Design Guide

Improving Commercial Kitchen Hot Water System Performance

Energy Efficient Heating, Delivery and Use

The information presented is applicable to new construction and, in many instances, retrofit construction. The target audience consists of kitchen designers, mechanical engineers and contractors, code officials, foodservice operators, property managers, plumbing professionals and maintenance personnel.

This guide reviews the fundamentals of water heating for commercial food service and describes the design process. It concludes with real-world design examples, illustrating the potential for a high performance, energy and water efficient system. It is a supplemental guideline that complements current design practices (ASHRAE Handbook 2007) and codes.

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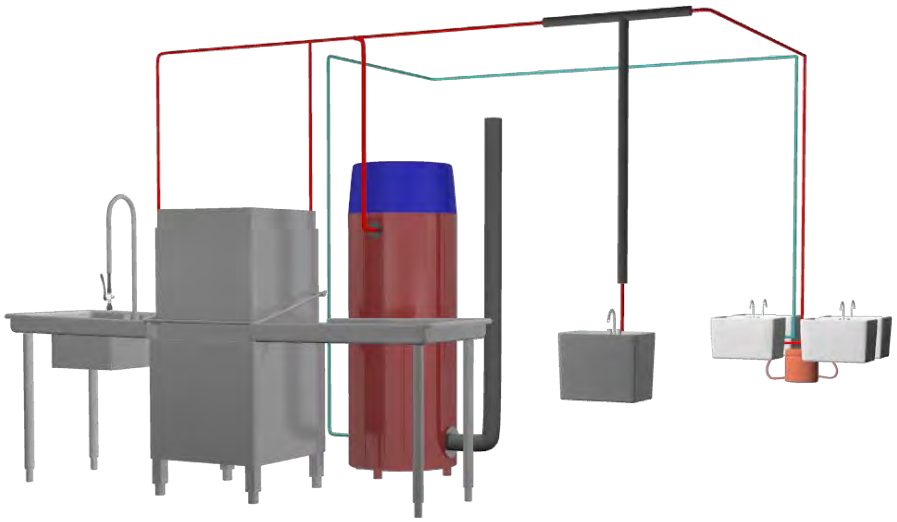
Introduction

This document guides the restaurant designer or engineer to use innovative strategies that will deliver the service of hot water as efficiently as possible while meeting the increasingly challenging regulatory codes and user expectations. This is fundamentally a four-step process: (1) reducing hot water use of equipment and faucets while maintaining performance; (2) increasing the efficiency of water heaters and distribution systems; (3) improving hot water delivery performance to hand washing sinks; and (4) incorporating "free-heating" technologies like waste heat recovery and solar pre-heating. Through high-efficiency system design and equipment specifications, the potential exists to cut the energy use for water heating restaurants in half.

Background

Hot water is the life-blood of restaurants. The hot water system provides the service of hot water to clean hands, wash dishes and equipment, and for cooking purposes. For food safety reasons, foodservice facilities are not allowed to operate without an adequate supply of hot water for sanitation. Therefore it is essential to design the water heating system to meet the needs of hot water using equipment under peak operation.



Restaurant operators expect: (1) unlimited access to hot water, (2) immediate hot water delivery to faucets and equipment, (3) a system that is reliable with little or no maintenance, and (4) minimal investment and operating costs. Unfortunately owners' expectations of their hot water system are rarely met. Moreover, the performance of hot water distribution systems is in decline; when we turn on a hand-sink faucet it can take a considerable amount of time to get hot water (if it gets there at all). It is time to rethink the design of hot water systems to effectively integrate food safety, plumbing, and efficiency regulations and take advantage of high-efficiency water heaters, advanced distribution concepts and efficient water-using equipment through a holistic design process.

Water and Energy Saving Potential

Foodservice operations in California consume upwards of 350 million therms of gas annually for water heating – representing 15% of the total gas consumed by commercial buildings in California. They also use an estimated 115,000 acre-feet of water per year. The saving potential is considerable and in great need. Our freshwater resources are under siege and it is becoming a struggle for communities to meet the water and energy needs of a growing population.

$1.10 / Therm

$0.15 / kWh

$8.00 / HCF

Figure 1. Average California utility rates for restaurants in 2010.

Annual Operating Costs

An unyielding upward trend in utility costs in the U.S. of 6% annually – well above the annual inflation rate of 3% – is troubling for the foodservice sector. For the restaurant owner, this means a larger portion of revenue will be needed to pay for utility costs associated with the hot water system. The annual cost for conventional water heating systems operated in California in a typical quick-and full-service restaurant is displayed in Table 1. The projected operating cost of $3,500 and $19,650 translates to a substantial portion of the restaurant's total utility bill. The utility rates shown in Figure 1 for natural gas, electricity, water and sewer will be applied throughout this guide for cost estimating.

Table 1. Typical hot water system cost for restaurants.

	Water Use (gal/d)	Gas Use (therms/yr)	Water/Sewer Cost*	Gas Cost**	Electricity Cost***	Annual Utility Cost
Quick Service	500	1400	$2,000	$1,500	-	$3,500
Full Service	2500	8800	$9,800	$9,700	$150	$19,650

California 2009 nominal utility rates: *$8.00/unit for water and sewer
**$1.10/therm for natural gas
***$0.15/kWh for electricity (recirculation pump)

Glossary of Abbreviations, Conversions and Terms

Abbreviations
FSTC – Food Service Technology Center
HCF (or CCF) – 100 cubic feet
gph – gallons per hour
gpm – gallons per minute
gpr – gallons per rack
psi – pounds per square inch

Conversions
1 Therm = 100 kBtu = 100,000 Btu
1 unit of water = *1 HCF* = 748 gallons
1 *acre-feet* = 325,851 gallons

Terms
British thermal unit (Btu) is the energy required to raise the temperature of 1 lb of water 1°F.

Btu/h is a unit of power, it also describes the power or maximum input rating of water heaters.

Installed cost encompasses capital, labor and installation cost of a project or the final cost installed.

kWh or *kilowatt-hour* is used to express the energy delivered or used and is the product of power in kilowatts multiplied by time in hours.

Latent heat of vaporization is the heat released when water vapor condenses back to a liquid onto a surface, the latent energy absorbed during evaporation [during the gas combustion process] is released as heat onto the [heat exchanger] surface.

Recovery rate is the number of gallons of water the storage water heater can bring to temperature per hour and it is a function of temperature rise (output temperature – inlet temperature).

R-value is a measure of thermal resistance, the bigger the number, the better the insulation's effectiveness.

Therm is a unit of heat energy that is used for converting a volume of gas to its heat equivalent to calculate the actual energy use.

Thermal efficiency is a dimensionless performance measure of a water heater; expressed as a percentage it is *heat (energy) output divided by heat (energy) input.*

Fundamentals

Conventional hot water systems are comprised of three fundamental component groups: water heater(s) with or without storage, distribution piping, and an array of hot water-using appliances and faucets. In advanced systems, a fourth component is added upstream the water heater to pre-heat the supply water using waste heat or solar. This guide will only briefly touch on "free heating" technologies as more research, development and demonstration projects are needed for a better understanding of the design parameters and economics.

Most water heaters installed in restaurants are storage (or tank) type units designed to hold water at a preset temperature until it is needed. A small number of larger foodservice facilities use a boiler with an external storage tank. A growing number of operations, particularly quick-service restaurants, have entertained tankless water heaters. The dominant energy source for heating water in California foodservice facilities is natural gas, followed distantly by electric resistance and propane.

Distribution systems consist of a network of piping, preferably wrapped in insulation to reduce heat loss. In moderate to large systems (e.g., full-service restaurants), a recirculation loop and pump are installed to maintain hot water in the supply lines for faster delivery of hot water to appliances and faucets. Otherwise, it literally can take minutes for hot water to arrive at its intended temperature at important fixtures such as hand-washing sinks and dishwashers, jeopardizing proper sanitation. In food service, the hot water system is designed to deliver water at temperatures typically ranging between 120°F and 140°F to faucets and equipment. An exception is hand sinks where the water temperature may be reduced to 100°F.

Point-of-use equipment includes fixtures such as faucets, pre-rinse spray valves, and dishwashers. The use of this equipment varies throughout the work day, but peaks typically during the lunch and dinner rush. End-of-day cleaning of the facility and associated use of a mop sink for filling buckets or attaching a hose for wash down can be a major hot water draw.

Design Path for Savings: A Systems Perspective

Designing in a reverse direction, starting with the hot water using equipment and moving back to the water heater, is an effective thought process to achieve high system efficiency and performance. Reducing hot water consumption not only results in lower water and sewer costs; it is the most effective way to reduce water heating energy. This simple tactic is overlooked as operators do not receive a dedicated bill for hot water use – they just don't see the dollars going down the drain.

Step 1: Designers should start by specifying high-performance equipment and accessories that use less hot water. The best location in the kitchen to achieve savings is the dish room, where the largest portion of hot water is consumed. Reducing the water use per rack of the dishwasher and flow rate of the pre-rinse spray valve is the foundation of an optimized hot water system.

Step 2: The distribution system is the second target. Delivering hot water more efficiently yields permanent energy savings and improved system performance. Once the fixtures and the sanitation equipment are specified, the placement of sinks and equipment in relation to the water heater is a key factor to the efficiency and performance of the distribution system.

Step 3: The heart of the system is the water heater. If natural gas is the energy choice, specifying high-efficiency [condensing] water heaters, either storage or tankless, is imperative.

Step 4: Before the hot water system design is finalized, consider integrating pre-heating technologies such as refrigerant heat recovery, dishwasher heat recovery or solar.

Step 5: Proper installation and simple monitoring equipment can play an important role in commissioning and maintaining the system. Verify that the blueprints enable the contractor to build to the specifications. Requiring that the contractor take digital photographs of the entire hot water distribution system (before it is concealed by drywall) is one way to secure pipe layout and insulation specifications.

Design Path for Savings

Specify efficient hot water using equipment and fixtures.

Specify branch and twig sizing and pipe insulation to meet plumbing codes and satisfy water flow requirements including: time to tap, volume, temperature, and water velocity.

Optimize position of hot water using sinks and equipment in kitchen, restroom, bar, and etc.

Size and optimize the layout of distribution (trunk) line(s) based on the type of distribution system chosen.

Specify and centrally locate high-efficiency water heater(s) and, if applicable, point-of-use tankless heaters.

Consider pre-heating (free heating) technologies like solar and waste heat recovery.

Track hot water use by placing a water meter on the supply line to the water heater.

Commission hot water system and set thermostat to meet requirements of the restaurant.

Equipment and Fixtures

The hot-water-conserving equipment and fixtures are pivotal to an optimized hot water system. These are the only parts of the system that regularly interface with the user and are easiest to remove and replace, namely the dishwasher, the pre-rinse spray valve and the aerators on hand sink faucets. Efficient equipment or fixtures, as long as they offer equal performance to conventional models, will translate into long-term savings.

Pre-Rinse Spray Valve

The pre-rinse spray valve (PRSV) is a handheld device designed for use with commercial dishwashing and ware washing equipment that sprays water on dishes, flatware and other foodservice items for the purpose of removing food residue (Figure 2).

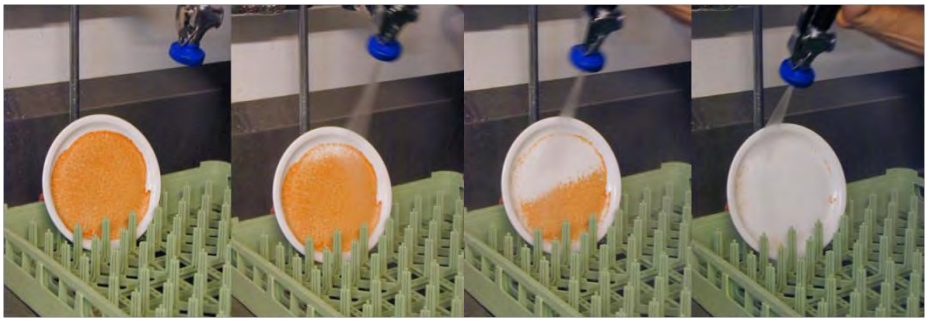


Figure 2. ASTM Std. F-2324 "cleaning" test of a low-flow PRSV.

