what I have learned from these hot water users and from research that has been conducted in the lab and in the field, and later how we can apply this knowledge to define the characteristics of high performance hot water systems.

What People Want and Expect

The first question we should ask any prospective client is "What do you want from your hot water system?" What they have told me they want are clean clothes, clean hands, dishes, body, relaxation, enjoyment — in other words, the service of the hot water. Well, these are the things that people actually want, in the simplest of terms: warm house, cold beer. They don't really care how the house gets warm or the beer gets cold, they just want it to be that way when they want it.

The next question we need to ask is, "What do you expect from your hot water system?" The customer expects safety, reliability and convenience.

- **SAFETY:** Customers expect the water to be neither too hot, nor too cold. They also expect it to contain no harmful bacteria or particulates, although quite a large number of people put up with hard water and other physical water issues. In food service and health services, customers expect sanitation.

- **RELIABILITY:** Customers expect that the entire hot water system will require little or no maintenance, that it will last forever and that it will be low in cost, both when they buy it and to run and maintain it over its operational life.

How many of you have a water heater in your facility or your home? Have you ever maintained the water heater in your facility? Drained it out, checked the anode, made sure that the temperate and pressure relief valves were working properly? You know, if you do that you can make a water heater last a really long time, but if you put the water heater in the back corner and ignore it, well, it probably won't last as long as you might like it to.

- **CONVENIENCE:** Customers also expect the ability to adjust both temperature and flow, although most showers only give the option of adjusting temperature. They expect that the system will be quiet — no water hammer, no sounds in the middle of the night from their recirculation system, no significant noise from a water heater (gurgling or fan noise from power vented systems). They also expect to


IF YOU HAVE A PROBLEM
DO NOT
RETURN THIS
WATER HEATER
TO THE PLACE OF PURCHASE.
Call 1-877-817-6770
For ALL installation, warranty and performance questions.
ENERGYGUIDE
Estimated Yearly Operating Cost
520
Cost Range of Similar Models
4879
Estimated Yearly Energy Use
Your cost will depend on your utility rates and use.
IMPORTANT
STATE OF CALIFORNIA NOTICE
DANGER
Water temperature over 125°F can cause severe burns instantly or death from scalds.
Children, disabled and elderly are at highest risk of being scalded.
See instruction manual before setting temperature at water heater.
Feel water before bathing or showering.
Temperature limiting valves are available. See manual.
HOT
BURN

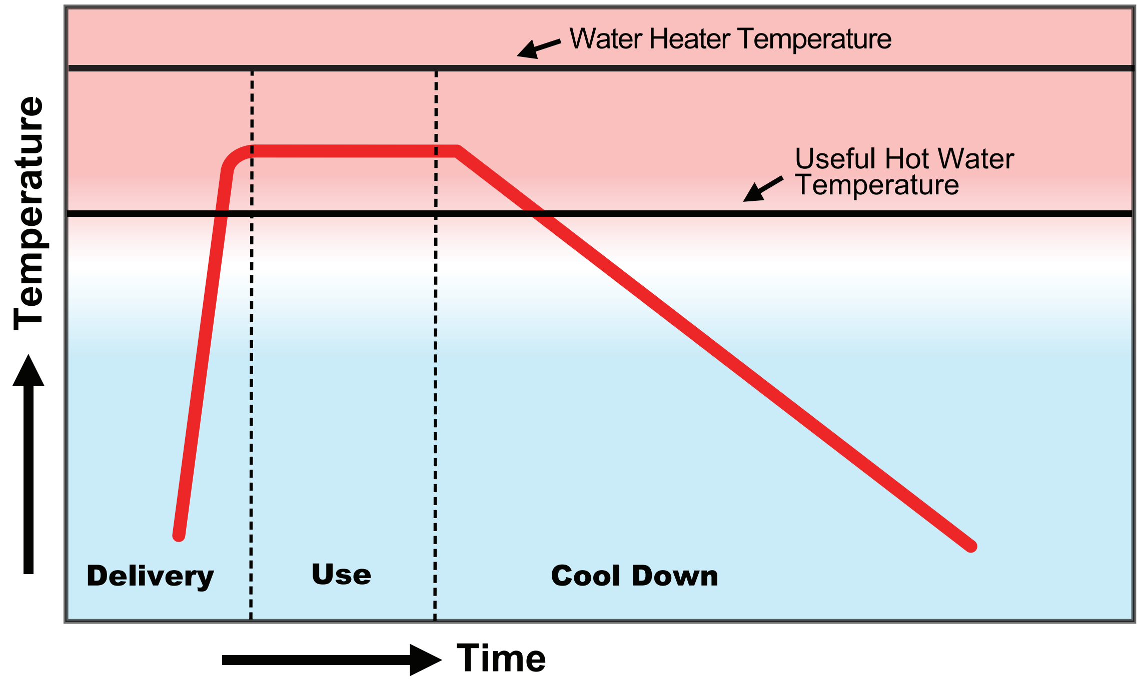


Figure A: Typical hot water event.

GRAPHIC PROVIDED BY GARY KLEIN

never run out of hot water — a problem that many have experienced, but which actually seems to happen relatively infrequently. While it would be nice to have the ability to have several hot water devices operate simultaneously, this is not usually expressed as a big concern. They already have that ability, although tank volume and the burner or element capacity limits the duration of simultaneous events; and they generally schedule their hot water use so that big hot water uses do not overlap.

In addition, faucet, shower and appliance flow rates have been declining, effectively increasing the water heater's ability to sustain simultaneous events for a longer time.

Finally, they expect that hot water will arrive very quickly after they turn on a tap, although the vast majority complain about the length of the time-to-tap, which they describe as a random event, varying from 10-15 seconds at fixtures near the water heater to well more than two minutes at the fixture furthest from the water heater. Less than five percent of the people say they get hot water everywhere in less than five seconds after they turn on the tap. Most of these have a recirculation system; the others have a small house with a short distance from the water heater to the fixtures. In commercial buildings, such as restaurants, most people do not actually expect to get hot water in the public bathrooms, even though it is required by health codes!

Depending on the specific application, I suspect you and your customers want most, if not all, of these same services and have very similar expectations, too. Of all of the issues raised above, what the people I have interviewed want the most is to reduce the time-to-tap, followed by never running out in their shower — theirs, not their children's!

Typical Hot Water Event

Figure A shows a typical hot water event. There's a delivery phase, a use phase and a cool down phase. People would like the delivery phase to be short. According to those I have interviewed, a few want hot water to arrive immediately after they open the tap, which I explain is possible, but rather expensive. Well more than 90 percent say they want the time-to-tap to be between two and three seconds. We will see later on that this level of performance is achievable at reasonable costs.

The use phase is the use — washing dishes, taking showers, whatever it might be.

And then when you turn off the tap, the temperature of the water in the pipe starts to cool down, all the way from the water heater to the hot water outlet. It takes on the order of 10 to 15 minutes for the water in uninsulated pipes to cool from about 120° F down to 105° F when the pipes are located in air at a temperature between 65° F and 70° F, which is typical for most buildings. The water cools down more quickly when the surrounding temperature is colder, such as in a basement or a crawl space, or when the pipes are located under or in a concrete slab. The water cools down more slowly when the pipes are in a hot attic in mid-summer or when they are insulated. We will discuss this further later in this series.

The water heater temperature must be higher than the mix-point temperature you'd like to have, and the useful hot water temperature needs to be less than the point at which you mix it. Why? You need to have some head-room from the mixing point down to the useful hot water temperature point because of variations in desired temperature for any given application on any given day.

The Hot Water System

Now, let's talk about the hot water system. There are five components of hot water use in the building:

- Water heaters
- Pipes
- Faucets, showers, appliances and other fixture fittings
- Hot water running down the drain
- Behaviors

Which is the biggest variable in determining water and energy use? I ask this question of lots of people and get all sorts of answers, but the fact is behaviors are the single biggest variable and that is what's going to determine water and energy use.

How much do behaviors make a difference? Well, let's just pick on your home for a minute. Was today's hot water use *exactly* the same as yesterday's? Will it be *exactly* the same as tomorrow's? I get up at about the same time everyday, but I don't take a shower at exactly the same time, nor is it exactly the same length. I wonder if this happens to you in your home and in your facilities? I suspect it does.

Again, based on my large sample, there are probably an infinite number of hot water use behaviors and patterns. In homes, they often fall within "windows of opportunity" — morning rush hours and evening plateaus; and on weekends, all bets are off! The pattern varies depending on the facility you're in, but the concept of windows of opportunity still applies.

All of these behavior patterns boil down to two possible results: when you turn on the tap, either hot water comes out pretty darn quick or it doesn't. Which is it in your home, at your place of work, your favorite restaurants? I suspect for many of you and your customers, the answer is "it doesn't."

Another factor is how do the interactions among these components affect system performance? Imagine you have long uninsulated pipes between the source of hot water and the fixtures that are being used a lot. Do people wait a long time for hot water? What if you could move the water heater closer, make the pipes better insulated or deliver hot water quicker by use of a pump or electric heat trace? Do you think that that would improve system performance?

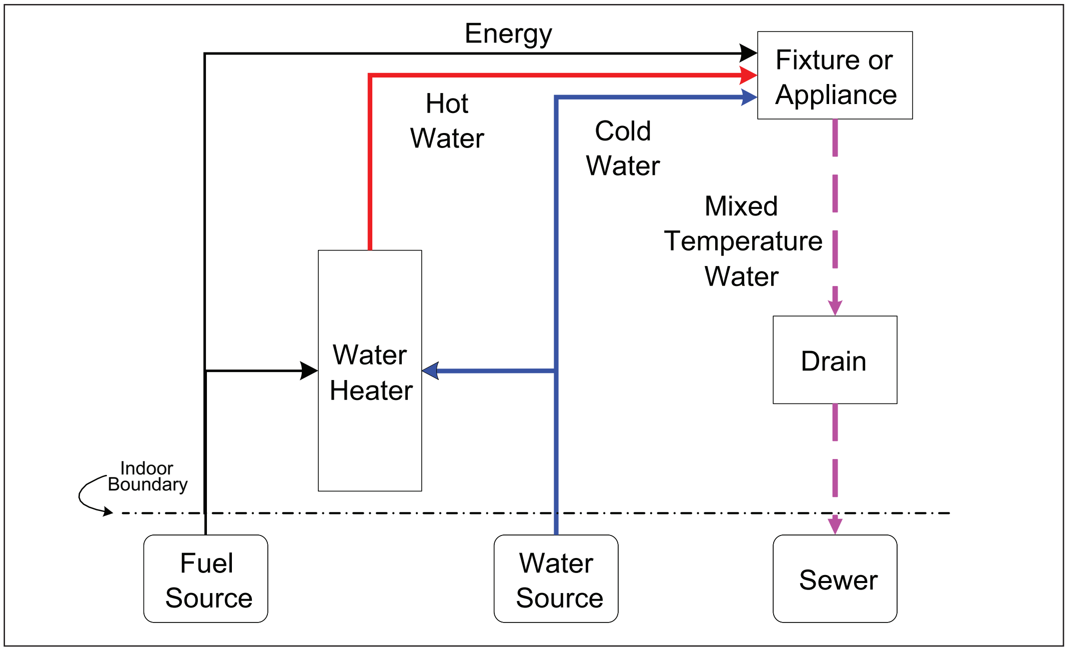


Figure B: Typical "simple" hot water system for single-family or single unit applications.

What about single lever valves on faucets or on showers where, when you turn on all hot, you actually get some hot and some cold? What if the valves performed differently so that when you wanted all hot water, you got all hot water? What about when you wanted cold water, you got all cold water? Well, all of these interactions affect the system's overall performance and you as a consumer pay for the system inefficiencies or, conversely, its efficiencies.