Low-flow, high-performance pre-rinse spray valves are the single most cost-effective piece of equipment for water and energy savings in commercial kitchens. Building on a successful California Public Utility Commission funded program in 2005, at least half of 100,000 pre-rinse spray valves used in commercial kitchens in California have been retrofitted with efficient models (using 1.6 gpm or less). Realizing that efficient spray valves perform equally with inefficient or conventional counterparts, the federal government passed laws in 2005 limiting their flow rate. The federal regulations combined with the success of efficient pre-rinse spray valves in kitchens have helped to support a market transformation [1]. This momentum has propelled manufacturers even further, with the introduction of models that use less than one gallon per minute. A busy full-service restaurant can clock three hours of pre-rinse operation a day. Even at one hour of use per day, the best-in-class 0.64 gpm spray valve can save 100 therms and $330 annually when compared to the

Federal Regulations – Energy Policy Act of 2005: Pre-Rinse Spray Valves

Commercial pre-rinse spray valves manufactured on or after January 1, 2006, shall have a flow rate of not more than 1.6 gallons per minute.

federally regulated 1.6 gpm valve (Figure 3). When compared to a high-flow value at 4.5 gpm, the savings would be 400 therms and $1,350 annually.

Pre-Rinse Spray Valve Performance Summary

Specification sheets on the PG&E Food Service Technology Center website list flow rate and cleanability times for each model tested in the laboratory.

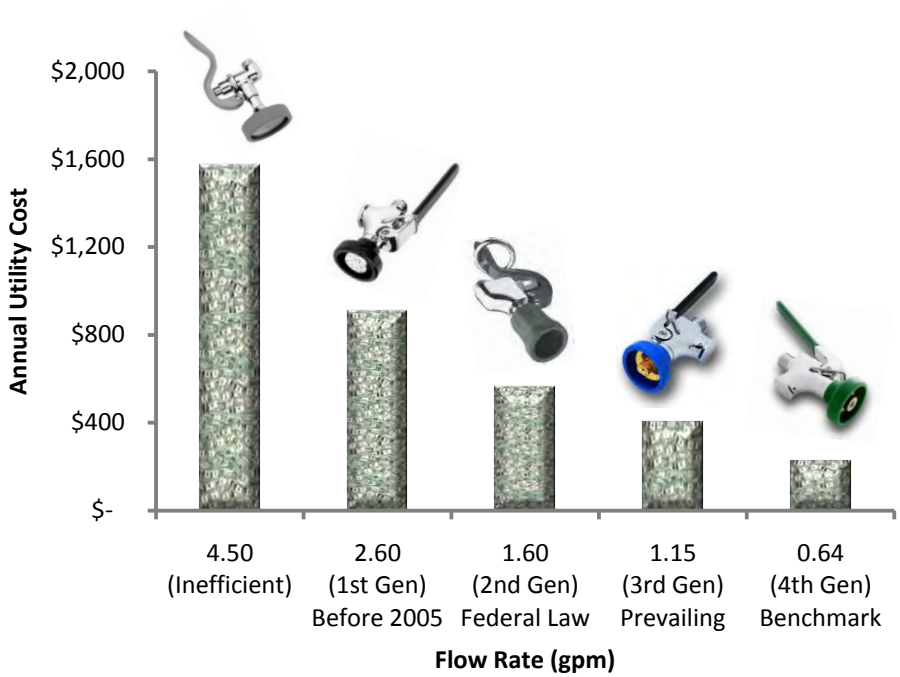


Figure 3. Utility cost of pre-rinse spray valves based on 1 hour of daily use.

Codes and Regulations on Lavatory Faucets

Several regulations passed in the early 90's culminated with the creation of a single federal standard in 1998 restricting the maximum flow rate for private* and public** lavatory faucets at 2.2 gpm at 60 psi [2].

The American Society of Mechanical Engineers (ASME) standard is the governing standard and test procedure for faucets. Section 5.4.1 and Table 1 of ASME A112.18.1– *Plumbing Supply Fittings* established the maximum flow rates for public lavatory faucets at 0.5 gpm (other than metering faucets). This standard on public lavatory faucets has been adopted by reference by all major plumbing codes including the Uniform Plumbing Code, International Plumbing Code and the National Standard Plumbing Code [3].

* "Private" applications include faucets in residences, hotel/motel guest rooms and private rooms in hospitals.

** "Public" applications include lavatory faucets in office buildings, schools, gyms, restaurants, bars, retail stores and all public buildings.

Aerators

Aerators are inexpensive devices added to faucets at the threaded spout to reduce the water flow rate while maintaining enough force for effective hand washing (a restroom lavatory sink or a kitchen hand-washing sink is used almost exclusively to wash or rinse hands). Large restaurants can have up to a dozen hand-washing sinks and it is still common to find high flow (typically 2.2 gpm) aerators installed. The maximum flow rate can be set much lower without negatively impacting user satisfaction (i.e., 0.5 gpm or less). You can still purchase aerators that range from the federally mandated maximum 2.2 gpm aerator for a private lavatory down to the best-in-class 0.375 gpm high-performance model. But there is still a lack of awareness, or reluctance, in the restaurant industry to install low-flow aerators (0.5 gpm) on lavatory faucets.

The upcoming section on hot water delivery performance demonstrates that a conventional distribution system (with a relatively large volume of water in the pipes that cools between draws) works poorly with 0.5 gpm aerators. This often leads to their exchange for high flow aerators (or removal) after a new restaurant is in operation to reduce that wait time for hot water. The peak flow rate of a hand sink faucet with the aerator removed could be as high as 8 gpm. If this faucet was used one hour per day, the annual utility cost would exceed $2,800. The estimated utility costs of various aerators operated for one hour per day are displayed in Figure 4. An annual saving of 190 therms and $640 is estimated by replacing a 2.2 gpm aerator with a 0.375 gpm aerator.

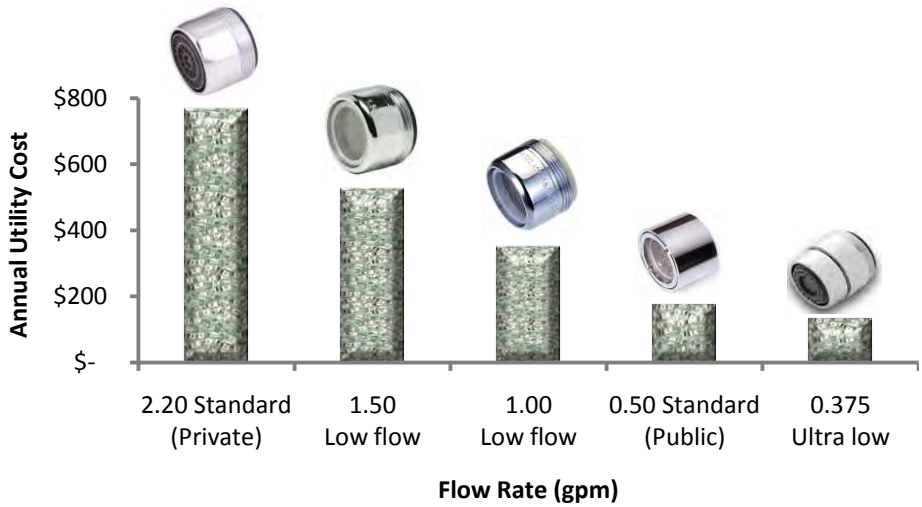


Figure 4. Total utility cost for a hand sink at various aerator flow rates.

Glasswasher

Undercounter

Door type

Conveyor type

Figure 5. Commercial dishwashers.

Photo Credit: Jet Tech, Winterhalter, Hobart, Meiko

Commercial Dishwashers

The commercial dishwasher, also called a warewasher or dishmachine, uses cleaning chemicals, electricity, natural gas, and water. Figure 5 illustrates the array of dishwashers available for use in restaurants (excluding the large flight-type machines used in very large foodservice operations). It is important to be familiar with the dishwasher specifications and to know the daily usage (racks per hour) in order to estimate operating costs and assess the value of choosing a more efficient model. The water use per rack is a fundamental measure of efficiency as it correlates with the energy used to heat water and the amount of cleaning chemicals required for each cycle. Hot water use between models within a class varies considerably as shown in Table 2.

Table 2. Hot water use (gal. per rack) of low and high temperature dishwashers.

Type	Inefficient	Conventional	ENERGY STAR	Best in Class
Glasswasher	> 2.5	1.5 low 1.2 high	-	0.74 low 0.50 high
Undercounter	> 2.0	1.95 low 1.50 high	1.7 low 1.0 high	0.74 low 0.70 high
Door Type	> 2.0	1.85 low 1.40 high	1.18 low 0.95 high	0.73 low 0.70 high
Single-tank Conveyor	> 1.4	1.23 low 1.10 high	0.79 low 0.70 high	0.49 low 0.35 high
Multiple-tank Conveyor	> 1.2	0.99 low 1.10 high	0.54 low 0.54 high	0.39 low 0.28 high

Older and less efficient equipment on the market is being replaced with ENERGY STAR qualified models to save energy and water. Historically, manufacturers with efficiency-driven designs have focused on reducing the rinse water volume per rack. More recently, they have ramped up research and development and are introducing innovative technologies like waste heat recovery, insulated panels, and ventless models. A high-temperature ventless dishwasher does not require a vent hood, saving on HVAC costs, and is easily retrofittable into older facilities with existing low-temperature machines.

Distribution Systems

The distribution system is often overlooked as a component of the hot water system that affects both energy and water use. There are four main types of distribution systems applicable to the foodservice environment:

1. Simple distribution (supply piping with no return loop)
2. Continuous recirculation (supply piping with return loop and pump)
3. Demand circulation (demand pump with or without a return loop)
4. Distributed generation (primary and point-of-use heating)

The majority of systems installed in restaurants are based either on simple distribution or continuous recirculation. Regardless of which type, many of systems operate inefficiently and lack the hot water delivery performance desired in the foodservice environment. Demand circulation and distributed generation provide hot water on demand at the point of use and, unlike continuous recirculation systems, are compatible with tankless heaters. Manifold distribution systems are not discussed as they generally are not applicable to commercial food service.

Distribution System Components

Twig:	Serves one fixture
Branch:	Serves two or more twigs
Trunk:	Serves two or more branches; may be connected to a return line leading back to the water heater [4]

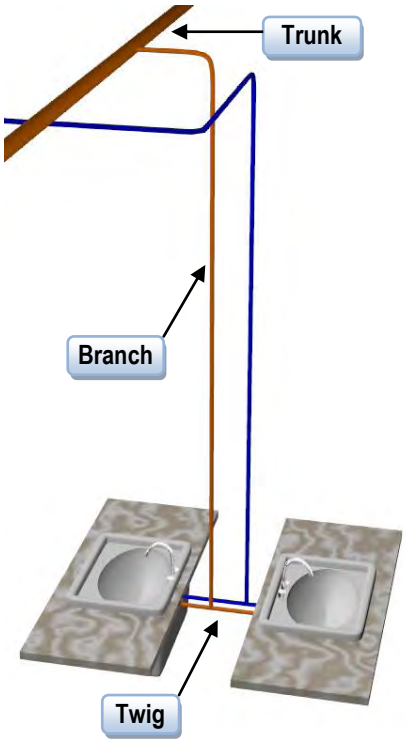


Figure 6. Simple Distribution.

Simple Distribution

A simple distribution system uses a trunk, branch, and twig configuration to deliver water from the heater to the points of use (Figure 6). The benefit of this system is that it is simple and reliable and is compatible with all water heaters. The drawback is a potentially long wait time for hot water, especially at first use or after periods when water cools down in the pipes. Increasing the length or diameter of the distribution line increases wait times at the farthest fixtures because a larger volume of room-temperature water must be purged before hot water arrives. Simple distribution systems are typically used for small quick-service restaurants and specialty shops where distribution lines are less than 60 feet. The two most popular configurations include a single-line distribution system that feeds all sinks and equipment, and a two-line distribution system that provides hot water (typically at 140°F) to the sanitation sinks and dishwasher, while a second line provides tempered (mix of hot and cold water, typically 100 to 110°F) to handwashing sinks.

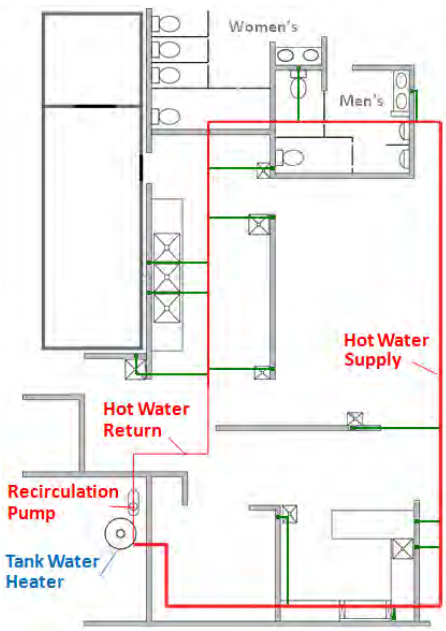


Figure 7. Recirculation line.

Continuous Recirculation

Continuously circulating hot water through the main distribution line and back to the heater ensures that there is hot water in the trunk line at all times, in essence moving the water heater closer to points of use (Figure 7). However, depending on the branch and twig pipe size (i.e., volume of water in pipes between the trunk line and point of use) and fixture flow-rates, this configuration does not always ensure immediate delivery of hot water to the faucet. This is particularly the case when low-flow aerators have been specified. But regardless of how well the strategy works, water is being circulated at 140°F (or more), continuously losing heat to the surroundings. The hotter the water is in the lines, and the poorer the insulation, the greater the heat loss and energy consumed by the water heater.

For California restaurants, environmental health guidelines state: "Where fixtures are located more than sixty feet from the water heater, a recirculation pump must be installed to ensure that water reaches the fixture at a temperature of at least 120°F" [5]. Although it is possible to design without continuous recirculation in larger restaurants, you will need to work with your county plan reviewer to get a variance from this rule (based on an engineered design of an alternative and equally effective distribution strategy). Examples of such systems are illustrated in the design examples of this guide.

Demand Circulation

Demand circulation, as the name implies, incorporates a control strategy that operates the recirc pump only when there is a need for hot water. The operation of the pump can be initiated by an occupancy sensor in the vicinity of a hot water fixture. One system on the market features an integrated pump and temperature sensor placed under the hand sink (Figure 8). When the occupancy sensor triggers the pump, it purges room temperature (or luke-warm) water from the hot water supply line and transfers it into the adjacent cold water supply line (remember, the cold water line coming into the building is also connected to the inlet of the water heater). When the built-in temperature sensor measures an increase in water temperature, it assumes that hot water is just about to arrive at the fixture and it shuts off the pump, preventing hot water from being transferred into the cold water line. Now, when the hot water tap is turned on, the delivery of hot water happens within seconds. Every time the occupancy sensor calls for the pump to run, the unit checks the water temperature. If it senses that the water in the pipe has not cooled down, it does not activate the pump.

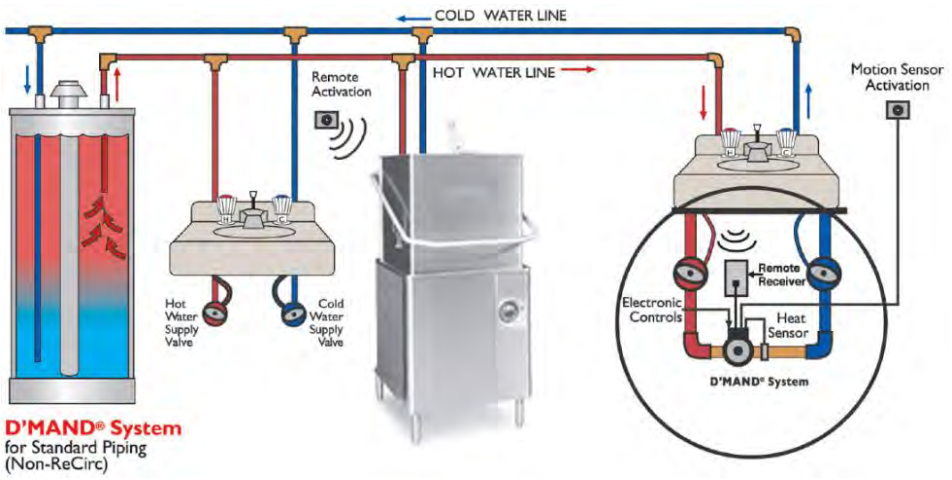


Figure 8. Demand circulation diagram.
Photo Credit: Taco (Modified)

If the demand control and pump is installed at the furthest hand sink from the water heater, it will keep the trunk line between the heater and all points in between full of hot water (assuming that the pipes are insulated). Thus, as illustrated in Figure 8, hot water will be delivered quickly to the other fixtures and appliances in the restaurant.

Distributed Generation

Distributed generation can be a 100% distributed system utilizing point-of-use water heaters or a hybrid hot water system that combines a central water heater (storage type or tankless) with point-of-use electric heaters. In the hybrid configuration a simple distribution system delivers hot water to sanitation equipment and kitchen sinks which are clustered near the primary water heater. And on-demand or mini-tank electric water heaters are placed strategically below the hand sinks in remote lavatories (Figure 9). The point-of-use heaters that are sized appropriately for flow rate and temperature rise can be plumbed to the cold water line, thus eliminating the need for a dedicated hot water line. Using distributed electric heaters for hand-washing sinks is a cost-effective option, especially when specifying the "best-in-class" 0.375 gpm aerator for the faucets. This approach minimizes water and energy use while enhancing the customer experience by reducing the wait for hot water. Research is recommended when specifying a unit, as the reliability of some point-of-use electric heaters in heavy use applications has been called into question.

Figure 9. Electric tankless heater.
Photo Credit: Clage

Pipe Insulation

Pipe insulation is by far the most effective solution (if not the most overlooked) to improving the effectiveness of the distribution system to deliver hot water on demand. Typically, fiberglass or foam insulation can be used on hot water piping to prevent heat loss. This saves energy, extends the cool-down time, reduces operating cost, and improves the effectiveness of the distribution system to deliver hot water. Title 24, California Energy Commission's Energy Efficiency Standards sets mandatory minimum requirements for pipe insulation thickness for service water heating systems in commercial facilities. The pipe insulation requirements of Title 24 should be considered a minimum for a non-recirculating system, since adding insulation to the entire hot water distribution system should be a mandatory design specification (Title 24 only requires the first 8 ft. of pipe to be insulated). This includes pipes leading from the water heater, above the ceiling tiles, behind the walls, and leading from the wall to the appliance or sink.

Title 24, Section 123
Pipe Insulation Requirements

With hot water pipe diameter of 2" or less, 1"-thick insulation is required for:

a) All recirculating sections of piping
b) First 8' of piping from the heater in non-recirculating distribution systems
c) Sections with electric heat trace

Required Insulation type includes: foam, fiberglass, or another material with equivalent insulation effectiveness [6].

Recirculation Pump Timer

To reduce operating costs associated with the continuous operation of a circulation system, the recirc pump should be time-controlled and operated only when the restaurant needs hot water. Adding a time clock or timer (Figure 10) that turns the pump on shortly before restaurant staff begins preparation and off just before closing hours could save 8 to 10 hours of run time for a two-meal per day restaurant. The recirc pump can also be temperature-controlled with an aquastat that only runs the pump when the temperature of the return loop falls below a specified value. However, a PG&E Food Service Technology Center (FSTC) retro-commissioning study of water heating systems was not able to confirm the net benefit of aquastats [7].

Figure 10. Timer mounted on a recirculation pump.

Hot Water Delivery Issues

There are two areas in food service, the dishwasher and hand sinks, where immediate delivery of hot water is critical to completing the task in a sanitary fashion. The rinse operation of the dishwasher requires inlet water temperatures typically in the 140°F range to the dishwasher (for low-temp applications) or to the booster heater (for high-temp applications). If hot water has cooled to room temperature in the pipes (between the recirc line and the dishwasher), the dishwasher may not be able to compensate for the sub-140°F inlet water on its next load, thus compromising sanitation.

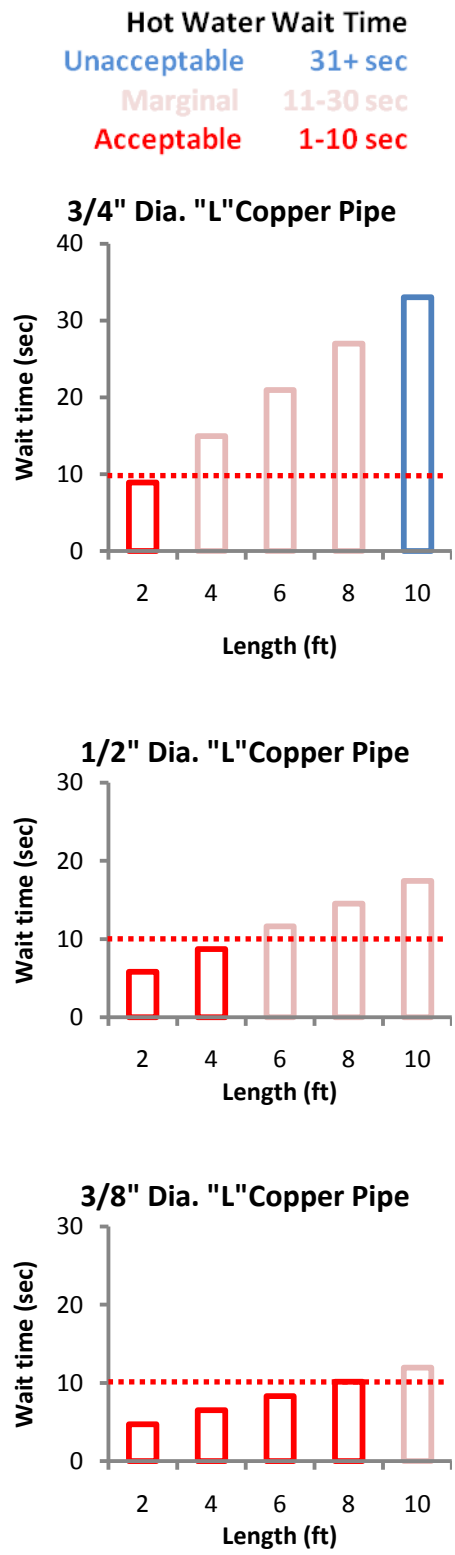


Figure 11. Wait times associated with the size of branch piping to a hand sink with a 0.5 gpm aerator.

A more noticeable problem is the timely delivery of hot water to hand-washing sinks. With a simple distribution system, a hand sink could be located 60 feet from the heater and the trunk must be purged of room temperature water the first time the hand sink is used. If the piping is not insulated, hot water may never reach a hand sink that is being used intermittently because the water always cools down between uses. The sad part is that the operator pays to heat the water that never makes it to the tap.

The goal is to reduce hot water wait time to 10 seconds or less, which is considered acceptable for public lavatories. A wait time of 11 to 30 seconds is considered borderline and a wait time of 30 seconds or more is unacceptable [8].

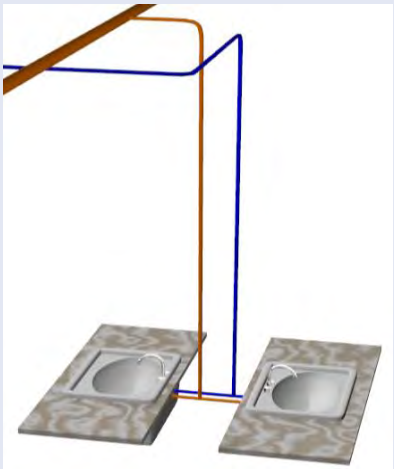
Extending Cool-Down Time

Insulation extends the cool-down time of the hot water in pipes. It increases the time that branch and twig piping stays hot between water use events, thereby increasing the availability of hot water at the faucet and mitigating hot water delivery problems. Applied to $^3/_8$-inch and ½-inch diameter pipes, 1-inch thick insulation will double the cool-down time compared with uninsulated pipes; applied to ¾-inch diameter pipes, it triples the cool-down time [9].

Improving Hot Water Delivery

A strategy to improve delivery performance is to reduce the diameter of the branch and/or twig piping leading from the trunk line to the hand sink(s). Some examples of pipe size and resulting hot water wait times are shown in Figure 11. To simplify the wait time estimation, it was assumed that the portion of twig line leading from the shut-off valve to the faucet aerator holds 0.024 gallons of water, which is equivalent to using 2 feet of ½-inch diameter piping and corresponds to 3 seconds of additional wait time.

Restaurant designs typically specify ¾-inch diameter branch piping (leading to the shut-off valve) for two lavatories or more. With 10 feet of ¾-inch diameter branch piping and a 0.5 gpm aerator installed, the wait time would be 33 seconds before the 0.28 gallons of water is purged and hot water reaches the faucet. For best design, ¾-inch branch piping should be used when serving five lavatories or more; using it to serve two lavatories is overkill. Similarly, ½-inch piping is appropriate for four lavatories that have a maximum flow rate of 2 gpm (Figure 12).



Branch Pipe Diameter Guidelines for Public Lavatories

3/8" Diameter: Serves 1-2 Lavatories

1/2" Diameter: Serves 3-4 Lavatories

3/4" Diameter: Serves 5+ Lavatories

If ¾-inch branch piping must be used between the trunk line and the twig line, then two feet is the longest length before wait times breach the ten second threshold for acceptable performance. In this situation, extending the trunk line vertically down the wall reduces the length of branch piping to the faucet (Figure 13). While this approach resolves the delivery performance issue, it increases the length of the trunk line and system cost. A variation of the vertical trunk section is the use of dropped return and balancing valves (known as circuit setters) to allow a trickle of circulated hot water to flow down the vertical branches; the goal is to flow just enough hot water to counteract the heat loss in the branches.