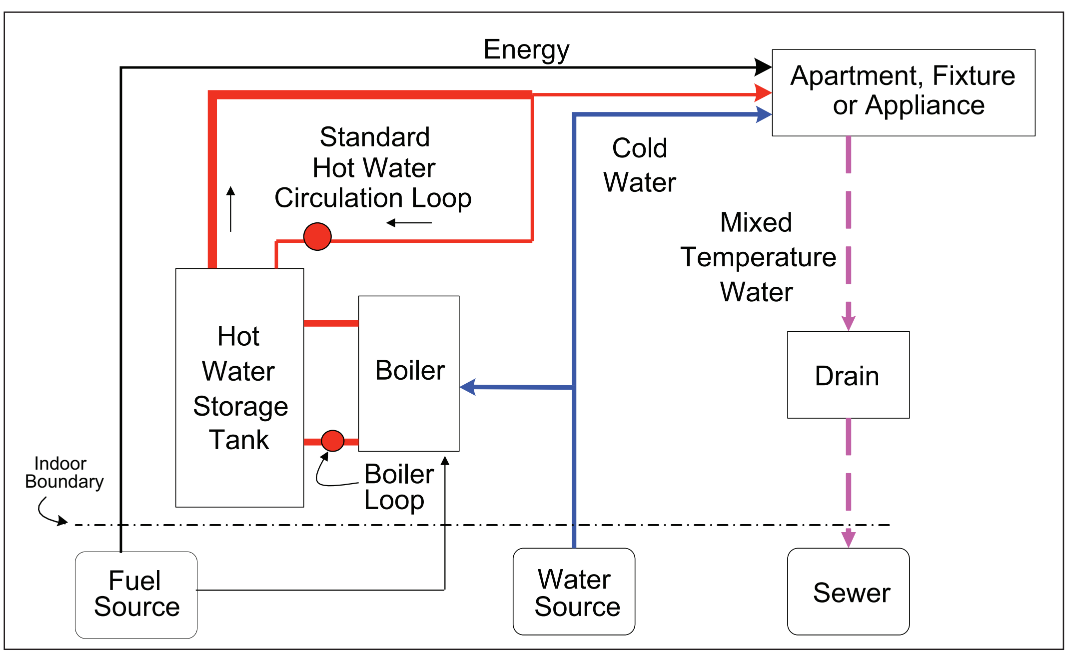
Figure B shows a typical simple hot water system. You see it in single-family housing, or single unit applications in multi-family buildings. You see it in commercial facilities. Fuel comes in, cold water comes in and it goes to a water heater. Hot water goes to fixtures or appliances; so does cold water. Some appliances use energy — dishwashers, washing machines — and there's mixed temperature water running down the drain, ultimately into the sewer.

(When I started doing these kinds of analyses I began asking people "Why do we run hot water down the drain?" I understand why we run the water down the drain, but why do we run it down the drain still hot? What if we could capture some of the waste heat? Wouldn't that be a good idea, too? We'll discuss how to do that later in this series.)

Figure C is a typical central boiler hot water system. You generally see these in bigger buildings, whether they are residential or commercial. Often there is a boiler to make the heat, a hot water storage tank to store the heat for capacity and peaking, and then there's a circulation loop, most often using a 24/7 pump (sometimes controlled with a timer or an aquastat) to deliver hot water out to the far reaches of the building.

Figure C: Typical central boiler hot water system.

GRAPHICS PROVIDED BY GARY KLEIN



What's Next:

In future installments, we will discuss the hot water distribution system: how to improve existing ones and how to build them more efficiently to begin with; the uses of hot water; drain water heat recovery; the ways to make hot water more efficiently and effectively; and how all of these components come together in a high performance hot water system.

Hot Water and How Best to Get It

A SERIES ON HIGH PERFORMANCE HOT WATER SYSTEMS
PART TWO: DISTRIBUTION

Story by Gary Klein

Before we talk about hot water distribution systems, we need a few definitions.

A ***twig line*** serves one faucet, shower or appliance, either hot or cold water; the hot and cold water outlets. The diameter of the twig should be determined by the flow rate of the device it serves. For instance, a garden tub with a 10-gpm flow rate should have a larger diameter twig than a 0.5-gpm lavatory sink. By definition, there can be no simultaneity on a twig, as it serves only one device. (I have begun using "twig" to follow the tree analogy. My friend and colleague, Phil Campbell reminds me that the *Uniform Plumbing Code*® refers to these sections of pipe as fixture branches. Thank you, Phil!)

A ***branch line*** serves two or more twigs, a trunk line serves a combination of twigs and branches and the main line serves the building. The diameter of the branch, trunk and main lines should also be determined by the flow rate of the devices that they serve, coupled with an estimate of the likelihood of how many devices on the branch, trunk or main line would be operated simultaneously for any significant period of time.

In the previous paragraphs, I used the words "should be determined" when referring to the selection of pipe diameters. Flow rate isn't the only parameter, but it is a very important characteristic that should be more readily apparent when looking at pipes serving devices with widely varying flow rates. At the present time, the underlying mathematics behind Water Service Fixture Units (WSFU) and their implementation in various plumbing codes are being revisited to take into account the changes to flow rates that have occurred in the past 20 years and that are expected in the next 20. We will go into more detail on WSFU later in this series.

The ideal hot water distribution system would minimize the time-to-tap. To do this, it would have the smallest volume of water in the pipe from the source of hot water to the fixture. Sometimes the source of hot water is the water heater; sometimes it's a trunk line. In the ideal hot water distribution system, all the hot water outlets would be close to the water heater that serves them, and there might well be more than one water heater per building. For a given layout of hot water locations, the system will have the shortest buildable trunk line, few or no branches, the shortest buildable twigs and the fewest plumbing restrictions.

Whether the hot water pipes should be insulated and with how much insulation depends on several factors, including the location and length of the piping and the time between hot water events. Insulation makes a significant difference in reducing the time-to-tap when the time between hot water events on the same twig, branch or trunk is between 10 and 60 minutes for pipes from 3/8 to 1 inch in diameter. The time delay gets longer as the diameter of the pipe increases.

The need for insulation is understood when the pipe is installed in adverse environmental conditions, such as in the ground, under a slab or in a cold crawl space. But I would remind

About the Author:

Gary Klein has been intimately involved in energy efficiency and renewable energy since 1973. One fourth of his career was spent in the Kingdom of Lesotho, the rest in the United States. He has a passion for hot water: getting into it, getting out of it and efficiently delivering it to meet customer's needs. Recently completing 19 years with the California Energy Commission, his new firm, Affiliated International Management LLC, provides consulting on sustainability through their international team of affiliates. Klein received a BA from Cornell University in 1975 with an Independent Major in Technology and Society with an emphasis on energy conservation and renewable energy.

"Here's the challenge: Deliver hot water to every fixture or appliance, wasting no more than one cup waiting for the hot water to arrive and wasting no more energy than we currently waste running water down the drain while we wait."

that normal room temperatures of roughly 70-degrees F are more than 35 degrees from a minimum acceptable hot water temperature. We insulate buildings for this temperature difference; we should do the same for our hot water piping. Oh, yes, all hot water piping, regardless of material (e.g. copper, steel or plastic), needs to be insulated.

High Performance Hot Water Systems

Now we're ready to talk about high performance hot water systems. Here's the challenge: Deliver hot water to every fixture or appliance, wasting no more than one cup waiting for the hot water to arrive and wasting no more energy than we currently waste running water down the drain while we wait.

Okay, you've thought about it a bit — how would you do it? Well, it turns out we have found five different ways to do this. I'll discuss them momentarily, but they all revolve around the answer to the following question: If you want to waste no more than one cup waiting for the hot water to arrive, what is the *maximum* amount of water that can be in the pipe that is not usefully hot? The *maximum* is one cup. In fact, it must be less than a cup because you do have to heat the pipe and there are some losses while you do it If you want to ensure that hot water will arrive before more than one cup runs down the drain, there can only be about 2/3 of a cup in the pipe.

The energy part of the challenge is perhaps less obvious. For this, we need to understand how much energy is wasted in typical hot water distribution systems while waiting for the hot water to arrive. It turns out there are two kinds of waste in the delivery phase. Structural waste is due to the volume of water between the source of hot water and the hot water outlets. Behavioral waste is what we do with it. The more volume, the longer it takes for hot water to arrive. The longer it takes, the more likely we are to give up (think waiting for hot water at a sink in a public restroom) or to leave and go do something else (Do you know anyone who, while waiting for the hot water to arrive at their shower, goes to the kitchen to make coffee, checks their email or texts their friends and returns when there is steam billowing out of the shower compartment?)

The actual wastefulness of a hot water distribution system is hard to determine since it is a combination of structural and behavioral considerations and you probably won't let me put a camera in the shower to let me know when you actually get in! The magnitude of this waste will be covered in the next article.

More volume in the piping also means more energy that will be lost when the water in the pipes eventually cools down. In practice, this means that we need to make sure that the hot water piping is "right sized" taking into consideration flow rates, pressure drop, velocity, noise, water hammer and simultaneous uses on branch and trunk lines. Structural waste also includes the energy losses of the water heater, as well as letting the energy in hot water you have used run down the drain. These topics will be covered in future articles in this series.

Without further ado, here are the five possible solutions:

1. You could build every building with central core plumbing, such that all hot water fixtures in that building are within one cup of one water heater. It's technically possible to do, but it's not likely to be done in many buildings given the way our floor plans are laid out.

2. You could have one water heater for every hot water fixture. It's more expensive to bring energy to the water heaters than it is to bring plumbing, so that's one reason it's not done very often. You also have the additional costs for the water heaters, the

flues (if the water heaters are fossil fired) and the space, not to mention future maintenance. So, you want to be careful about putting in lots and lots of water heaters, but that's another way of getting the volume down to less than one cup of waste.

This method of improving the delivery phase of a hot water event is often called point-of-use. In most peoples' minds, point-of-use means a small water heater such as the ones found under the sink in a dentist's office. However, each point-of-use water heater needs to be sized for the intended use: a 0.5 gpm lavatory faucet needs a different water heater than a 2.5 gpm shower, a 70 gallon garden tub or a commercial dish machine. Point-of-use is really about location, not the capacity of the water heater.

3. You could put two to three water heaters per building or home. Implementing this solution depends on the clustering of hot water outlets, such as back-to-back or stacked bathrooms, or other hot water locations. It's the same idea as one water heater for every hot water fixture, but you're going to space them out a little bit farther apart. You still have some issues with the running of the power for the water heater, the power or the energy supply for the water heater, but none-theless it makes sense, particularly as buildings get bigger. Our estimates are that you ought to be putting in a second water heater when the distance between fixture groupings gets to be on the order of 75 feet.

A good example of using distributed water heating for clustered hot water outlets is for the supply of hot water to the sinks in public restrooms at hotels and airports. There are usually several sinks, all of which could be served by one water heater located under the sinks or elsewhere in or nearby the bathroom. Since the faucets all have 0.5 gpm aerators (federal law since the 1990s), the trunk line from the water heater only needs to be ½ inch diameter and the twigs need to be no larger than 3/8 inch. The short, small diameter, pipes will be insulated and once the first person draws hot water, everyone else will have hot water quickly throughout the day. You can make sure the trunk line is filled with hot water before anyone turns on the tap by using an on-demand pump to prime the line

with hot water triggered by a motion sensor when someone walks through the doorway to the restroom.

4. You could put heat trace on the pipes. Heat trace is electrical resistance heating elements that are strapped to the pipe and then insulation is wrapped around the entire combination. The electric resistance elements are self-regulating cables. It's a very sophisticated technology and you can have as many feet of heat trace pipe as you would like to have. Since you can run the heat trace very close to each hot water outlet, it can easily meet the water waste portion of the challenge. However, it is not clear that it will use less energy than is currently wasted while waiting for the hot water to arrive. Sometimes heat trace is used in combination with a circulation loop; the heat trace is used to maintain the temperature in the branches and twigs, and a pump is used to maintain the temperature in the trunk line. We're still investigating where it makes the most sense, but it looks competitive in certain applications, particularly where there would normally be very long return line runs found in large commercial buildings or multistory buildings.

5. And then finally you could put a circulation loop one cup from every hot water fixture. We have found this to be the most buildable option, and all circulations systems, how-ever their operation is controlled, can save water if the volume from the circulation loop to the hot water outlets are minimized. Only one that we have found can actually save energy.

In the next article, we will examine each of these hot water distribution strategies in detail.

Meeting the One-Cup Challenge

A SERIES ON HIGH PERFORMANCE HOT WATER SYSTEMS

PART THREE: CENTRAL CORE PLUMBING

About the Author:

Gary Klein has been intimately involved in energy efficiency and renewable energy since 1973. One fourth of his career was spent in the Kingdom of Lesotho, the rest in the United States. He has a passion for hot water: getting into it, getting out of it and efficiently delivering it to meet customer's needs. Recently completing 19 years with the California Energy Commission, his new firm, Affiliated International Management LLC, provides consulting on sustainability through their international team of affiliates. Klein received a BA from Cornell University in 1975 with an Independent Major in Technology and Society with an emphasis on energy conservation and renewable energy.

Story by Gary Klein

We concluded the last article of this series with a listing of five hot water distribution strategies that would be able to deliver hot water while running less than one cup down the drain after we turn on the tap. In this article, we will begin discussing each of these methods in some detail.

Central Core Plumbing

In the last article, we described a central core plumbing hot water distribution system that met our challenge as one in which all hot water fixtures in a building are within one cup of one water heater. While this is technically possible to do, it is not likely to be done in many buildings given the way the hot water locations are laid out. It gets more difficult to do as buildings get larger.