Heat Trace

Using electrical heat trace is another way of maintaining the temperature in the hot water pipe. In this application, shown in Figure 14, a heating cable runs the length of the pipe under the insulation and maintains the temperature of the hot water by passing heat through the pipe into the water, counteracting the heat loss through the pipe and insulation. The inherent disadvantage of this method is that the water is being heated twice.

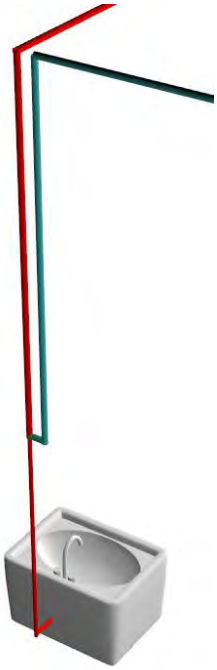


Figure 13. Vertical trunk drop.

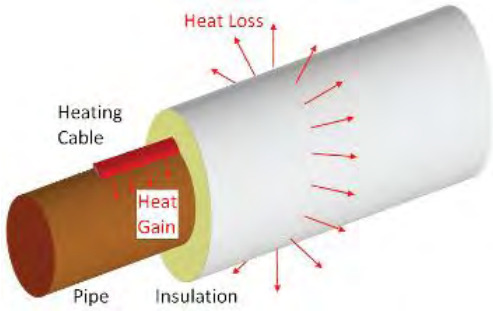


Figure 14. Heat tracing to maintain hot water temperature in piping [10].

Final Considerations

- Mirror men's and women's lavatories so they are on opposite sides of the same wall and share a common branch pipe.
- Place sanitation equipment in a cluster and locate the heater on a shared wall to minimize the need to install piping up to the ceiling and back down.
- Centralize the water heater in or near the kitchen to minimize pipe runs to equipment and fixtures.
- Consider point-of-use heaters for remote hand sinks, eliminating the need for hot water lines.

Water Heater Selection and Specification

Figure 15. Water heating installations (a) storage water heaters (b) tankless units with controller, pump and storage tank (c) boiler with pump and storage tanks.

In California foodservice establishments, natural gas is preferred for heating water as it costs approximately two-thirds less than heating with electric resistance. Electric water heaters typically are used only in facilities that don't have access (or easy access) to natural gas. There are three main types of gas water heaters that are typically installed: storage (i.e., tank-type), tankless and boiler-based (Figure 15). Boilers are not a focus of this guide since their physical size, complexity and installed cost make them an unlikely choice for most restaurants. Tankless water heaters require the least space for installation, but may be faced with other performance limitations. The dominant choice for restaurants has been the storage water heater because it heats and stores water in one appliance.

The authors of this design guide are foremost supporters of high-efficiency, condensing gas heaters – either storage or tankless.

Standard Efficiency versus High Efficiency [Condensing]

Based on the Air-Conditioning, Heating and Refrigeration Institute (AHRI) appliance thermal efficiency ratings, condensing heaters are 10 to 20% more efficient than non-condensing models [11]. Thermal efficiency is the ratio of energy output to energy input measured under full-burner-load lab tests. The heat exchanger in a standard efficiency heater allows a considerable amount of heat to be vented up the flue instead of being transferred to the water (Figure 16). If the thermal efficiency of the heater is 80%, that means that 20% of the gas energy is being vented at a relatively high temperature (e.g., 350°F). A high-efficiency or condensing heater extracts more energy from the combustion gases, largely by condensing the water vapor contained in the products of combustion and transferring this heat of vaporization to the water. Most of the energy generated by the combustion process is used to heat water and the thermal efficiencies are in the 95% range while flue temperatures are as low as 100°F (Figure 17).

Thermal Efficiency versus Operating Efficiency

In an installed system with dynamic water flow conditions, idle periods and burner cycling, the overall operating efficiency is lower than the rated thermal efficiency. FSTC field testing in restaurants [12] has documented "real world" operating efficiencies that averaged 5 to 10 percentage points (calculated on a daily basis) lower than the rated thermal efficiency. The heaters exhibited higher efficiency during heavy-water-use days and lower efficiency during light-use days.

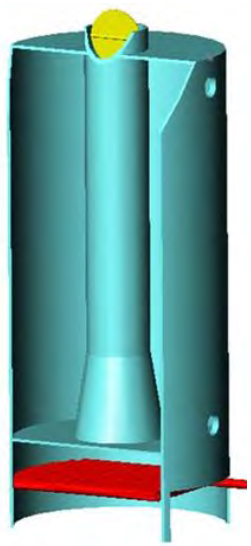


Figure 16. Standard efficiency heater.

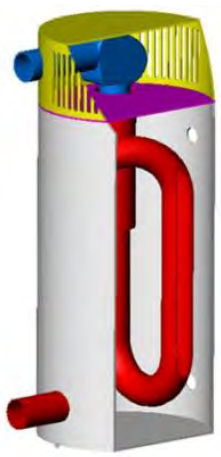


Figure 17. Condensing storage heater.

Standby Heat Loss

Standby heat loss from a storage water heater itself is not significant when compared to the energy required to heat large volumes of hot water used in foodservice operations. Compared to residential systems with typical use of 60 gal/d, where the standby heat loss from the tank itself could represent 30% of the total water heater energy use, in restaurants it typically accounts for less than 4% in quick-service and approximately 1% in full-service. Furthermore, the standby loss from condensing tank heaters is 15 to 40% less than that of standard efficiency units due to better insulation and reduced flue losses. Although a tankless heater doesn't experience heat loss during standby periods, it does experience residual heat loss between operating cycles when the heat exchanger has time to cool down. Heat loss during idle periods is not a significant energy component when considering either storage or tankless heaters for foodservice applications. Sometimes it is implied that the significant "standby energy benefit" of tankless heaters for residential applications will translate to similar savings in foodservice applications – this is simply not true.

Tank versus Tankless

A storage water heater can run out of hot water during heavy usage if it is undersized, which is a sanitary concern in foodservice operations. Moreover, emptying a whole tank of hot water in a short time period, which is a possibility during intense wash downs, may lead to thermal shock of internal components due to the incoming rush of cold water. This may contribute to premature tank failure. Designers typically oversize the burner capacity or add additional storage to accommodate these acute periods of heavy hot water use. The life of the water heater may be extended by designing with reserve storage capacity to handle atypical elevated hot water use events. A capacity of 200,000 Btu/h may be adequate 90% of the time, but for those extreme-use days the designer may opt for 400,000 Btu/h. As shown in Figure 18, consumption on a heavy-use day can be almost twice the average use of hot water [13].

A tankless heater is an attractive option with respect to its lower purchase cost and space-saving benefits. However, the tankless or "on-demand" water heater also has limitations when used in commercial kitchens [14].

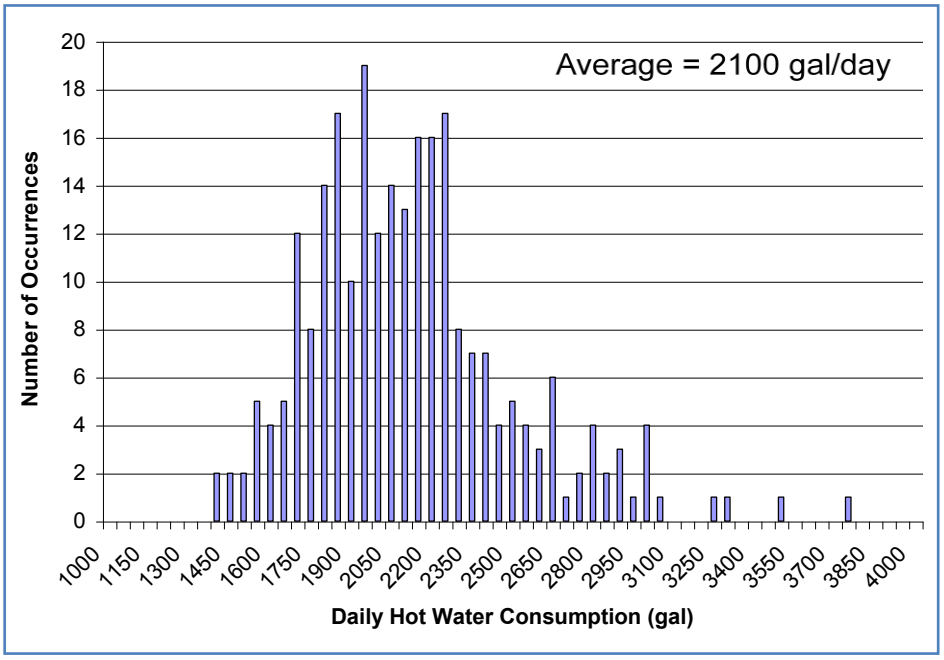


Figure 18. Hot water consumption frequency distribution for full-service facility.

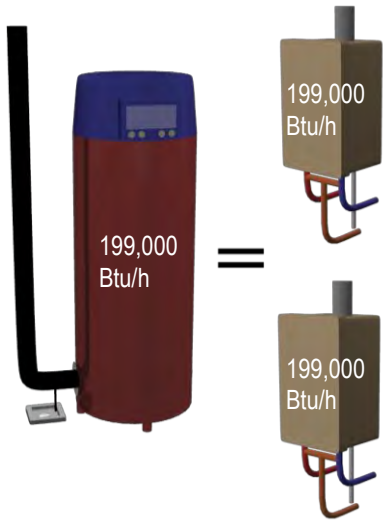


Figure 19. Typically one storage heater is equivalent to two tankless heaters.

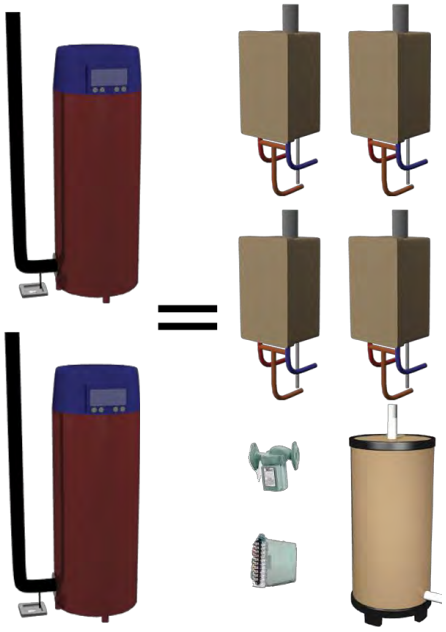


Figure 20. Two storage heaters are equivalent to four tankless with controller, tank and recirc pump.

After an initial hot water draw, a subsequent draw may deliver a slug of cold water into the distribution line as the heater is "waking up" to initiate the burner sequence. This leads to a cold-water sandwich phenomenon between two hot-water draws. Furthermore, the startup sequence inherent in tankless heaters creates an additional lag in hot water delivery, requiring a couple of seconds before firing and ranging from 10 to 30 seconds before the heated water is near the set temperature [15]. The cold-water sandwich and hot-water lag issues may create an incompatibility with a dishwasher and its need for immediate hot water.

With regard to water heating performance (on-demand heating capacity), two tankless heaters (each with the same Btu/h input as the storage water heater) will generally be needed to replace one storage heater to meet the hot water flow requirements (Figure 19). Alternatively stated, a 199,000 Btu/h storage water heater is equivalent to two, 199,000 Btu/h tankless units.

Integrating a tankless heater with a recirculation system generally requires an investment in a more complex system. One strategy is the addition of an external storage tank, controller and pump shown in Figure 20 (same configuration as a water heating boiler). An alternative solution for smaller applications is to install a small electric resistance water heater downstream of the tankless unit to provide a storage reservoir for the recirculation system. This latter option may offset any

energy cost benefits, as the electricity consumed to replace the heat being lost from the recirc line is a significant component of the overall water heating load.

Figure 21. Demand circulation [16].

Tankless heaters are not designed to modulate down to accommodate the small 5 to 15°F temperature rise needed to offset the heat loss from a recirculation loop. Nonetheless, tankless heaters may be used with a recirc loop without the need for a storage tank by using an aquastat to activate the circulation pump only when the return temperature drops below, for example, 110°F. In some cases, a recirc loop may nullify the manufacturer's warranty and may shorten the operating life of the heat exchanger because of the increased cycling of the burner to maintain the loop temperature. In a larger restaurant with multiple tankless heaters, plumbing the recirc line to a "sacrificial" unit may be an option as long as the operator understands that replacing a failed heat exchanger becomes a new maintenance task. Another option is using demand circulation (Figure 21) where the tankless heater only cycles on before a hot water draw.