Figure 1 shows a plan view of a traditional central core plumbing system. There are two basic configurations used to pipe a central core hot water distribution system: Long Trunk-Short Twigs (figure 1) or Short Trunk-Long Twigs (figure 2). I think of both of these configurations as radiating out from the water heater and both are found in traditional hot water distribution systems. However, in recent years Short Trunk-Long Twigs has come to be referred to as "home-run manifold" or "parallel piping," terms that have been popularized by the manufacturers of valved manifolds. It is useful to think of a tee as a one-port manifold. Most tees do not have valves and they are not necessary for implementation of Central Core Plumbing systems. Using a non-valved manifold with several tees will work quite well. The key is to limit the volume between the water heater and the hot water outlets.

Central core hot water distribution systems were common in single family houses built before World War II. The reason? Single family houses were relatively small and most of the housing stock in the United States had been built in parts of the country where basements were the normal way to build a foundation. Water heaters were located in the basement, right next to the gravity furnace or the boiler. The number of hot water outlets was very limited as the house generally had 1-1.5 bathrooms, a kitchen and a laundry sink in the basement.

Even though multi-family buildings with a central water heating system could not meet the one-cup challenge, the hot water locations in each unit were even more limited than those in single family homes, typically one bathroom and a kitchen. The hot water locations were stacked and most buildings were not more than 4-5 stories since elevators were still not common or required. In general, commercial buildings also had fewer hot water locations than we see today and they had similar height restrictions.

The hot water distribution system was typically made from galvanized piping, which has a relatively small inside diameter for a given nominal pipe diameter when compared to copper, which become the most common hot water distribution system material in the last 40 years of the 20th century. This meant that for a given distance between the water heater

Figure 1 (right) illustrates an example of a central core plumbing schematic with long trunk-short twigs.

Figure 2 (far right) illustrates an example of a central core plumbing schematic with short trunk-long twigs

ILLUSTRATIONS BY ANNE HESS

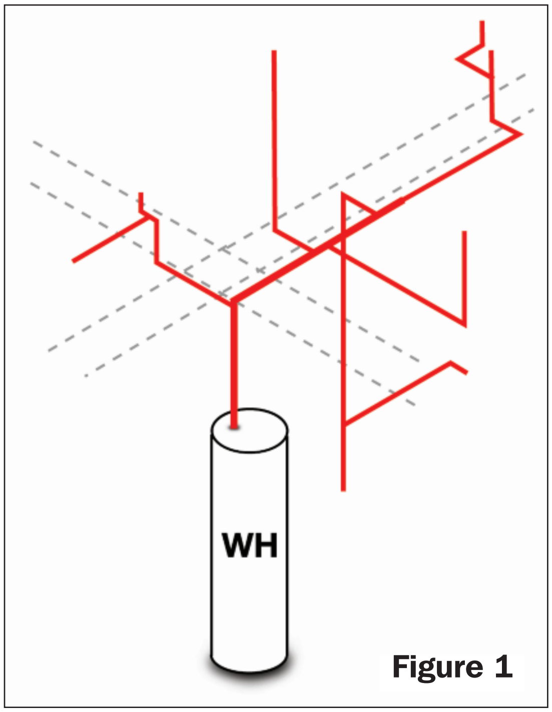


Figure 1

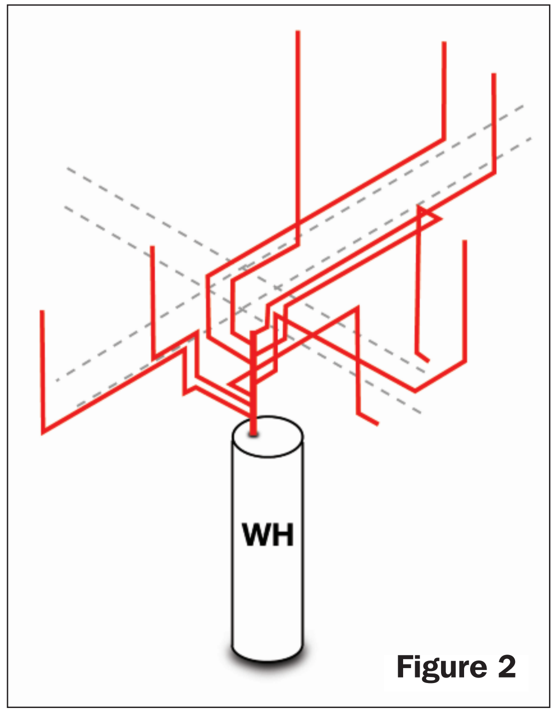


Figure 2

Table 1: Feet of Water Distribution Tubing that Contains One Cup of Water

Nominal Size (inch)	Copper Type M	Copper Type L	Copper Type K	CPVC CTS SDR 11	CPVC SCH 40	PEX AL-PEX ASTM F 1281	PEX CTS SDR 9
3/8”	7.5	8.2	9.5	NA	6.8	12.7	12.5
1/2”	4.7	5.2	5.5	6.4	4.2	6.1	6.8
3/4”	2.3	2.5	2.8	3.0	2.4	2.4	3.4
1”	1.4	1.5	1.5	1.8	1.4	1.4	2.0
1 1/4”	0.9	1.0	1.0	1.2	0.8	0.9	1.4
1 1/2”	0.7	0.7	0.7	0.9	0.6	0.6	1.0
2”	0.4	0.4	0.4	0.5	0.4	0.4	0.6

Table 1 (above) shows the number of feet per cup of water distribution materials that are in use today.

INFORMATION SOURCED FROM GARY KLEIN

and the hot water outlets the volume of water in the piping was relatively small.

Even with all of these considerations, the volume of water in the piping was rarely as small as one cup. A ¾-inch riser came out of the water heater. Branches and twigs came from this riser and were generally ½-inch nominal piping. Roughly 3 feet of ¾-inch or 6 feet of ½-inch galvanized pipe contains one cup of water. So, if the riser was 3 feet and the longest branch and twig combination was 30 feet, the combined volume of water in the pipe would have been 6 cups.

Table 1 shows the number of feet per cup of water distribution materials that are in use today. For each nominal pipe diameter, copper has the largest internal diameter of these materials and therefore has the fewest feet per cup. PEX has the smallest internal diameter (with the exception of 3/8-inch PEX-AL-PEX) and has the most feet per cup.

The central core systems shown in Figures 1 and 2 shows a maximum volume between the water heater and the valve or angle stop of the outlets that is greater than one cup. In these drawings, we have allowed the volume to be a maximum of four cups on any path from the water heater to a hot water outlet. This is admittedly difficult to do, but still possible to build given the current requirements in the plumbing code. To meet the four-cup limit, it will be necessary to locate all of the hot water outlets very close to each other and to the water heater. To be completely accurate, we really should be accounting for the volume between the valve or angle stop and the faucet, shower, tub or appliance, too. The volume from the angle stop to the sinks is very small; on the order of 1/10th of a cup since it is often a ¼-inch nominal diameter tube approximately two feet long.

On the other hand, the volume from the shower or tub/shower valve to the shower-head is on the order of one cup and when we are limiting the volume to the valve to four cups an additional cup increases the volume by 25 percent. This suggests that showers and tub/shower combos need to be located closer to the water heater so that the volume can be less than four cups all the way to the shower-head.

How close? Based on the *2009 Uniform Plumbing Code* and common plumbing practices, the riser out of the water heater and the rest of the trunk line will be ¾-inch nominal diameter and the branches and twigs will be ½-inch. (SEE RELATED INFO. ON PAGE 47) Let's see how this plays out for both configurations.

Long Trunk-Short Twigs: If the riser contains three cups, there is only one cup left to get to the outlets. Using the numbers in Table 1, the riser will be 6.9-10.2 feet long and the sum in any branch and twig combination will be 4.7-6.8 feet.

The hot water outlets will need to be closer to the water heater if copper tubing is used. PEX gives the greatest flexibility in locating the hot water outlets. If 3/8-inch nominal tubing was used for the twigs and any applicable branch and twig combinations, the length from the riser would increase to 7.5-12.7 feet. This would give still more flexibility for all piping materials.

Short Trunk-Long Twigs: Assuming that the riser contains one cup, this leaves three cups to get to the furthest hot water outlet. Using the numbers in Table 1, the riser will be 2.3-3.4 feet long and the sum in any branch and twig combination will be 14.1-20.4 feet.

The hot water outlets will need to be closer to the water heater if copper tubing is used. PEX gives the greatest flexibility in locating the hot water outlets. If 3/8-inch nominal tubing was used for the twigs and any applicable branch and twig combinations, the length from the riser would increase to 22.5-38.1 feet. This would give still more flexibility for all piping materials.

Figure 3 is a photo of a Short Trunk-Long Twig central core plumbing system, showing a copper manifold and PEX (cross-linked polyethylene) twigs. The copper manifold is connected right to the top of the water heater and each of the PEX twigs has its own valve so it can be separately turned off if you want to do any maintenance. You'll notice that the twigs are 3/8-inch diameter nominal pipes (the system was engineered and approved by the local jurisdiction). The twigs are shown in PEX, but they could be of any approved plumbing material.

In general, it is easiest to visualize how to keep the volume to less than four cups if the water heater is located below the hot water outlets, such as when it is installed in a basement. The Short Trunk-Long Twig option gives the most flexibility in the distance between the water heater and the hot water outlets.

If the Long Trunk-Short Twig option is chosen, the hot water outlets will need to be in rooms directly above or right next to the water heater and the twigs will probably need to go horizontally within the walls. Remember that if we put a tee 2/3 of the way up the three-cup trunk, we gain another cup of volume from the trunk line (4.7-6.8 feet in ½-inch nominal pipe, or 7.5-12.7 feet in 3/8-inch nominal pipe). If we put a tee 1/3 of the way up the three-cup trunk, we gain two cups and twice as much additional distance, but the system then begins to look and perform like the Short Trunk-Long Twig option.

All of the hot water distribution piping should be insulated. The new IAPMO *Green Plumbing and Mechanical Code Supplement* will have a section that requires that hot water distribution piping be insulated using a strategy that aims for equal heat loss per foot. For a given insulating value of the insulation (k-factor), this can be achieved by using pipe insulation with a wall thickness equal to the nominal pipe diameter. This means that ½-inch nominal piping will have ½-inch wall thickness pipe insulation, ¾-inch will have ¾-inch, 1-inch will have 1-inch, etcetera, up to 2-inch nominal pipe diameters. After 2-inch nominal pipe, the wall thickness can be maintained at 2 inches. (The German energy

Water Heating Design, Equipment and Installation are also covered in Chapter 6 of the new *2010 Green Plumbing and Mechanical Code Supplement,* to help better achieve maximum water efficency.

WWW.IAPMOGREEN.ORG

Figure 3 is an a example of Figure 2 with a Short Trunk (Copper) and Long Twigs (PEX).

PHOTO COURTESY OF GARY KLEIN

code continues the wall thickness equal to the nominal pipe diameter pattern up to 4-inch nominal pipe diameters. This seems like a smart idea if there is the space to do so.)

Pipe insulation should completely surround the pipe and be as continuous as possible. It is not necessary to insulate the piping as it passes through the building framing, nor is it necessary to insulate the piping exposed under typical lavatory and kitchen sinks. A later article in this series will go into insulation in more depth.

Performance

How well will these two configurations perform in terms of water, energy and time? All of the hot water piping has been insulated, which results in doubling the cool down time in the ½-inch piping (increasing it from roughly 10 up to 20 minutes) and tripling the cool down time in the ¾-inch piping (increasing it from roughly 15 to 45 minutes). In both configurations, it is necessary to clear out the four cups of cold water in the hot water distribution system. At two gallons per minute, it will take approximately 10 seconds to get hot water to the first fixture that is turned on, which is admittedly quite good. However, after that the two configurations perform differently.

The reason has to do with the different volume in the twigs. In Long Trunk-Short Twig, the second and subsequent events only need to clear out a maximum of one cup. In Short Trunk-Long Twig, it is necessary to clear out a maximum of three cups.

Think of two of the pairs of hot water outlets shown in Figure 1 as a bathroom (sink and tub/shower combo) and another pair as the kitchen (sink and dishwasher). Since the piping is insulated, it will stay hot 20 minutes in the ½-inch nominal twigs and 45 minutes in the ¾-inch nominal trunk. This allows for a relatively long time between hot water events on any one twig; good for people sharing the same bathroom who need their privacy and it gives plenty of time to get to the kitchen and make breakfast before the trunk line will have cooled off. Now, let's go through morning "rush hour" where everyone has to get up and out of the house on the way to work and school.

Long Trunk-Short Twig: The first person would run a minimum of four cups down the drain at the shower. This primes the entire trunk line so that one cup will come out any time another tap is opened. At 2 gpm this will take an additional two seconds. Assuming that one person uses the sink and the tub/shower combo in each bathroom and the kitchen sink is used to make breakfast, the waste of water will be four cups (first draw) plus four cups (one to clear out the cold water in each twig). This is a total of eight cups of water and 18 seconds. The eight cups of water will cool down by the time they return from work and school and the energy in it will have been dissipated, sometimes beneficially, sometimes not.

Short Trunk-Long Twig: Again, the first person would run a minimum of four cups down the drain at the shower. This also primes the entire trunk line, but since it is only a cup long, three cups will come out any time another tap is opened. At 2 gpm this will take an additional six seconds. Assuming that one person uses the sink and the tub/shower combo in each bathroom and the kitchen sink is used to make breakfast, the waste of water will be four cups (first draw) plus 12 cups (three to clear out the cold water in each twig). This is a total of 16 cups of water and 28 seconds. The 16 cups will cool down by the time they return from work and school and the energy in it will have been dissipated, sometimes beneficially, sometimes not.

Both of these examples are for a house with the same use patterns, so we are comparing the wastefulness of each configuration. (The location of the hot water outlets relative to each other and to the water heater is more limited in the Long Trunk-Short Twig configuration, but still buildable).

Since both configurations have the same maximum volume in the piping between the water heater and the hot water outlets, cold starts (first thing in the morning or any use after the piping has cooled down) will have the same waste of water energy and time. The difference comes during hot starts, which occur after the trunk line is filled with hot water. Over the life of the building, there will be a combination of hot and cold starts and during the hot starts the Long Trunk-Short Twig configuration outperforms the Short Trunk-Long Twig in terms of water (eight cups versus 16 cups, a savings of 50 percent), energy (also a savings of 50 percent) and time (18 seconds versus 28 seconds or a savings of 36 percent).

In the next article, we will continue the discussion of the five hot water distribution strategies that would be able to deliver hot water while running less than one cup down the drain after we turn on the tap.

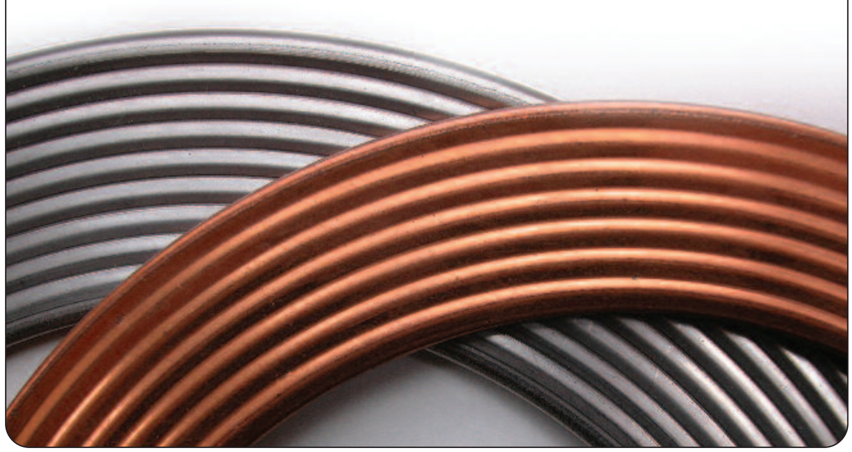
RELATED INFO

Some Things Never Change... but Should They?

These are the same nominal diameters used more than 60 years ago. This seems a bit odd to me since flow rates for faucets and showers — and fill volumes and flow rates for appliances such as dishwashers and washing machines — are significantly lower than they were then and they appear to be getting even smaller in the future. The diameter of the twigs should be based on the flow rate of the outlet and the pressure drop in the piping. The diameter of the branches and the trunk should also be based on the flow rate of the devices that they serve, but primarily on an estimate of the likelihood of how many devices on the branch and trunk line will be operated simultaneously for any significant period of time.

Since the central core system limits the length, there should be relatively few fittings, so the pressure drop in the piping should be relatively small to begin with. Flow rates are lower, so pressure drop to velocity is lower, too. For twigs serving outlets with less than 2 gpm, the diameter could be no larger than 3/8-inch. This diameter also applies to branches serving a group of outlets with a combined simultaneous flow rate of 2 gpm. The trunk line could be ½-inch nominal for simultaneous flow rates up to 3.5 gpm in copper and 5.5 gpm in PEX.

A longer discussion of this topic can be found in Residential Hot Water Distribution System Research Suggests Important Code Changes, G. Klein and R. Wendt, which appeared in Official's January/February 2007 issue.



A report on
Potential Best Management Practices
-
Tankless Water Heaters

Prepared for

The California Urban Water Conservation Council
716 Tenth Street, Suite 200
Sacramento, CA 95814
(916) 552-5885

Year 4
May 2010

By
John Koeller
Koeller and Company
5962 Sandra Drive
Yorba Linda, California 92886-5337
koeller@earthlink.net
(714) 777-2744
and

Gary Klein
Affiliated International Management

Sacramento, California
gary@aim4sustainability.com

Table of Contents

NOTE: For a full introduction to the
Council's Potential Best Management Practice (PBMP) process,
refer to the Year Three report that details the purpose and
status of that process since its inception in 2004:
http://www.cuwcc.org/products/pbmp-reports.asp

Tankless Water Heaters

Introduction

Are tankless water heaters a water savings technology? In short, the answer is no. There are ways to install them so as to improve the water use efficiency of a hot water distribution system, but as manufactured, they do not save water. In fact, with two exceptions, all tankless water heaters available at the time of writing this paper waste more water than storage water heating technology. This paper provides the evidence.

What is a Tankless Water Heater?

There are two Federal statutes that govern the efficiency of water heaters, the National Appliance Energy Conservation Act (NAECA) and the Energy Policy Act (EPAct). These statutes define a category of water heaters called instantaneous. Instantaneous water heaters have large firing rates relative to their small water capacities. By law, they are allowed to have an internal volume of up to 2 gallons of water. This volume limitation applies to all instantaneous water heating technology, regardless of the fuel source (natural gas, propane, electric or oil).

Up until January 2010, none of the water heaters sold under this legal category were, in fact, instantaneous. An instantaneous water heater is a water heater in which hot water leaves the water heater immediately once a tap is opened. For this to happen, there needs to be a stored volume of hot water before the tap is opened. In other words, the water heater must have some storage. Naming the category instantaneous caused some significant market confusion because customers thought that by installing one of these water heaters they would get hot water at their tap instantaneously, something they really want to have. Instead, it took longer for hot water to arrive at their hot water outlets, and more water was wasted too!

Over time, the market has come to call the instantaneous category tankless. In fact, these water heaters are not truly “tankless”, since as stated above, they are allowed to store up to 2 gallons of water internally. Most of the natural gas and propane tankless water heaters available in the U.S., however, have approximately one quart of internal capacity; one has 0.75 gallons (heat exchanger and a 0.5 gallon tank) and one has two gallons. See Figures 1 through 3 for examples of gas tankless water heaters. Electric tankless water heaters have volumes ranging from about one cup to one gallon. See Figures 4 through 6 for examples of electric tankless water heaters.

Figure 1. Gas Tankless Water Heater
Internal volume is approximately 1 quart (Rinnai)

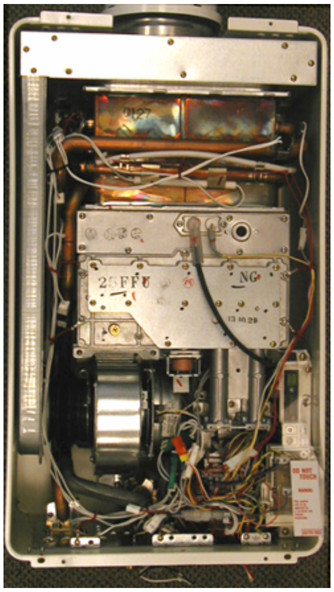


Figure 2. Gas Tankless Water Heater
Internal volume is approximately 3 quarts (Navien)

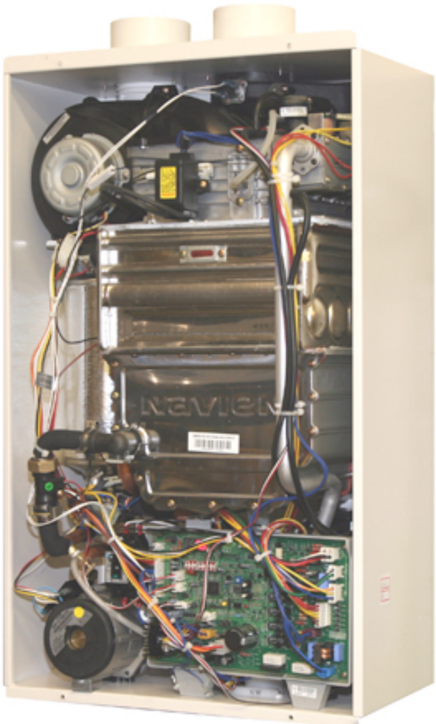


Figure 3. Gas Tankless Water Heater
Internal volume is approximately 2 Gallons (Grand Hall)

Figure 4. Electric Tankless Water Heater
Internal volume is less than 1 Cup (Skye)

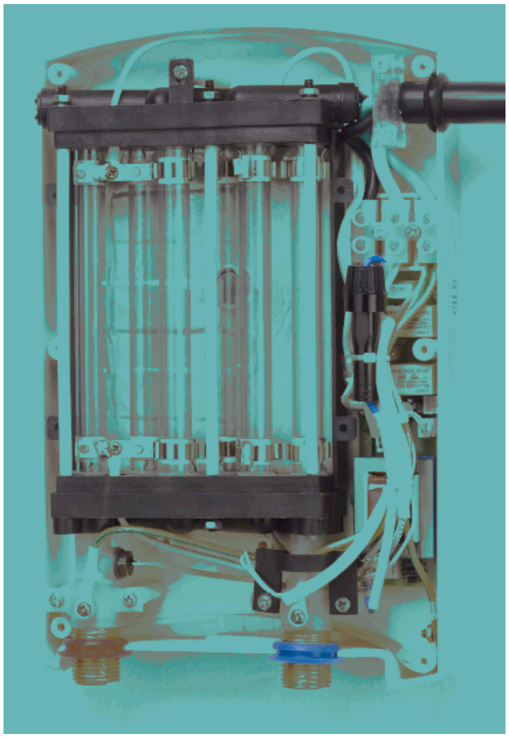


Figure 5. Electric Tankless Water Heater
Internal volume is approximately 2 cups (Stiebel Eltron)