A fundamental performance difference between storage and tankless heaters that may not be obvious to either the designer or end-user relates to the output temperature. A storage water heater will always deliver water at or above its setpoint (unless it is undersized for the load) while a tankless unit will deliver water at or below its setpoint temperature. Field monitoring by the FSTC [12] has shown that for the same setpoint temperature (e.g., 130°F), the average mass-weighted temperature of water supplied by the tankless unit is approximately 10°F below the mass-weighted temperature supplied by the storage heater. Turning the thermostat on the tankless up by 10°F or on the storage heater down by 10°F will result in equivalent outlet temperatures. Thus, at the same setpoint temperature, a tankless unit inherently will use less energy than its storage heater counterpart, but it also will be doing less "water heating" work.

Considerations for Tankless Heaters

Care should be taken when specifying tankless heater(s) for new facilities requiring 0.5 gpm aerators on public hand sinks, because in many cases, the tankless heater will not fire the burner to supply hot water at such a low flow rate. This also occurs when 0.5 gpm aerators (rated at 60 psi) are installed and operated in systems with pressure below 60 psi, or when the tap is only partially open, because the flow rate will be even lower. In this case, the heater will allow unheated water to pass through and enter the hot water distribution line. In smaller restaurants without recirculation,

Figure 22. Point-of-use electric tankless.
Photo Credit: Stiebel Eltron

Figure 23. Filling of a 3-comp sink.

Fill Time of a 3-Comp Sink

Large 3-Comp Sink

Sink 24" X 24" X 14" = 4.6 ft^3

4.6 ft^3 x 7.48 Gallons/ ft^3 = 35 gal

Assume sink is filled ¾ full = 26 gal

Hot water for wash and rinse = 52 gal

Storage: 52 gal /15 gpm = 3½ min

Tankless: 52 gal / 3.7 gpm = 14 min

Small 3-Comp Sink

Sink 18" X 18" X 12" = 2.3 ft^3

2.3 ft^3 x 7.48 Gallons/ ft^3 = 17 gal

Assume sink is filled ¾ full = 13 gal

Hot water for wash and rinse = 26 gal

Storage: 26 gal /15 gpm = 1 ¾ min

Tankless: 26 gal / 3.7 gpm = 7 min

Figure 24. Pipe diameter guidelines.

the low-flow-rate issue of tankless heaters can be overcome with the addition of a small electric tank downstream of the heater to provide a reservoir of water to meet the low flow demand and also eliminate the hot water lag associated with tankless heaters. A solution is to use the tankless heaters for all sanitary equipment in the kitchen that cause no minimum flow rate issues and route only cold water lines to hand sinks served by point-of-use electric tankless heaters. These point-of-use heater can operate with flow rates as low as 0.2 gpm (Figure 22).

Water heater capacity is dependent on the temperature rise across it, which is a function of cold water inlet temperature and hot water outlet temperature. It is therefore important to design for the coldest expected inlet temperature conditions to meet the hot water load at all times throughout the year. As an example, the winter temperature rise in Northern California is approximately 90°F, which is approximately 15°F higher than the temperature rise during the summer.

A colder inlet temperature (and greater temperature rise) affects the performance of storage and tankless heaters differently. A storage heater may experience lower outlet temperatures if the heater is undersized under heavy load conditions, particularly during the winter. A tankless heater will experience reduced maximum flow rates with colder inlet temperatures, which may reduce flow at the mop sink or compartment sinks.

A typical user will turn the hot water handle to the full flow (approximately 15 gpm) to fill up a sink (Figure 23). To fill a 35-gallon wash and a second 35-gallon rinse compartment ¾ full, it would take approximately 14 minutes with a tankless heater. This is more than 10 minutes longer than with a storage heater (Figure 24). This fill-time estimate is based on using a 199,000 Btu/h standard efficiency tankless with a maximum flow rate of 3.7 gpm at a 90°F temperature rise [17]. At best, with a condensing tankless heater flowing at 5.3 gpm (70°F rise in the summer), it would still take 10 minutes to fill. The practical design solution is to use multiple tankless units.

Sizing Water Heaters

The hot water demand over a given time period is the primary factor in sizing heaters. Following the water heater sizing guidelines to meet food safety regulations in your county is the first priority. To size a storage or tankless heater to meet food safety regulations, the first step is to tabulate the hot water fixtures. Typical fixture counts of hot water using equipment and sinks, ranging from a deli to a large full-service restaurant, are presented in Table 3.

Table 3. Fixture count for various sized restaurants.

Fixture Type	Fixture Count			
	Deli	Quick Service	Small Full Service	Large Full Service
Restroom sinks	1	2	2	4
Hand sinks	1	2	3	6
3-comp sink	1	1	1	2
Dishwasher			Door-type	Conveyor
Pre-rinse valve			1	1
Mop sink	1	1	1	1
Utility and Prep sinks		1	1	2
Dipper well				1

Table 4. Fixture flow rate guidelines for sizing heaters.

Fixture Type	Flow Rate	
	Tankless (gpm)	Tank (gph)
Restroom sinks	0.5	5
Hand sinks	0.5	5
3-comp. sink (18" X 18")	2	42
3-comp. sink (bar)	2	18
Door-type dishwasher	4.4*	30**
Conveyor dishwasher	2.1	126
Pre-rinse spray valve	1.6	45
Mop sink	2	15
Utility sink	2	5
Utensil pre-soak sink	2	5
Dipper well	0.5	30

*Rate of rinse flow for door-type rated at 0.74 gallons/rack, 58 racks/h and 10 second rinse/rack

**Door-type maximum rinse consumption at 43 gph x 0.7 (rack loading factor) = 30 gph

Flow rates for fixtures in the guidelines that are not fixed and are allowed variability in the estimation of peak flow rate include dishwashers and dipper wells.

After tabulating the hot water using equipment, each piece of equipment must be characterized for its maximum hot water use to calculate the peak hot water demand. California flow rate guidelines of fixtures [5] for use in sizing storage and tankless heaters are referenced and shown in Table 4. Since there is no storage in a tankless heater, the flow rates of individual fixtures are expressed in gallons per minute (gpm) to calculate the peak demand. A storage heater has a tank of hot water that acts as a buffer, so peak fixture flow rates can be expressed in gallons per hour (gph). It is important to interpret the flow rate guidelines with caution, as sizing water heaters for food safety versus good design can yield different results. For example, when sizing tankless heaters, the fixture flow rate guideline for a 3-comp sink at 2 gpm is not an issue from a food safety standpoint, but is inconsistent with real-world practices in kitchens where flow rates of 15 gpm are desired for filling. It may be argued that this inconsistency in the guidelines poses a food safety issue due to changes in staff practices to compensate for poor performance (e.g., using cold water to supplement hot water for a faster fill time).

Using the flow rate guidelines, the minimum recovery rate of storage heaters in Table 5 and minimum flow rate of tankless heaters in Table 6 for various sized restaurants are displayed. Manufacturer's specifications on gas input rates for

condensing heaters are displayed that meet or exceed the calculated minimum recovery and flow rates at a 90°F rise, respectively. The gas input rate of tankless heaters far exceeds the input rates of storage heaters (by a factor of at least 3 to 1) to meet the same demand.

Table 5. Sizing of condensing storage heaters based on recovery rates.

Fixture Type	*Storage Heater Minimum Recovery Rate*			
	Small Quick Service	Medium Quick Service	Small Full Service	Medium Full Service
Restroom sinks	5	10	10	20
Hand sinks	5	10	15	30
3-comp sink	42	42	42	60
Dishwasher			30	126
Pre-rinse spray valve			45	45
Mop sink	15	15	15	15
Utility or pre-soak sink		5	5	10
Dipper well				30
Min. recovery rate (gph)	54*	66*	162	336
Min. input rate (Btu/h)	76,000	76,000	150,000	300,000

*Minimum recovery rate discount factor of 20% for using single service utensils.
Example: Small quick-service restaurant recovery rate = 67 gph X 0.8 = 54 gph

Table 6. Sizing of condensing tankless heaters based on flow rate estimates.

Fixture Type	*Tankless Heater Minimum Flow Rate*			
	Small Quick Service*	Medium Quick Service*	Small Full Service	Medium Full Service
Restroom sinks	0.5	1	1	2
Hand sinks	0.5	1	1.5	3
3-comp sink	2	2	2	4
Dishwasher			4.4	2.1
Pre-rinse spray valve			1.6	1.6
Mop sink	2	2	2	2
Utility or pre-soak sink		2	2	4
Dipper well				0.5
Min. flow rate (gpm)	5	8	14.5	19.2
Min. input rate (Btu/h)	200,000	400,000	800,000	1,000,000

*Small establishments, at the minimum require hot water at 120°F equating to a 70°F temperature rise in winter (condensing heater flow rate of 5.3 gpm). In larger facilities, to stay on the conservative side a 90°F temperature rise is required for sizing the minimum input rate (4.1 gpm).

Storage Water Heater Sizing to Meet the After Hours Cleanup

Example: Hosing down the restaurant at 15 gpm requires 450 gallons of hot water over the ½ hour use phase. Specifications of storage heaters that meet this load at a 70°F temperature rise are listed below:

Standard Efficiency:
- Two 100 gal (300,000 kBtu/h) heaters 200 gal of storage and 420 gal recovery

High Efficiency:
- One 130 gal (500,000 Btu/h) heater 130 gal of storage and 410 gal recovery

- Two 100 gal (240,000 kBtu/h) heaters 200 gal of storage and 410 gal recovery

Figure 25. Pipe diameter guidelines.

It is important to note that sizing heaters for food safety reasons only protects the restaurant from running out of hot water during operating hours where food preparation and dish sanitation are the priorities. This is not an all-inclusive water heater sizing guideline as cleaning practices can heavily sway these requirements, ballooning the minimum recovery rate of storage heaters. For example, end-of-day

Figure 26. Condensing storage heater displaced volume of 14 ft³, 31 ft³ for non-condensing. Photo Credit: Rheem

Figure 27. Tankless installed over mop sink.

Figure 28. Tankless heaters, controller and 200 gallon storage tank.

cleaning may include a wash down that can consume 450 gallons of hot water in a half hour (Figure 25). Only the largest condensing heater designed for a restaurant application is able to provide 450 gallons of hot water in a half hour. It is best to add additional storage capacity by installing a second heater to make sure hot water is available and to protect against thermal shock (of the heater). The examples for sizing heaters to meet the late night cleaning demand are estimates only.

Tankless heaters are not affected as much by heavy cleaning periods as they inherently limit the peak flow. But cleaning performance may be affected if the cleaning staff is trying to do multiple tasks at the same time. For example, hosing down floors and filling up a 3-comp sink at the same time may demand a flow of 30 gpm. But four tankless units providing a total capacity of 16 gpm must split the available hot water between the two tasks. The installation of a high pressure, low-flow spray nozzle to wash the floors is a viable solution. Staggering cleaning tasks at the end of the night is a good practice, particularly for tankless heaters.

Space Requirements

If reducing water heater footprint is a design goal to maximize usable kitchen space, then specifying condensing storage or any type of tankless heater will support this goal. Condensing tank models require less kitchen space compared to standard-efficiency storage heaters rated at similar recovery rates. For example, the installed volume (including clearances between the heater and its surroundings) of a condensing model (130,000 Btu/h) of 14 cubic feet is less than half that of a standard efficiency tank (154,000 Btu/h) displacing 31 cubic feet (Figure 26).

Tankless gas water heaters are not Flammable Vapor Ignition Resistant compliant and as such, require a specified clearance to combustibles and non-combustibles. This effectively increases the displaced volume when installed indoors. In reality, however, the displaced volume of tankless heaters is less since manufacturers' guidelines for hazard and service-related minimum clearances may not be fully adhered to in the real world. Installing a condensing tankless unit on the wall above the mop sink (Figure 27) is a good use of space and the condensate from the unit can drain right into the mop sink (modified with a condensate drain) while saving energy and reducing operating costs. In full-service restaurants, there may be no appreciable space saving benefit to be gained by using multiple tankless heaters complete with circulation pump and storage tank (Figure 28).

Payback on High Efficiency Water Heaters

Site surveys by the FSTC show that most restaurants in California use conventional gas-fired storage water heaters with a rated thermal efficiency of 80%. This efficiency was used as the base case for a cost comparison with condensing storage heaters with a rated efficiency of 95%. A simple payback was developed using field-monitoring results generated by the FSTC. The analysis accounts for hot water and gas use, temperature rise and system efficiency in three typical restaurant segments, namely: large full service, small full service, and quick service. Operating cost, street price and installed cost of representative water heater models are imbedded in the analysis (Figure 29).