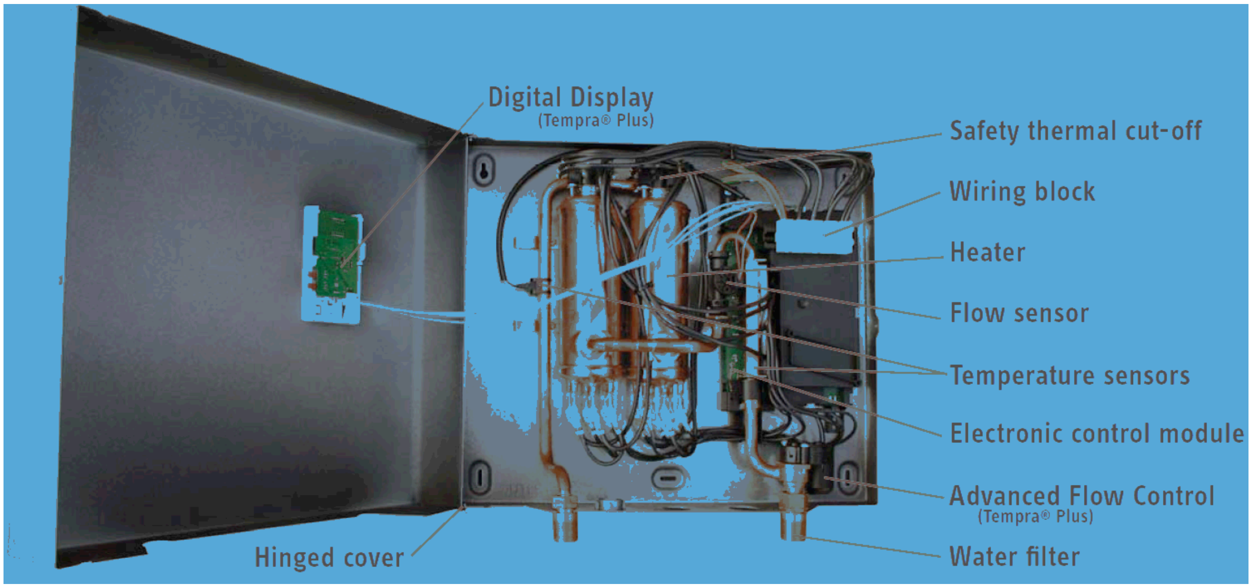
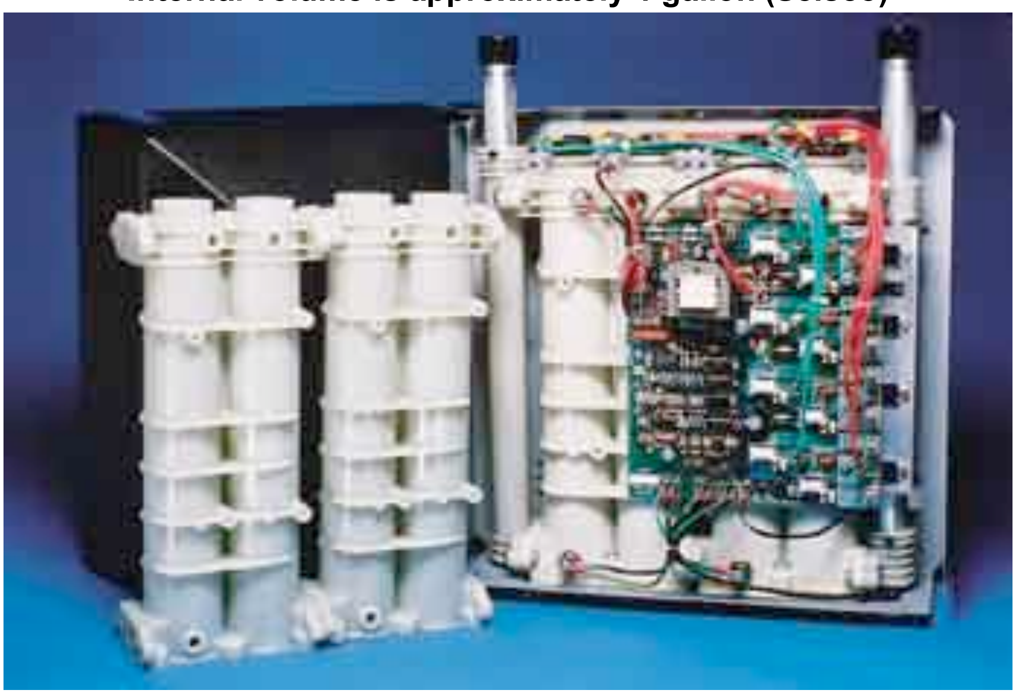


Figure 6. Electric Tankless Water Heater
Internal volume is approximately 1 gallon (Seisco)

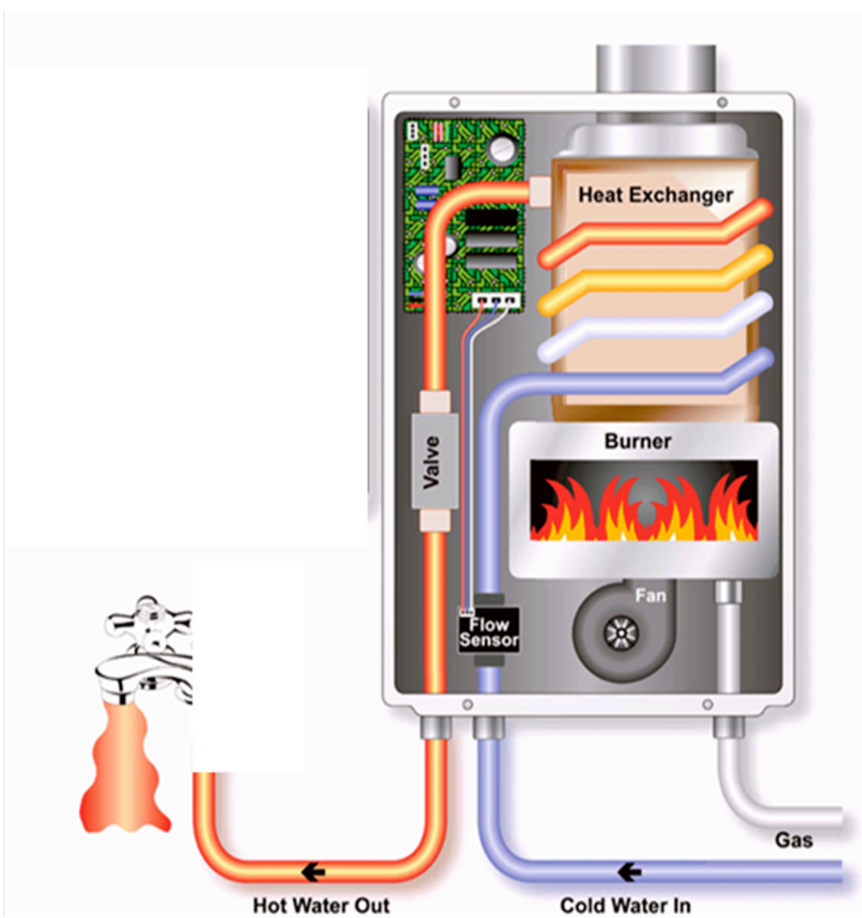


How Do Tankless Water Heaters Work?

This paper focuses primarily on the performance of whole-house gas tankless water heaters (meaning both natural gas and propane) and, secondarily, on electric tankless water heaters.

Figure 7 shows a schematic of a typical gas tankless water heater. When a hot water outlet (e.g., faucet or shower) is opened, cold water starts flowing through the water heater. When the flow is greater than the trigger point for the device, typically 0.75 gallons per minute (gpm), the flow switch sends a signal to the heater's computer. At this point, the heater's fan comes on to clear any residual combustion byproducts from the combustion chamber. Next, the gas valve opens and the burner modulates the firing rate in an amount proportional to the flow rate. The water is heated as it travels through the heat exchanger. This continues throughout the duration of the hot water event. When the hot water event is completed, the flow switch signals the computer that flow has stopped and the gas valve is turned off. The fan continues operating to clear any combustion byproducts from the combustion chamber and to cool down the heat exchanger.

Figure 7. Schematic of a Gas Tankless Water Heater



Electric tankless water heaters operate in a similar fashion (See Figure 5 for details). When a hot water outlet is opened, cold water begins flowing through the water heater. When the flow is greater than the trigger point for the device (typically in the range of 0.25 – 0.75 gpm), the flow switch sends a signal to the internal computer. At this point, electricity is fed to the elements in an amount proportional to the flow rate. Water is heated as it travels through the water heater. This continues throughout the duration of the hot water event. When the hot water event is completed, the flow switch signals the computer that flow has stopped and the electric power to the elements is turned off. The basic method of operation is very similar to that of a gas tankless water heater. Most manufacturers have a mechanical flow switch that senses flow in a similar fashion to the flow switch in a gas tankless water heater. One company uses temperature difference to determine flow and can operate at very low flow rates.

Why Tankless Water Heaters Cannot Save Water

There are two main reasons why tankless water heaters are not water saving devices when compared to storage water heaters installed in the same location.

1. At the beginning of a hot water event, tankless heaters start with cold water. The water passing through the heat exchanger needs to ramp-up to the desired temperature. During this time, cold water runs through the water heater and enters the plumbing system (trunk line) on its way to the hot water outlet (e.g., faucet or shower). This is true for both gas and electric tankless water heaters, although we have only found data on this event for gas tankless water heaters.
2. When sized properly (as they should be!), tankless water heaters allow for "continuousness", or "never running out of hot water in my shower". The question is whether people will take advantage of this capability and how much this will affect their overall water usage. There are some indications that with this attribute, users change their habits and take longer showers, thereby potentially offsetting expected "savings".

The next two sections of this paper discuss these two issues.

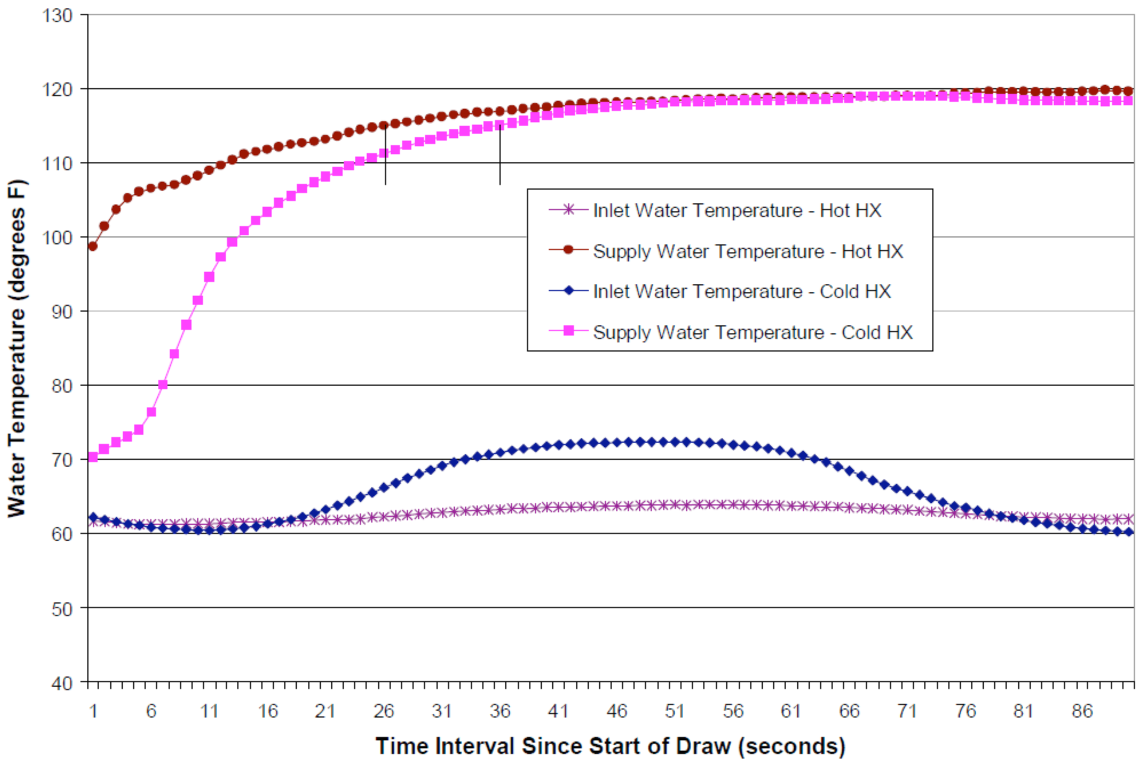
Wait Time & Water Waste at the Beginning of a Hot Water Event

When the user opens a hot water faucet valve, the typical tank-type storage water heater immediately sends hot water into the piping system. With a tankless water heater, on the other hand, water first begins to pass through the cold heat exchanger, which heats up quickly. However, there is still a delay before the full temperature is reached and, as such, cold or lukewarm water is delivered by the heater into the plumbing system. Several studies document the waste of water and time.

California Energy Commission (CEC)

Tankless water heater manufacturers claim that there is a small delay (about three to four seconds) before the burner ignites when activated by the internal computer. This claim is reasonably accurate. However, the Davis Energy Group, under the auspices of a study funded by the CEC, found that it took significantly longer before hot water actually exited the water heater[1]. Figure 8 shows that, with a flow rate of 1.9 gpm (typical of a water-efficient faucet or shower), it took 26 seconds to reach 115°F supply water temperature when a previous draw had been taken 5 minutes before (heat exchanger was still relatively hot, or Hot HX). It took 36 seconds when hot water had not been drawn for 45 minutes (heat exchanger was relatively cold, or Cold HX). The impact was negligible (29 and 37 seconds, respectively) when the same test was conducted at a flow rate of 3.3 gpm.

Figure 8. Hot and Cold Start-up Performance of a Tankless Water Heater



The time it takes for the temperature to ramp up to the desired delivery temperature results in additional water waste. Using the flow rates and times from the Davis Energy Group's study findings for the CEC, Table 1 shows the volumes wasted for both hot and cold heat exchangers.

[1] Davis Energy Group, 2006. *"Field and Laboratory Testing of Tankless Gas Water Heater Performance"* prepared for Lawrence Berkeley National Laboratory, April 14.

Table 1. Water Wasted During Temperature Ramp-Up

Flow Rate (gpm)	Hot Heat Exchanger (Hot HX) 5 minutes between hot water events		Cold Heat Exchanger (Cold HX) 45 minutes between hot water events	
	Time to 115°F supply water temperature (seconds)	Volume of Water Wasted (gallons)	Time to 115°F supply water temperature (seconds)	Volume of Water Wasted (gallons)
1.9	26	0.82	36	1.14
3.3	29	1.60	37	2.04

The waste of water is proportional to the flow rate since the heater controls adjust the burner firing rate to match the flow rate. That is, doubling the flow rate doubles the water waste. The reason it takes more time, with the additional water waste when the time between hot water events is longer, is because the heat exchanger has had more time to cool down and the ramp-up process starts from a lower temperature. Figure 8 presents data on the ramp-up time for heat exchanger temperatures (at the start of the burner firing) at 70°F and just under 100°F. When the heat exchanger is located in a colder environment, such as in a garage, basement or on an outside wall during the winter, the heat exchanger will be significantly colder (perhaps as low as 40°F) and the ramp up times and water waste will be even larger.

How significant is this 0.8-2.0 gallons of water wasted per hot water event? Davis Energy Group stated, "The added time delay may or may not be a concern for homeowners, depending upon their expectations and the type and configuration of their hot water distribution system."[2] However, the importance of the additional time delay and water waste really depends on the length of the hot water event and on the volume of water that is in the hot water distribution system. At the low end, if the duration of the hot water event after the hot water has arrived at the fixture is 30 seconds, the additional delay ramping up to temperature doubles the length of the hot water event. If the duration of the hot water event is 300 seconds (say for a five minute shower), the ramp-up time adds 10 percent to the length of the hot water event. While the volume of water wasted waiting for the hot water to arrive is the same in both cases, the time impact could vary from significant (for a 30 second event) to trivial (for a 300 second event).

Therefore, where there are a large number of small duration hot water events, such as at lavatory sinks in public restrooms, which can experience actual hot water use of less than 10 seconds, the waste of water and time are proportionally much larger and perceptually more noticeable.

The time delay due to ramping up the temperature must be added to the time delay in delivery of hot water through the water distribution system. Assuming that there is one gallon of water in the hot water distribution system piping between the water heater and a given hot water outlet (a very typical amount), and assuming a 1.9 gpm faucet or shower outlet, it will take more than

[2] Ibid

30 seconds to clear out the “not hot” water in the piping. Adding 15 secondsin wait time and 0.5 gallons of water, the time-to-tap and volume-to-hot increases by 50 percent, which is significant in both quantity and perception.

Figure 8 also shows that if the desired or needed hot water supply temperature is lower (say 105°F), the time delay decreases to 5 seconds with a hot heat exchange and to 17 seconds with a cold heat exchanger. This leads to the conclusion that locating the water heater as close to the hot water outlets as possible, or insulating the hot water distribution system, or both, would be beneficial from both the time delay and water waste perspectives. The reason to do this is to minimize the temperature drop in the piping between the water heater and the hot water outlets. In addition, the smaller the volume in the hot water distribution system, the smaller the energy losses in the piping will be. Moving the water heater closer to the hot water outlets and insulating the hot water distribution system would be a benefit for storage water heaters as well. As such, these strategies are not inherent to the type of water heater and cannot be claimed as a water use efficiency measure solely for tankless water heaters.

Water Efficiency Labelling and Standards (WELS) Scheme

The Australian Government funded a study[3], conducted under the auspices of the Water Efficiency Labelling and Standards (WELS) Scheme[4], that looked at whether gas tankless water heaters wasted water and, if so, how much. In this study, the water wastage was the volume of water that flowed through the unit from the time the burner of the unit was activated until the temperature of the water (as recorded by the data logger) reached, on the first occurrence, the temperature differentials of 5°C (9°F) and 1°C (1.8°F) from the average steady state temperature. This test procedure is different from that used by the Davis Energy Group, which measured wasted water from the time the flow sensor registered flow. From the perspective of the customer who turns on a tap, the WELS test procedure underestimated the waste of water and time.

The pattern shown in Figure 9, which is derived from the Szann study, is very similar to the one developed by the Davis Energy Group. The X-axis is in seconds. The water heater set point is equivalent to 140°F, which is 18 degrees higher than the one tested by the Davis Energy Group. The red line shows the temperature at the outlet of the water heater. From the time the burner ignited, it took 10 seconds for the water to reach 115°F (45°C in the figure), 15 seconds to get within 5°C of the set point and more than 30 seconds to get within 1°C. The green line shows the temperature at a discharge point (hot water outlet). It takes 26 seconds to reach 115°F (45°C in the figure), 34 seconds to get within 5°C of the set point and more than 70 seconds to get within 1°C. This highlights the additional waste of water and time to clear out the “not hot” water in the hot water piping.

[3] Szann, Aleksander, “Water Wastage of Instantaneous Gas Water Heaters”, Department of the Environment, Water, Heritage and the Arts, Australian Government, 2008.
[4] http://www.waterrating.gov.au/about/index.html

Figure 9. Water Heater Profile – Time

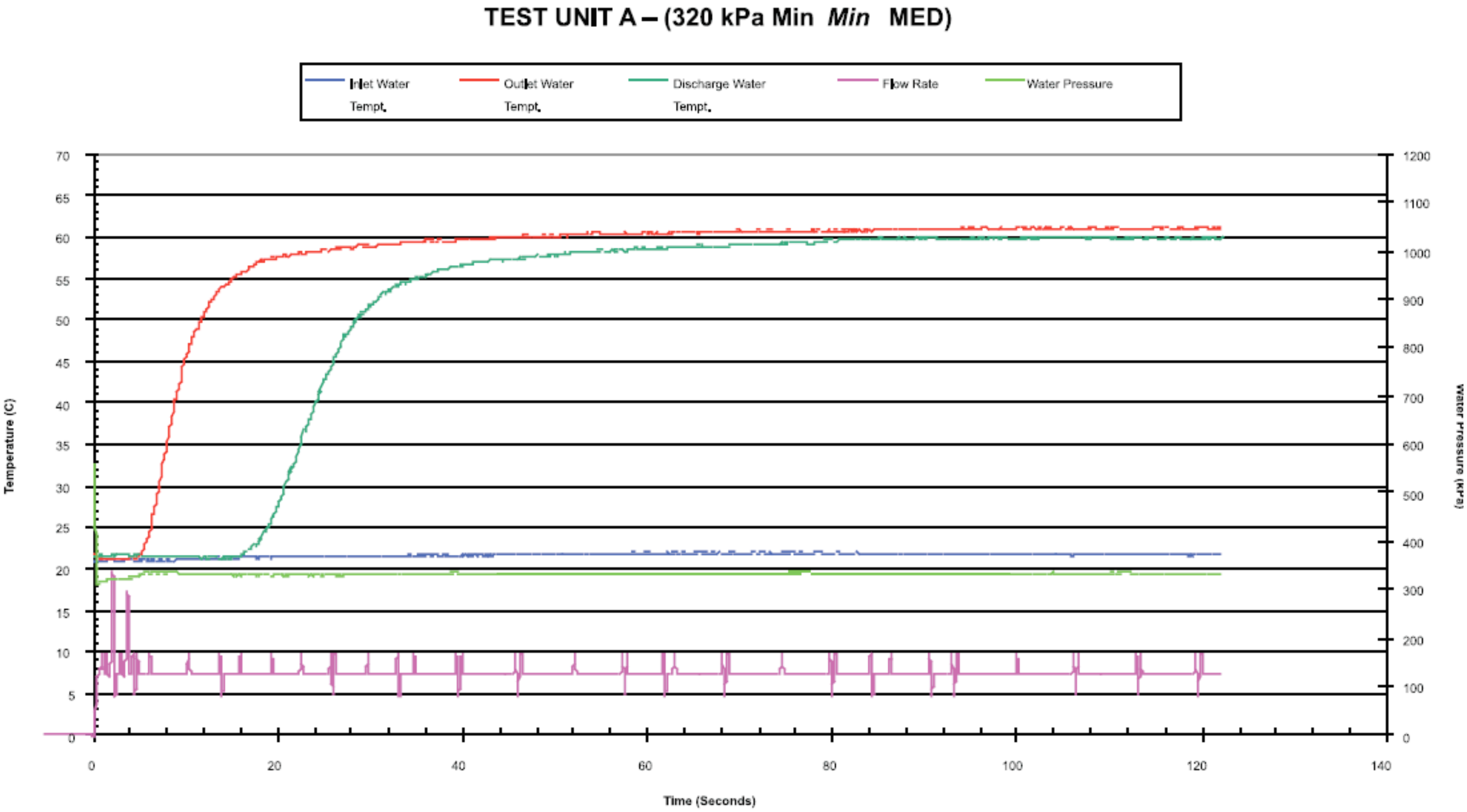
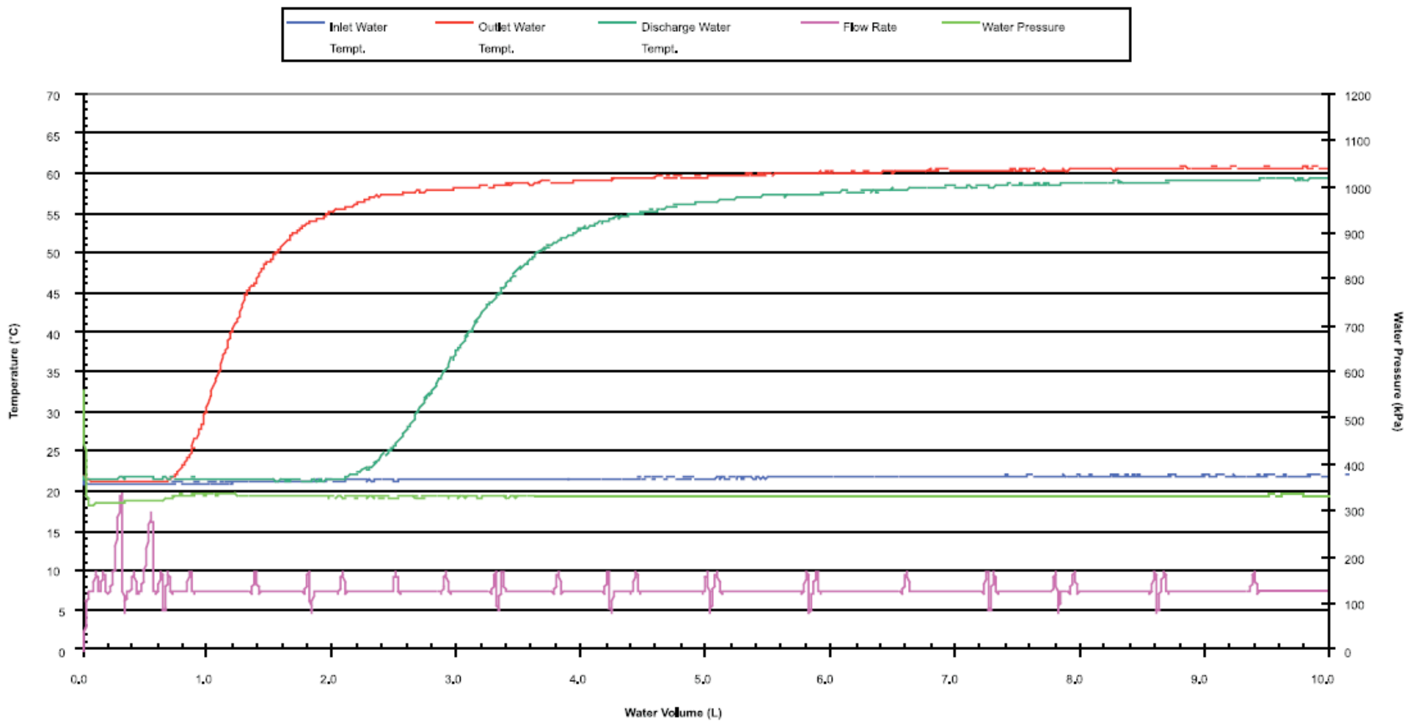


Figure 10 shows another test of the same water heater, but now the X-axis is in liters of water. The ramp-up rate is similar but not identical to the one in Figure 9. As before, the red line shows the outlet temperature and the green line shows the discharge temperature. From the time the burner ignited, 0.34 gallons (1.3 liters) were wasted until the water reached 115°F (45°C in the figure), 0.53 gallons (2.0 liters) until the water was within 5°C of the set point and more than 1 gallon (4.0 liters) until the water was within 1°C.

Figure 10. Water Heater Profile – Volume

TEST UNIT A – (320 kPa Min *Min* MED)



The results of tests on eight water heaters are shown in Table 2. The volume of water wasted at the outlet of the water heater ranged from about 0.3 gallons to more than 2.5 gallons per hot water event. More water was wasted at the discharge. As mentioned above, the WELS methodology understates the waste of water and time.