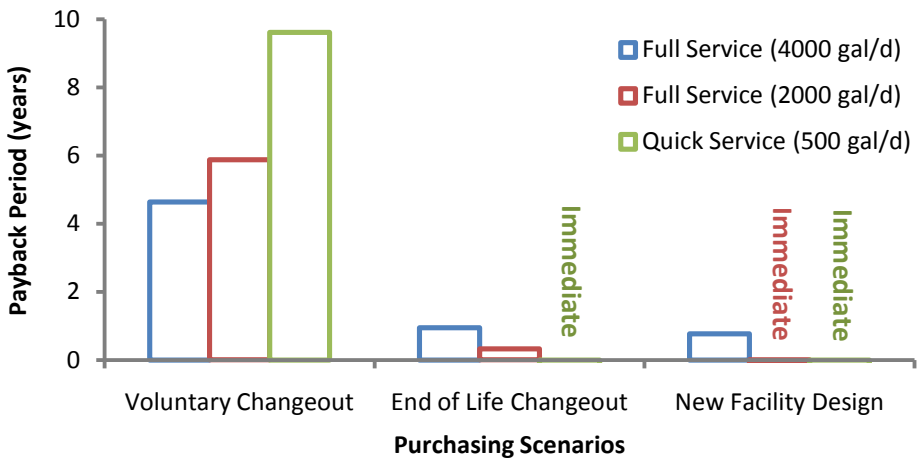
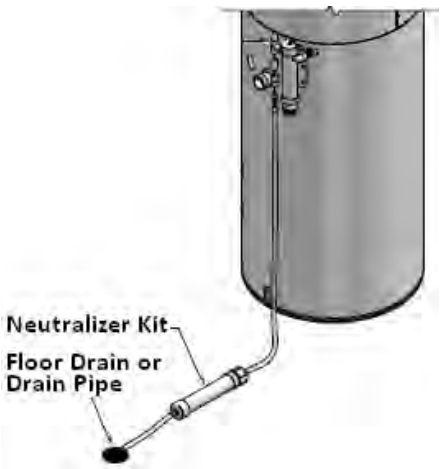


Figure 29. Simple Payback projections for condensing water heaters.

High-efficiency, condensing storage heaters installed in new facilities or as replacement units in existing restaurants reflect a payback of one year or less. In new installations, condensing heaters may be less expensive to install than standard efficiency heaters, presenting an immediate payback. Even for a voluntary change out in a large full-service restaurant, the payback period is in the four-year range. You may wish to consider changing out an inefficient water heater immediately as having to change out the water heater in an emergency may significantly increase the installed cost. If you factor in the reduced liability of a voluntary or planned change out, a longer payback period can be viewed in a more favorable light. But regardless, it is a sound investment to specify condensing water heaters.



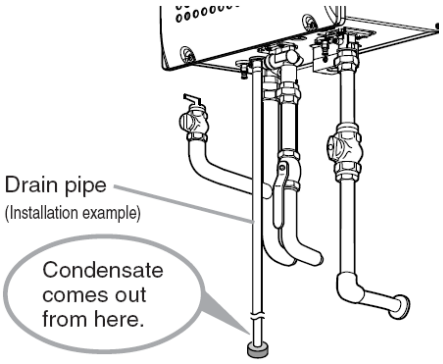


Figure 30. Condensate pipe and drain for storage and tankless heater.
Photo Credit: Lochinvar, Noritz

Installation Considerations

High-efficiency water heaters condense water vapor contained in the exhaust gases, thus producing liquid condensate as a byproduct. A pipe must be connected from

Figure 31. PVC venting on condensing tankless.
Photo Credit: Noritz

Figure 32. Stainless steel flue on storage heater.

the heater to route the condensate to a drain in proximity to the heater (Figure 30). Alternately, a condensate pump can be used to discharge the liquid to a remote drain. Unfortunately, this condensate is an acidic solution that may require treatment prior to disposal (depending on local codes). The acidic condensate can be treated with a basic substance in advance of the drain, typically calcium carbonate, to produce a more neutral solution that is acceptable to discharge into the drain pipe.

The venting costs (materials and installation) for condensing water heaters in new facilities is typically less expensive due to horizontal venting options that may be shorter and due to lower temperature exhaust (e.g., 120°F) that permit the use of plastic piping in certain applications (Figure 31). The venting costs for standard efficiency heaters may be higher because they require steel piping to handle the higher exhaust temperatures. Higher grade stainless steel must be used with standard efficiency tankless and with high input rate storage heaters that must comply with the ASME code (Figure 32). Less expensive galvanized steel can be used with smaller storage heaters.

Gas piping for tankless heaters is costlier than for a comparable storage heater as larger pipe sizes must be specified to accommodate the three- to four-fold increases in gas flow. However, there are benefits to multiple tankless heaters. They provide insurance in case one heater fails, eliminating the need to shut down the restaurant.

Maintenance Considerations

A large portion of the United States has moderate to very hard water which, if not treated, leads to mineral deposits in the heaters. Large swaths of densely populated regions in California have hard water with calcium carbonate concentrations greater than 121 mg/L [18]. Note: water hardness rating given on a regional level should not be used on the local level to make decisions – consult with the local water utility for hardness ratings before the design process.

Mineral deposits are detrimental to water heaters because they gradually coat heat exchanger surfaces, leading to reduced life of the unit due to hot spots and degradation of efficiency. Tankless heaters undergo more frequent heating cycles and have compact heat exchangers that are more sensitive to scale buildup that can restrict the flow of water. Therefore, they are more dependent on periodic maintenance, which usually requires flushing the heat exchanger with vinegar to remove the mineral deposits. Typically, this is not a do-it-yourself project because a pump is required for flushing, necessitating the assistance of a qualified technician.

Standard efficiency storage heaters also require scheduled maintenance to flush scale build-up in hard water locations. If not maintained periodically (depending on water hardness and hot water use), scale and sediment builds up at the bottom of the tank and around the base of the flue causes thermal efficiency loss, corrosion, lowered tank capacity and premature tank failure [19]. Anecdotal evidence suggests that maintenance is seldom done. However, storage heaters seem to be more forgiving when maintenance is neglected. Scale buildup may be even less of an issue with condensing storage heaters due to the design of the heat exchangers and location of the down-firing burners.

Warranty and Life Expectancy

Water heaters can burn out in a couple years if not maintained in high-volume restaurants, while in light-use facilities the life of the heater may extend to a decade or more. An advantage of a tankless heater is that one can replace a leaky heat exchanger inside the unit instead of replacing the entire storage heater. The more frequent maintenance of a tankless unit needs to be weighed against the less frequent, but complete replacement of storage heaters.

Water Temperature: A Balance of Cost and Safety

It is common to find hot water temperatures in restaurants elevated above 140°F. A simple energy-saving measure that reduces heat losses from the tank and piping is to turn down the thermostat, as long as water temperatures remain in the 120°F to 140°F range. If the temperature is turned down further, this practice has two limitations: 1) failing to meet the sanitary needs regulated by health departments and 2) not mitigating the risk of water-borne infections, namely Legionnaires' disease. In commercial kitchens, the pre-rinse station is one area where water aerosolizing does occur, which could be a potential risk if water temperatures fall below 120°F. However, no cases of Legionnaires' disease from domestic water heating systems in foodservice facilities have been documented. Fortunately, the disease is hard to contract by healthy individuals. For facilities like restaurants where it is less common for people to be susceptible, maintaining a minimum hot water temperature of 120°F in the water heating system is considered safe.

Background on Legionella

The bacteria Legionella can be present in public water supply systems and can grow in any water system that is not properly maintained. Legionella is contracted through inhalation of aerosolized water (water droplets) contaminated with the bacteria and may be found in domestic hot-water systems, cooling towers, fountains and even in freshwater ponds and creeks. In the United States, it is estimated that the disease affects between 8,000 to 18,000 individuals a year, yet only 1675 cases on average are reported to the Centers for Disease Control and Prevention suggesting that under-diagnosis or under-reporting is common. Major outbreaks are rare but are usually traced back to its source and documented. Commonly cooling towers and whirlpool spas are the usual culprits but Legionella has been found with less frequency in evaporative condensers, air-scrubbers, supermarket misters, potable water and decorative fountains. Note: 80% of the cases are independent cases that are rarely traced back, leaving a void to the contaminated source [20].

Solar Thermal and Heat Recovery Systems

Figure 33. Refrigerant heat recovery tank and compressor/condenser unit.

Figure 34. Solar thermal collectors.

"Free heating" technologies utilize renewable energy or waste heat to preheat water and thereby minimize the use of purchased energy by the hot water system. The most promising of these technologies for commercial food service include refrigerant heat recovery and solar thermal systems.

A refrigerant heat recovery system (RHRS) works by harvesting the super heat that would otherwise be rejected by the condenser in a refrigeration cycle (Figure 33). A RHRS can be added to walk-in coolers and freezers, ice machines, and air-conditioning systems. The recovered heat is transferred to the supply water by a refrigerant-to-water heat exchanger. Typically, a RHRS preheats the supply water in a storage tank that is installed upstream of the water heater. In addition to providing free water heating, manufacturers claim that the RHRS prolongs compressor life, enhances condenser performance and reduces refrigeration costs. The RHRS is a technology that offers a low payback period, but additional site-monitoring studies are needed to document their saving potential in restaurants.

As a renewable resource, solar water heating holds tremendous potential to preheat incoming water (Figure 34). Solar water heaters can be great complement to hot water systems in restaurants. Low-profile integrated collector/storage systems and thermosiphon systems operate passively without pumps, controls, thermostats, sensors, wiring or electricity. They are typically more reliable and are installed as a preheater in advance of the primary water heater. They are the lowest cost systems and store water on the roof, which minimizes the size of the water heating system in the kitchen. On the other hand, an active solar water heater is a long-term investment and may function as the primary water heat source on sunny days with a backup water heater installed to handle cloudy days and peak use periods. Demonstration and monitoring projects with existing and new restaurants are needed with both active and passive solar water heating systems.

Summary

The water heating system in a restaurant is just that—a system! Having an understanding of the quantity of water being heated, how much energy is consumed, how the water is distributed and where it is being used can provide the designer with a whole-system perspective. This wisdom may help the designer avoid potential pitfalls of system design. For example, specifying low-flow aerators on all hand sinks will certainly save (hot) water, but without taking the hot water wait time into account, there may be poor delivery performance unless an optimum distribution system is considered.

Figure 35. Easy to read water heater touch screen controls.
Photo Credit: A.O. Smith

Next Generation Systems

The standard storage water heater in restaurants and small commercial facilities incorporates rudimentary setpoint control with no visual temperature validation. The more advanced controls on new generation condensing storage heaters and boilers have central processing units and touch-screen displays that allow precise control of the heater (Figure 35). The smart water heater of the future could provide onsite and offsite monitoring, reporting daily, monthly and yearly water and energy use profiles. It could have the ability to alert the operator (by email) if hot water has been overdrawn or to identify hot water leaks or waste.

A new generation of dishwashers with integrated exhaust air and drainwater heat recovery, currently available in Europe, may soon be available in the U.S. These dishwashers are plumbed to the cold water supply line and use waste heat recovery to preheat the supply water and bypass the hot water distribution system entirely (Figure 36). Foremost, this technology saves energy. It also simplifies and reduces the length and diameter of pipes in distribution systems, reduces the size and output required from a central heater and is a big step towards net-zero-energy water heating in restaurants.

Figure 36. Diagram of integrated exhaust air and drainwater heat recovery in a door-type dishwasher.
Photo Credit: Winterhalter

Top Design Tips

A summary of the top design tips are displayed in Figure 37. Some of these design tips are incorporated in Design Example 1 for a full-service restaurant, saving approximately 50% of the energy and water used over a typical hot water system.