Table 2. Water Wasted Per Hot Water Event

Water heater	Water wasted			
	At outlet		At discharge	
	$t_{\Delta 5}$ (L)	$t_{\Delta 1}$ (L)	$t_{\Delta 5}$ (L)	$t_{\Delta 1}$ (L)
Test Unit A	2.1	4.4 (max 8.0)		
Test Unit B	1.2	1.4 (max 9.7)	3.2	3.4 (max 11.6)
Test Unit C	2.5	3.4	3.9	4.9
Test Unit D	1.3	1.4 (max 5.6)		
Test Unit E	2.2	3.3		
Test Unit F	1.4	2.3		
Test Unit G	2.0	2.8		
Test Unit H	2.0	2.4		

Consumer Reports Magazine (CRM)

As reported in 2008, CRM ran comparison tests between Takagi and Noritz gas-fired tankless water heaters and three storage water heaters[5]. They chose not to test electric tankless water heaters due to perceived capacity limitations. Their evaluation simulated the use of 76 to 78 gallons of hot water per day, the equivalent of taking three showers, washing one load of laundry, running the dishwasher once (six cycles) and turning a faucet on nine times, a total of 19 draws. CRM also ran more than 45,000 gallons of very hard water through the water heaters to simulate about 11 years of hot water use.

CRM found that users they polled reported getting a “cold water sandwich” at the beginning of some hot water events. In addition, users also reported that at low flow rates, such as when running a trickle of water for shaving, the gas-fired tankless water heater would not ignite, so only cold water would be delivered into the plumbing system.

They also reported that the water heaters they tested do not deliver water instantaneously, since it takes time to heat the water up to the target temperature. The volume of water that was wasted during temperature ramp-up was not reported.

Center for Energy and Environment

The Center for Energy and Environment in Minneapolis, MN is currently in the middle of a study comparing the performance of natural gas tankless water heaters with typical gas storage water heaters. Ben Schoenbauer, a research engineer with the Center provided information on the overall project and some of their preliminary results[6].

The study involves 10 homes. Two or three water heaters have been installed in each home and each is tested for one month to evaluate how each performs over a full range of seasons. The houses range in size from 1,000 to 2,500 square feet and the number of occupants ranges from one to five. Incoming cold water temperatures range from a low of 36^{o}F in February to a high of 74^{o}F in August. Temperature measurements are being taken approximately six inches away from the water heater on the hot pipe to determine the amount of time it takes to reach 95% of the way to the heater’s set point.

Several different types of tankless water heaters have been installed. The Center has observed two control strategies. One is a gradual ramp-up to the desired temperature, as shown in Figures 8, 9 and 10. The other is an overshoot – undershoot strategy that eventually settles down to the set point temperature. At flow rates between 1.0 and 2.5 gpm, they found that the overshoot – undershoot strategy is somewhat quicker (10 – 12 seconds) at reaching the set point than the gradual ramp-up strategy (approximately 20 seconds), but note that this strategy puts significantly hotter water into the hot water distribution system, thereby increasing the potential risk of scalding. At flow rates greater than 2.5 gpm, the overshoot – undershoot ramp-

---

[5] Consumer Reports Magazine, 2008. *“Tankless Water Heaters – They’re efficient but not necessarily economical”*, Posted September 2008 – Consumer Reports Magazine issue, October 2008.
[6] Personal Communication, 2010. Ben Schoenbauer, Research Engineer, Center for Energy and Environment, Minneapolis, MN, February.

up strategy can be as long as 20 seconds. When the flow rate is less than 1.0 gpm, it takes twice as long to reach 95% of the set point temperature.

Although the Center has not yet reported the amount of water wasted during ramp-up, it is possible to estimate this from the time information they have provided. At flow rates from 1.0 – 2.5 gpm, the volume wasted during ramp-up ranges from 0.17 – 0.83 gallons. This is lower than that reported by the Davis Energy Group, but still significant.

The Potential for Endless Hot Water

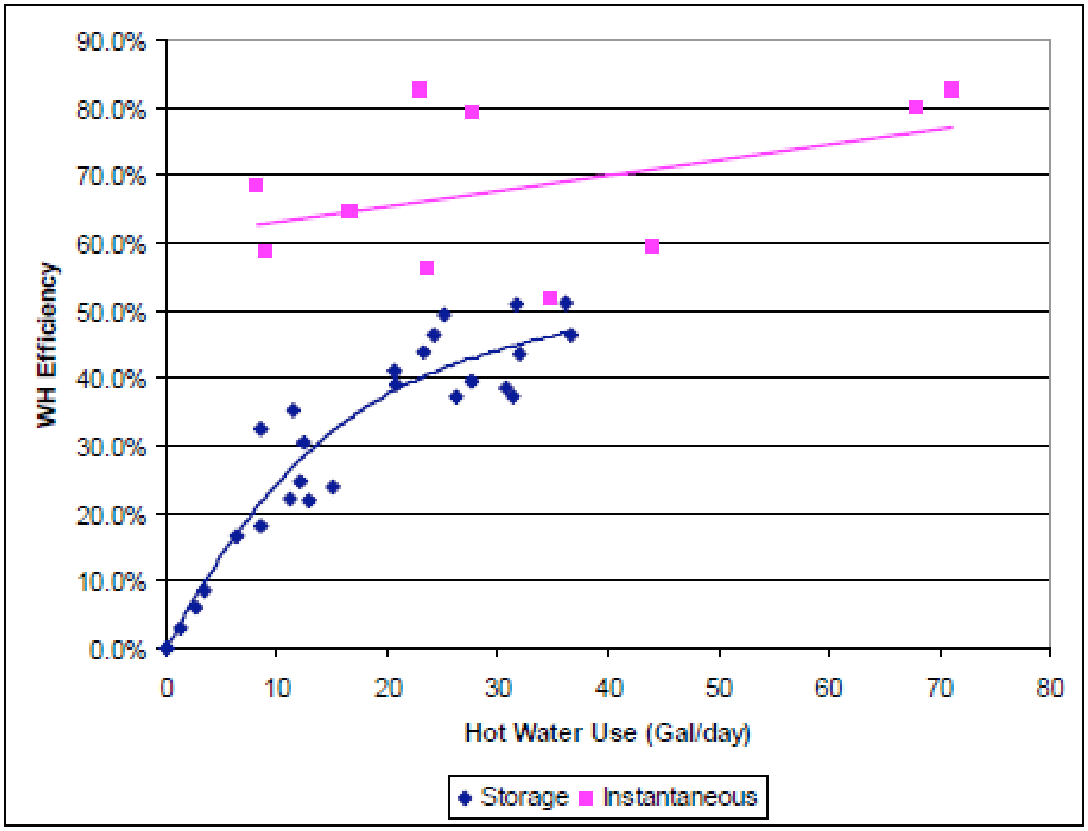
If people have the ability to take an extended or even an endless shower, will they do so?

California Energy Commission (CEC)

The Davis Energy Group, under the auspices of a study funded by the CEC, reported on a field test they had conducted for the Building America program in 2003[7]. Figure 11, which was originally used to compare the efficiency of a storage water heater with a tankless water heater, can also be used to compare water consumption. This figure shows the before (storage – one month) and after (tankless – two weeks) consumption of hot water for a two person household. When the storage water heater was in use, hot water consumption never exceeded 40 gallons per day. During the first two weeks after installation of the gas tankless water heater, daily hot water consumption was greater than 40 gallons three times, twice over 65 gallons.

[7] Davis Energy Group, 2006. *"Field and Laboratory Testing of Tankless Gas Water Heater Performance"* prepared for Lawrence Berkeley National Laboratory, April 14.

Figure 11. Comparison of Daily Water Heater Efficiency



Since this figure shows data only for the period of time immediately after the change-out of the water heater, it remains uncertain if the additional hot water use is a “trying out my new toy” phenomenon or if the increased hot water consumption will persist.

The Center for Energy and Environment

The Center is also measuring hot water usage. So far, the study has found that when the tankless water heater is in use, more hot water is being used, but the increase does not appear to be statistically significant. They have not yet reported on whether or not they have seen the “new toy” phenomenon.

What Can Be Done to Reduce the Waste of Water from Typical Tankless Water Heaters?

This paper has shown that the most widely sold gas tankless water heaters waste between 0.3 and more than 2 gallons of water ***for each hot water event*** while they ramp-up to the set point temperature. This waste is <u>in addition</u> to the waste of the cold water that must be purged from the hot water distribution system when a hot water event is initiated.

There are two ways to reduce this waste: (1) add a tank to the tankless water heater or (2) move the water heater closer to the hot water outlets. Combining both of these strategies is the best option.

<u>Adding a Tank to the Tankless Water Heater</u>

It is not necessary to add a large tank. The tank can be integral to the water heater or it can be added externally to the tankless water heater. Two gas tankless water heaters currently existing that provide tanks integral to the unit.

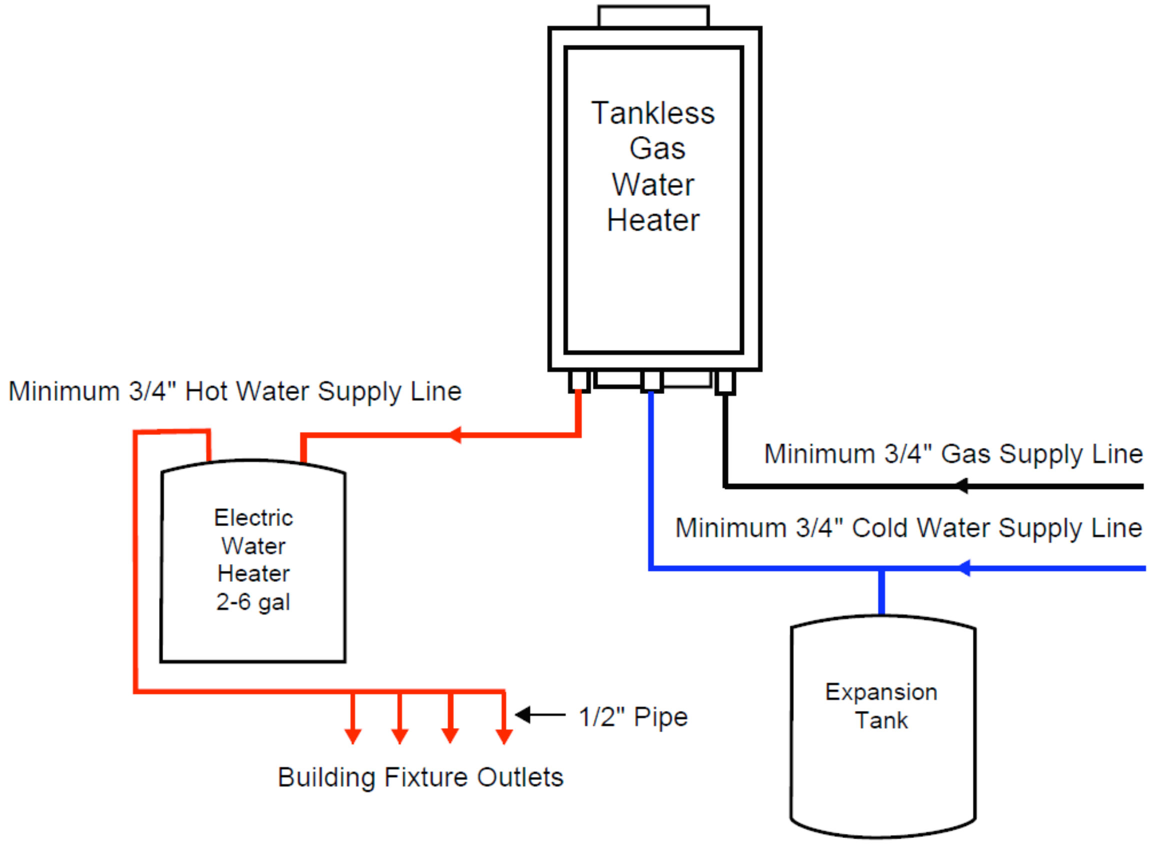
One of Navien's gas tankless models uses an integral tank located after the heat exchanger. It is located to the left in Figure 2. The tank contains approximately 0.5 gallons of water, which is kept hot by circulating water through the heat exchanger when the tank cools down. During operation, cold water enters the tank, which buffers its temperature. The mixed temperature water then passes through the heat exchanger where it gets heated to the set point.

The location of the tank after the heat exchanger means that when a tap is opened, hot water leaves the water heater immediately. This is good from the water use efficiency perspective. However, the tank is poorly insulated. This means that it loses heat rather quickly, causing the recirculating pump to come on and the burner to fire roughly every 30 minutes or so. This degrades the overall energy efficiency. When they complete their research, the Center will report on how well this technology performs compared to the other tankless water heaters they tested.

The newest gas tankless water heater manufactured by Grand Hall has a two gallon tank integral to the unit. A schematic of this water heater, the Eternal, is shown in Figure 3. The tank surrounds the burner, which maintains the tank at a preset temperature. During operation, cold water enters the tank, which buffers its temperature, while hot water leaves the tank. There is no delay while the water temperature ramps up to the set point. Performance at the beginning of each hot water event should look similar to that of a typical storage water heater. The Energy Factor of this water heater is claimed to be 0.96, which indicates that the storage tank is rather well insulated.

Alternatively, a tank can be installed external to the water heater. Figure 12 shows a schematic of a gas tankless water heater where a small electrically heated tank has been added after the water heater. An expansion tank has been added to accommodate any expansion that may occur when the water is heated during periods of no water use.

Figure 12. Gas Tankless Water Heater
with an External Electric Storage Water Heater



Drawing by Anne Hess

This configuration is what the gas tankless water heater manufacturers recommend when customers experience a "cold water sandwich". The "sandwich" occurs when hot water is demanded at a hot water outlet when the temperature of the water in the pipes has not yet cooled down, such as in the 5 minutes between hot water events studied by the Davis Energy Group. For example, imagine a morning where someone takes the second shower following soon after the first shower is taken. They turn on the shower valve and feel that the water is hot (the water in the pipe having not yet cooled down), so they get in and start their shower. After the hot water in the piping has passed through the showerhead, the cold water that went through the water heater during the initial ramp-up arrives. This slug of cold or lukewarm water can be quite a surprise (potential for thermal shock)! If the problem is annoying enough, the customer will either learn to wait long enough for the "sandwich" to pass through, which wastes even more water, or they install a post-heater tank.

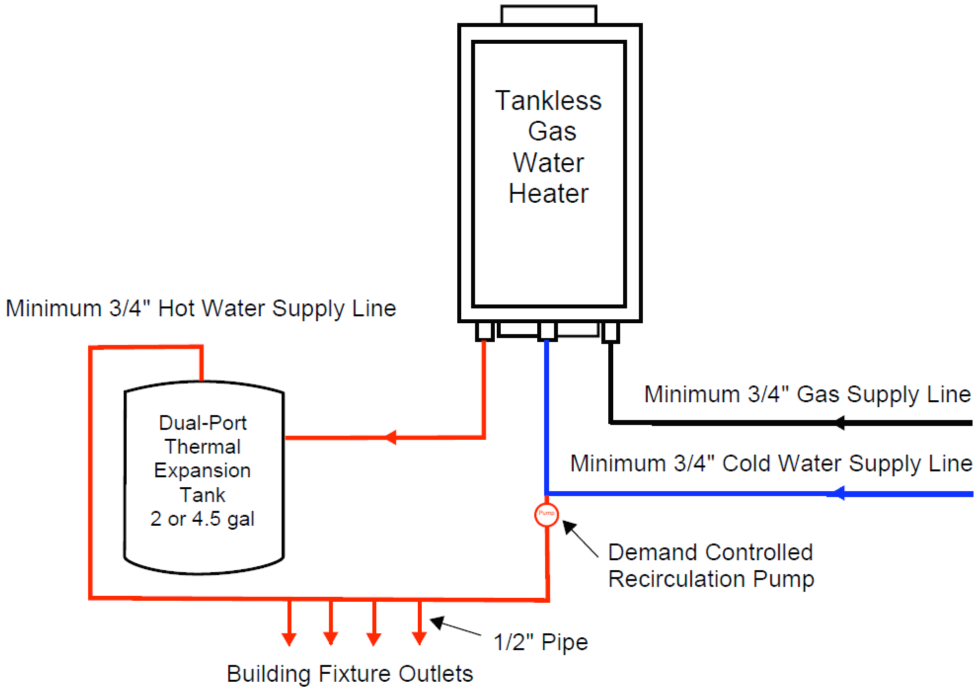
The electric energy required for the tank is mostly needed to overcome the standby heat losses of the tank itself. During operation with the tank in place, when a tap is opened, hot water leaves the tank. Cold water enters the heat exchanger and passes through to the electric tank that buffers the temperature. In the meantime, the gas tankless water heater has ramped up to the desired temperature and hot water passes through the small tank on the way to the hot water outlet (e.g., faucet or shower). When the event is complete, the valve is turned off, and the tank is full of hot water, which has been heated by the gas tankless water heater.

While the previous strategy solves the “cold water sandwich” problem and makes the waste of water no greater than would occur with a storage water heater in the same location, many people incorrectly believe that they are buying an instantaneous water heater. To accommodate that desire, the gas tankless water heater manufacturers recommend the installation of a recirculation pump in addition to the electric storage water heater. The pump is installed to run through the tank, maintaining the hot water distribution system at the desired temperature for many hours of the day. This strategy will save water, but it is very energy intensive. Running a recirculation loop continuously, assuming a 1.0 gpm flow rate and only a 5^{o}F temperature drop around the loop, will consume more than 6,000 kwh in a year just to keep the loop warm, making it a very expensive approach. Beyond that, additional electricity is needed to run the pump.

Saving water at the expense of using electricity is not a good trade-off, so another strategy needs to be implemented. Figure 13 shows a dual-port expansion tank located in the same position as the electric storage water heater in Figure 12. The dual-port expansion tank allows water to pass through when a hot water outlet is open, only acting as an expansion tank when the water is turned off. Two openings means that gunk does not collect in the expansion tank, a problem with traditional one-port designs. A demand-controlled pump is located where the recirculation pump would normally be installed.

Shortly before hot water is desired, the occupants “tell” the pump to come on by means of a button or motion sensor. The demand controlled pump comes on, causing the gas tankless water heater to begin ramping up to the set point temperature. This primes the hot water supply line, including the dual-port expansion tank with hot water. When the pump’s controls see a rise in temperature of approximately 5^{o}F, the pump shuts off. This process typically takes one to two minutes, depending on the volume of water in the hot water loop. When someone opens a tap, hot water comes out immediately, assuming that the volume between the hot water supply line and the hot water outlets is small (as it should be!). The gas tankless water heater has already fired so that the heat exchanger is still relatively warm. Any cold water that passes through during the ramp-up period of the actual hot water event is buffered by the hot water in the dual-port expansion tank, so no “cold water sandwich” results. It takes significantly less energy to prime the hot water supply line with hot water on-demand throughout the day than it does to keep a recirculation loop running all day. All of the water is heated by the gas tankless water heater and the only electricity needed is for the pump, which on a very busy day will run much less than one hour, probably less than 30 minutes.

Figure 13. Gas Tankless Water Heater,
Dual-Port Expansion Tank and Demand Controlled Pump



Moving the Water Heater Closer to the Hot Water Outlets

How close to the hot water outlets does the tankless water heater need to be? To be a water use efficiency measure, the tankless water heater needs to reduce the waste that is due to the plumbing (i.e., the water "stored" in the pipes during non-event periods) by an amount that is greater than the amount of water than is wasted while the water heater ramps up to temperature. The waste of water during temperature ramp-up varies from 0.3 to more than 2.0 gallons (4.8 – 32 cups respectively) per hot water event. Not knowing what the water-wasted-during-ramp-up characteristics of the water heater will be, we need to assume that it will waste at the larger end of the range.

The volume of water between a water heater and the hot water outlets it serves varies from less than 1 cup (rare, but possible for water heaters under a sink) to much more than 2.0 gallons. The only way a tankless water heater installation can save water is by removing more than 2.0 gallons from the hot water distribution system. It can only do this if there is at least 2.0 gallons in the hot water distribution system that can be removed, which means it will need to be located very close to the hot water outlets it will serve. If the hot water distribution system would normally have less than 2.0 gallons in it, then a "water wasteful" tankless water heater can never be considered water saving device.

Table 3 shows the number of feet of pipe equal to one cup for four nominal pipe diameters and several typical types of pipe. The length per cup of a given nominal pipe diameter varies because the internal diameter is not the same for each material. CTS stands for copper tube size.

Table 3. Feet of Piping Equal to 1 Cup of Water

	3/8" CTS	1/2" CTS	3/4" CTS	1" CTS
	ft/cup	ft/cup	ft/cup	ft/cup
"K" copper	9.48	5.52	2.76	1.55
"L" copper	7.92	5.16	2.49	1.46
"M" copper	7.57	4.73	2.33	1.38
CPVC	N/A	6.41	3.00	1.81
PEX	12.09	6.62	3.34	2.02

In general, the closer the water heater is to the hot water outlets, the smaller the diameter the pipe can be. For purposes of this discussion, the most likely pipe diameters will be ½- and ¾-inch nominal (due to the requirements of prevailing plumbing codes). This means that the length of pipe equal to 1 cup varies between 4.8 and 6.6 feet for ½-inch nominal pipe and between 2.3 and 3.3 feet for ¾-inch nominal pipe. For simplicity in this analysis, we can assume that 1 cup equals 5 feet in ½-inch and 2.5 feet in ¾-inch pipe.

Using the smaller of the volumes wasted while ramping up to temperature, 4.8 cups, this means that the water heater must be no further from all of the hot water outlets it serves than 24 feet in ½-inch pipe and 12 feet in ¾-inch pipe.

There is usually a combination of these two diameter pipes between the water heater and the outlets (¾-inch on the trunks and branches and ½-inch on the twigs), but what is important is that the combination of lengths cannot exceed the volume represented by one of the lengths. Assuming that the split in materials is 50/50, the total maximum length is 18 feet.

This is approximately the length of pipe to get across one room in a typical home. The plumbing is in the walls, floor or ceiling so it has to go a longer distance than if it could go diagonally through the room. Such a hot water distribution system is buildable, but it requires careful planning. It will also mean recognizing the installation, operating costs and maintenance of multiple water heaters in most buildings. In addition, each distributed water heater needs to be sized for the hot water demand at the location it serves. A single hand sink needs a much smaller water heater than a master bathroom suite with two sinks, a shower and a large master tub, or a group of back-to-back or stacked bathrooms. As the distance (volume) between groups of hot water outlets and from the water heater gets large, say over 80 feet (approximately 2 gallons in ¾ inch nominal piping), the installation of multiple water heaters makes more sense from the perspective of saving water, energy, and time-to-tap. However, at the current cost of water and sewer in most municipalities, the energy cost savings will outweigh the water cost savings.

Conclusion

In and of themselves, tankless water heaters are not a water saving technology and therefore, should not be recommended as a Best Management Practice for water utilities implementing water use efficiency programs. Locating water heaters closer to the hot water outlets they serve will save water, a design practice that could by implemented through building and plumbing codes as well as through “green building” mandates. Water heaters with some amount of stored water, located close to the hot water outlets, will save water because they do not need to ramp-up to temperature at the start of each hot water event. As noted earlier, there are only two legal gas tankless water heaters that have integral water storage at this time. These units will waste no more water than a storage water heater installed in the same location. If a storage tank is added externally to a tankless water heater, it will perform similarly to these units from a water use perspective (although their energy efficiency is likely to be less).

The only way for tankless water heaters without storage to yield water savings is to locate them close to the hot water outlets they serve, saving a quantity of water that is greater than that which would have been lost while ramping up to temperature. That is, these units need to be closer to the hot water outlets than the volume of water that is normally in the piping between these outlets and a remotely installed water heater. Given the amount of water that is wasted while ramping up to temperature, most tankless water heaters cannot save water using this strategy, since there is generally less volume in the piping than passes through the water heater while ramping up.

For tankless water heaters with either internal or external storage, as well as for storage water heaters, it is possible to improve water use efficiency (without decreasing energy efficiency) by installing an on-demand priming system which fills the hot water supply line with hot water just before hot water is needed at the outlets. This allows the water heater to be located relatively far from the hot water outlets. However, the improvement in water use efficiency is not due to the water heater. Instead, it is due to the improvement to the hot water distribution system.

Are tankless water heaters a water savings technology? In short, the answer is no.

References

Szann, Aleksander, *“Water Wastage of Instantaneous Gas Water Heaters”*, Department of the Environment, Water, Heritage and the Arts, Australian Government, 2008.

Spoor, Charlene, *“Residential Feasibility Assessment of Gas Tankless Water Heaters in PG&E Service Territory (2007 Update of Original 2004 Report)”*, Pacific Gas and Electric Company, Application Assessment Report #0412, February, 2008.

“Tankless Water Heaters – They’re efficient but not necessarily economical”, Posted September 2008 – Consumer Reports Magazine issue, October 2008.

“Field and Laboratory Testing of Tankless Gas Water Heater Performance” prepared for Lawrence Berkeley National Laboratory by Davis Energy Group (April 14, 2006).

Personal communication with Ben Schoenbauer, Research Engineer, Center for Energy and Environment, Minneapolis, MN, February 2010