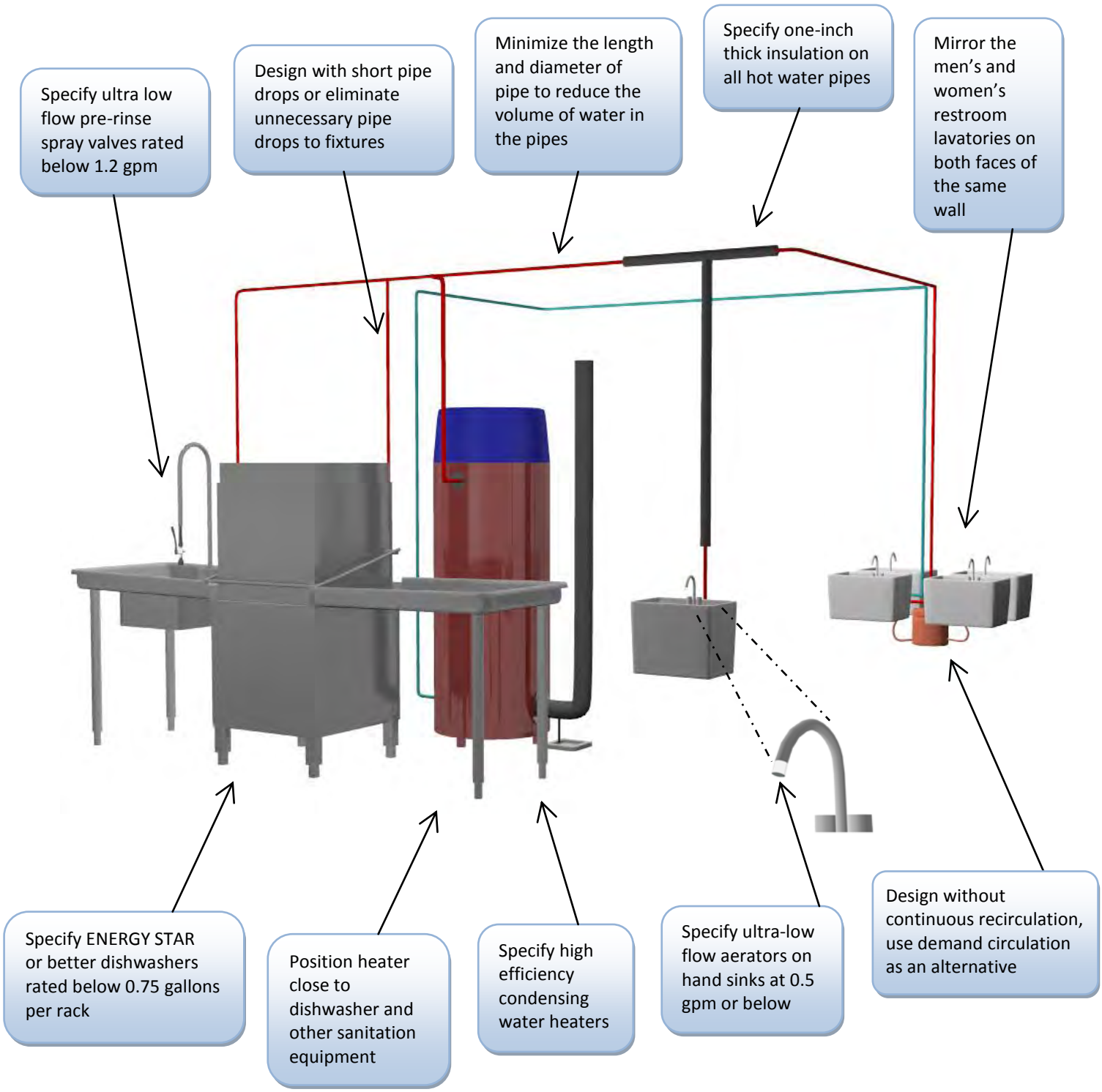


Figure 37. Top hot water system design tips for efficiency.

Design Examples

Hot water system design examples are based on actual kitchen layouts; they illustrate the design process and the potential for optimization. Each example starts with a conventional design as the base case. Design options for better water delivery performance and improved efficiency are presented. Each example concludes with best-case option that may be achieved through best-in-class equipment and practices. The focus of the full-service restaurant design example is on quantifying system efficiency and utility costs, reducing hot water use and introducing optimized distribution systems. The quick-service restaurant design example focuses on optimized distribution systems to reduce hot water wait times at fixtures.

Disclaimer: The design examples are for illustration of design concepts only. Application of the concepts to particular designs may result in savings that are lower or higher than those depicted in the examples. Close coordination with local code officials, manufacturers, engineers and contractors is recommended for all kitchen hot water system projects.

Design Example 1: Full-Service Restaurant

The hot water system diagram in Figure 38 consists of two storage water heaters with a recirculation pump that circulates water through the hot water supply line to the dishwasher and pre-rinse station, bar, restrooms, kitchen and back to the heaters through the return line. The hot water-using dipper well is the only aspect of this diagram that is atypical of most restaurants. However, this design example was based on an actual full-service restaurant that had been monitored by the FSTC [13]. The FSTC does not advise the use of dipper wells, especially hot water-using wells.

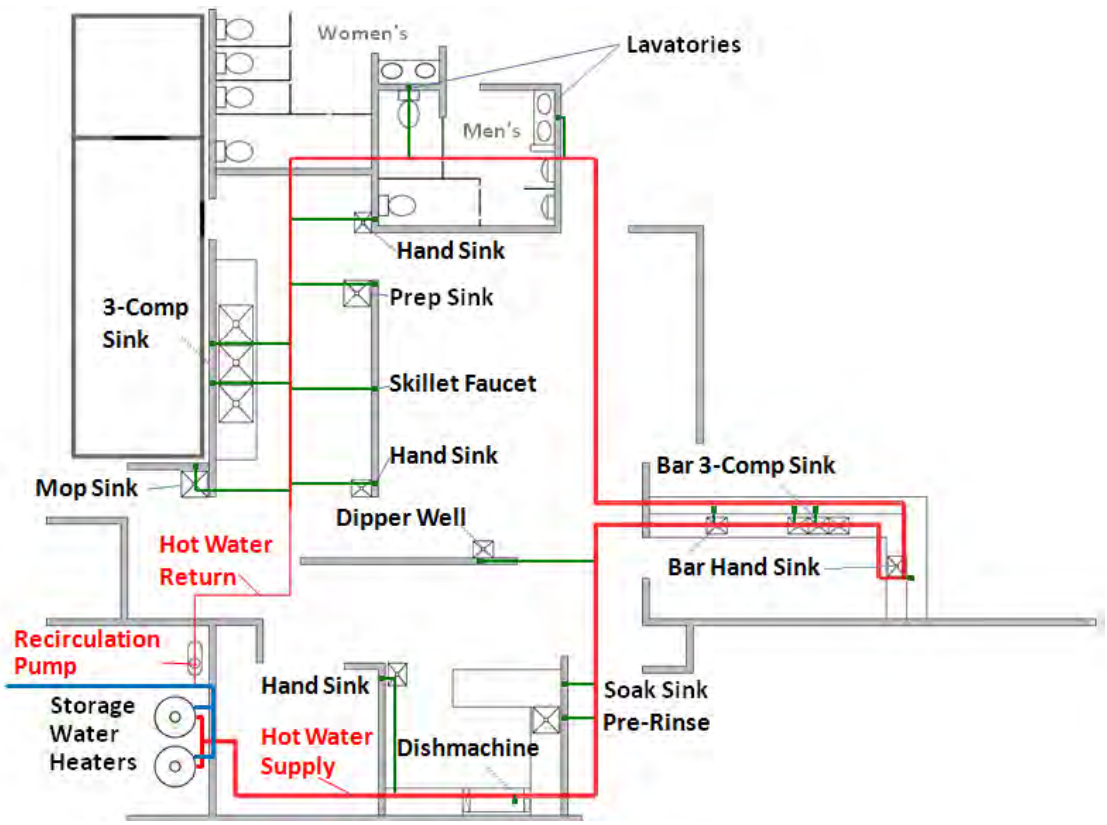


Figure 38. Conventional hot water system in a full service restaurant and bar.

The base configuration will be referred to as the *Business as Usual* scenario. In total, four system designs are developed. They are summarized in Table 7 to highlight the range in efficiency and performance that can be achieved through system optimization.

Table 7. Two conventional system designs and two optimized system design scenarios.

System Components	*Conventional System Designs*		*Optimized System Design Scenarios*	
	Business as Usual	**Regulatory Code as Threshold**	**Dabbling in the Efficiency Pool**	**Waist Deep in Efficient Design**
Aerators	2.2 gpm*	0.5 gpm	0.5 gpm	0.375 gpm
Pre-rinse spray valve	2.6 gpm*	1.6 gpm	1.15 gpm	0.64 gpm
Conveyor dishwasher	1.10 gal/rack	0.95 gal/rack	0.70 gal/rack	0.35 gal/rack**
Circulation system	Recirc pump 24 h/day	Recirc w/ timer 14 h/day	Recirc w/ timer 14 h/day	Demand circulation
Pipe insulation	No insulation*	½"-thick insulation partial installation*	1"-thick insulation on trunk line	1"-thick insulation throughout
Water heater	Min. recovery 445 gph 80% TE*** (2) 300,000 Btu/h	Min. recovery 445 gph 80% TE (2) 250,000 Btu/h	Min. recovery 340 gph 95% TE (1) 300,000 Btu/h	Min. recovery 295 gph 95% TE (2) 120,000 Btu/h

* Measure does not meet state or federal energy efficiency regulations
**With exhaust air heat recovery unit
***TE = rated thermal efficiency

Business as Usual (No Efficiency Upgrades)

Two 300,000 Btu/h standard efficiency heaters are specified to meet the 2,500 gal/d average hot water load. The water heaters are sized for 640 gallons (recovery rate), which is larger than the minimum hourly recovery of 445 gallons based on the water heater sizing guidelines on page 20-21. This added recovery capacity is to ensure hot water availability when heavy wash down of the restaurant takes place. In the distribution system, the trunk or recirculation line (shown in *red* on Figure 38) is 220 feet in length and is modeled without any pipe insulation. The recirc pump operates 24 hours per day and contributes to a system efficiency of only 68%.

The layout of this distribution system and appliances has factors that contribute to heat loss and system inefficiency. The first is a 52-feet section of 1¼-inch hot water supply piping from the bar to the lavatories. Unfortunately, this extends the length of the recirc line and associated heat losses. The heat loss from this section of bare pipe (using ASHRAE's heat loss data for bare copper pipe [21]) is estimated at 56,000 Btu/d, which equates to burning 80,000 Btu/d of natural gas (approx $0.90/d) to simply reheat the water that is returned to the tank. The second deficiency is the position of the mop sink and 3-comp sink at the end of the hot water supply line. When designing a distribution system, the diameter of the supply line must be sized to meet the flow rate requirements of all sinks and equipment. In this example, the diameter of the pipe starts at 1¼-inches for the first two thirds of the loop, narrows down to 1 inch before the lavatories and ¾-inch before the 3-comp sink before reaching the ¾-inch return line. Placing the 3-comp and mop sinks, each requiring up to a 15 gpm flow rate, at the end of the loop requires the extended use of 1¼-inch diameter piping. The larger the diameter, the more volume of hot water in the pipe and the greater the heat loss (and cost of pipe). Note that the end-use equipment and sinks modeled in this example represent inefficient water-using components still found installed in new facilities.

Regulatory Code as Threshold (minimum efficiency improvements)

In the *Regulatory Code as Threshold* system design, the focus is on a low-cost hot water system that attempts to meet minimum regulatory standards. Aerators and spray valves have been upgraded to models meeting the minimum federal energy efficiency guidelines. A conventional 0.95 gallon per rack high-temperature conveyor dishwasher with a 40°F electric booster heater (a low cost option) is specified. Together, these three upgrades save an estimated 590 gal/day and offer immediate payback, as there is no appreciable cost premium. An inexpensive time clock is specified to automatically turn off the recirculation pump after store closing, effectively reducing run time by 10 hours per day. Although 1-inch-thick pipe insulation is specified in the blueprints and required by code, unfortunately ½-inch-thick insulation is typically found. Still using standard efficiency heaters, the overall system efficiency is raised to 70% with the added insulation and timer, while the gas consumption is reduced by 30%, primarily due to the reduced hot water use.

Reducing the flow rate of aerators installed at hand-washing sinks from 2.2 gpm down to 0.5 gpm to meet code can be problematic as the hot water wait time increases significantly with this reduced flow rate. At the woman's restroom sinks (Figure 38), the branch leading from the trunk line measures 12 feet in length. Assuming ¾-inch diameter "type L" copper piping leading to a 2 ft. twig with ½-inch diameter piping, 0.32 gallons of room-temperature water must be purged at the first usage of the day. The estimated wait time for different aerators is illustrated in Figure 39. In the base distribution system design with a 2.2 gpm aerator installed, it takes 9 seconds before hot water in the recirc line reaches the tap on the first use. With a 0.5 gpm aerator installed in the *Regulatory Code as Threshold* scenario, the wait time increases to 39 seconds.

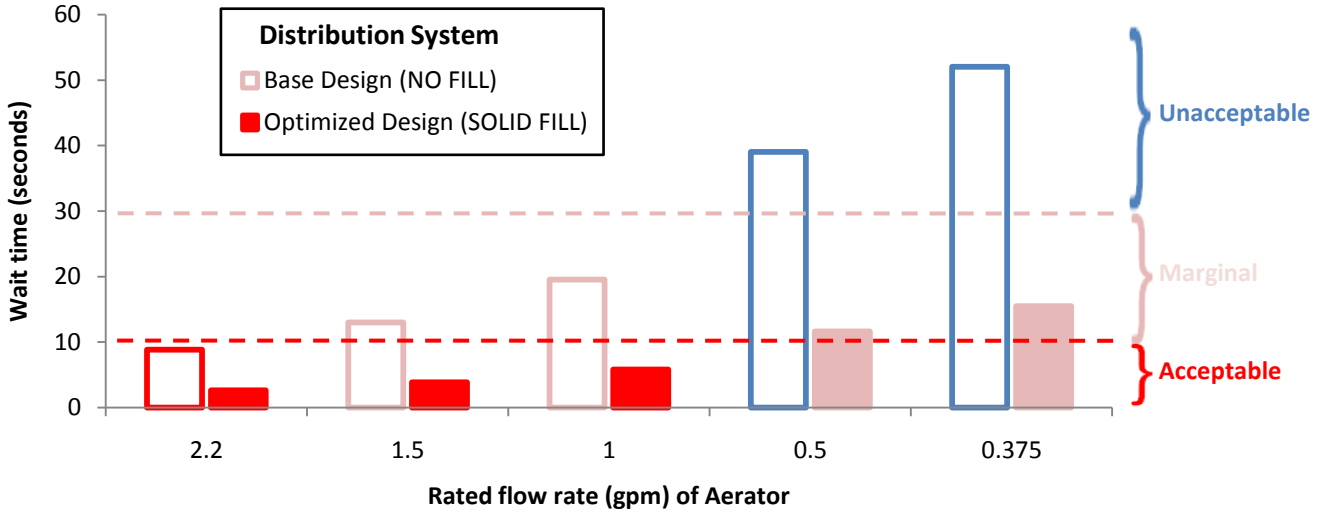


Figure 39. Hot water wait times at lavatory sinks with the base and optimized distribution system design.

The user at the hand sink is probably not going to wait more than 10 seconds for hot water and will elect to wash hands with the room-temperature water. This practice negatively impacts the customer experience. It may lead to aerators being damaged or removed in order to reduce the wait time. In new restaurants, one of the common retrofits

after start up is to replace the 0.5 gpm aerators with 2.2 gpm models. An alternative to removing the low flow aerators is to install a demand circulation system (page 10). This will automatically purge the room-temperature water from the branch lines and deliver water to the tap in under 10 seconds (even with a 0.375 gpm aerator installed). In review, it is easy to specify insulation thickness and aerator flow rates in the design stage to meet energy efficiency regulations, but difficult to hold spec during construction and facility operation.

Dabbling in the Efficiency Pool

In the *Dabbling in the Efficiency Pool* scenario, the design goal is to reduce utility costs and meet all codes and regulations by investing in more efficient equipment. With end-use equipment, hot water use is lowered even further by specifying a lower-flow pre-rinse spray valve. The dishwasher water use is lowered by specifying an ENERGY STAR qualified high-temperature model rated at 0.7 gallons per rack. Compared to the *Business as Usual* case, by simply reducing the hot water use at the dishwasher, the calculation for maximum hourly hot water demand or minimum recovery rate requirement of the water heater can be reduced from 445 to 340 gph.

The 0.5 gpm aerators must remain installed to sustain long-term hot water savings at the lavatory sinks. An elegant solution is to reconfigure the restrooms by mirroring the men's and women's lavatories and running the trunk line right over the top of the vertical branch pipe. This reduces the length of the branch line from 12 to 6 feet. Changing from two ¾-inch uninsulated branch lines to a single ½-inch line servicing all four lavatories improves hot water delivery performance by reducing the volume of water that periodically needs to be purged. This improves hot water delivery performance with a 0.5 gpm aerator from 39 seconds in the base distribution system design to 12 seconds in the optimized design (Figure 40). For most of the operating day, since four lavatories (instead of two) are plumbed to one line, the branch line will see twice the flow and the water in the pipe will cool down less frequently, further improving hot water delivery performance.

The need to oversize the water heater(s) to safeguard against wasteful cleanup practices, like using an open hose to wash down the kitchen, is eliminated by training staff to use proper equipment. Providing a low-flow (high-pressure) industrial-grade spray valve or a water broom for wash down is estimated to reduce hot water use at the mop sink by 100 gal/d. By specifying an ENERGY STAR qualified dishwasher and improving cleanup practices, the two 300,000 Btu/h standard efficiency heaters in the *Business as Usual* case (total recovery rate of 640 gph) are replaced with one 300,000 Btu/h condensing heater (recovery rate of 390 gph) that offers a higher operating efficiency and a lower capital cost (when compared to the two heaters). This design scenario specifies 1-inch-thick insulation on the recirc line. The measures in this scenario boost system efficiency to 85%. This is the first scenario that is fully compliant with new federal and state energy efficiency regulations.

Waist Deep in Efficient Design

In the *Waist Deep in Efficient Design* scenario, the operator has asked the designer to lay out the most efficient system while eliminating hot water delivery problems. A strategy to reduce wait time for hot water is to install a demand

circulation pump at the mirrored lavatory sinks to purge the room-temperature water to a dedicated cold-water return line (blue) without wasting water. A second system is installed at the bar (see Figure 40).

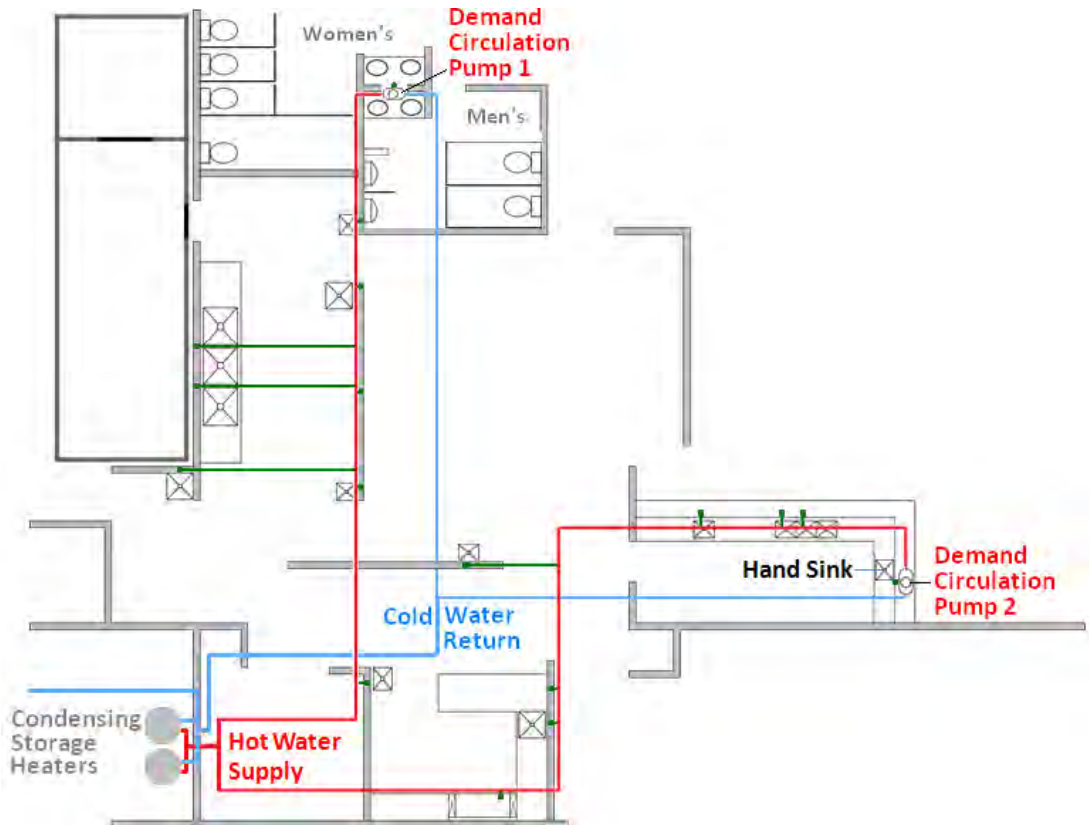


Figure 40. The distribution system of a full-service restaurant with demand circulation.

Combining demand circulation with a 0.375 gpm aerator, hot water will reach the tap within four seconds of someone activating the motion sensor placed in the hallway close to the restrooms. Although this strategy lengthens the branch lines leading to the mop sink and 3-comp sinks, it does not pose a delivery issue as faucets used for filling purposes flow at around 15 gpm. The trunk lines are rerouted directly over kitchen hand sinks and sanitation equipment in order to minimize the length of piping down to the fixture to 6 feet, further minimizing wait times to 12 seconds. Dropping the trunk line vertically could be combined with demand circulation to further reduce the length of piping leading to kitchen hand sinks and critical equipment, allowing for sub-10-second wait times. The need for continuous recirculation is eliminated.

One-inch-thick insulation is specified on all hot water piping including branches and twigs further reduces pipe heat loss. A benefit of insulation is that it triples the cool down time of water (from 140°F to a usable temperature of 105°F) in the pipes from approximately 20 minutes with no insulation to approximately 70 minutes with insulation [9] (mixing valves would need to be installed at the hand sinks to temper the hot water to 100 to 110°F for safe use). Tempering at the hand sink is preferred to tempering upstream at the heater, as it eliminates the need to install a separate distribution line to service the hand sinks. Tempering with a thermostatic valve at the point of use in

combination with demand circulation is a preferable strategy, as the additional temperature drop allowance from 140°F (instead of 120°F) to 105°F extends the cool-down time. Priming the lines with demand circulation at the beginning of the day takes approximately 30 seconds to displace 3 gallons of room temperature water in 70 feet of one-inch diameter piping. Insulation with a 35°F temperature drop allowance should maintain a usable hot water temperature in the lines for the rest of the day. If demand circulation was not installed, providing hot water to the lavatories at the beginning of the day would take 8 minutes if 0.375 gpm aerators are installed.

Similarly, the second demand circulation system eliminates the need for a continuous recirculation system to the dishwasher and bar. Interestingly, eliminating continuous recirculation improves the operating efficiency of the condensing water heaters due to temperature stratification in the tanks, which increases the efficiency of the counter flow heat exchange. Therefore, demand circulation and comprehensive insulation, coupled with the increase in operating efficiency of the condensing heaters, increases the overall system efficiency by an estimated 5%, totaling a 20% efficiency gain. To improve system performance, several other distribution strategies are available (e.g., moving the water heater to a central location, addition of point-of-use electric heaters, rearranging appliances), but are not covered in this example. They are covered in Design Example 2.

The dishwasher, pre-rinse spray valve, and aerators on restroom and kitchen hand sinks were replaced with best-in-class models, saving an estimated 1180 gallons of hot water daily from the *Business as Usual* case. Table 8 shows the [hot] water saving potential of each design scenario.

Table 8. Daily hot water use for each design scenario.

System Components	Estimate of Use	Business as Usual		Code as Threshold		Dabbling in the Efficiency Pool		Waist Deep Scenario	
Conveyor dishwasher	400 racks*	1.10 gpr	629	0.95 gpr	543	0.70 gpr	400	0.35 gpr	200
Pre-rinse spray valve	133 minutes**	2.6 gpm	347	1.6 gpm	213	1.15 gpm	153	0.64 gpm	85
3-comp sink	350 gallons		350		350		350		350
Utility, skillet, soak sink	100 gallons		100		100		100		100
Mop sink	20 minutes	15 gpm	300	15 gpm	300	10 gpm	200	10 gpm	200
Dipper well	600 minutes	0.5 gpm	300	0.5 gpm	300	0.5 gpm	300	0.5 gpm	300
Hand sinks	250 washes***	2.2 gpm	183	0.5 gpm	42	0.5 gpm	42	0.375 gpm	31
Lavatory sinks	400 washes***	2.2 gpm	293	0.5 gpm	67	0.5 gpm	67	0.375 gpm	50
Total Hot Water Use (gal/d)			**2500**		**1910**		**1610**		**1320**

*Daily use = (number of racks) x (conveyor loading efficiency of 70%) + (one wash tank fill)
**20 seconds per rack pre-rinse
***20 seconds per hand wash

The recovery rate in the *Waste Deep* scenario is reduced to 295 gph allowing for the specification of two 120,000 Btu/h condensing heaters that cost less than one 300,000 Btu/h heater and provide a level of redundancy. For complete redundancy, two 200,000 Btu/h condensing heaters could be installed, each providing a recovery rate of 255 gph. From the worst to the most efficient design scenario (Figure 41), a 64% natural gas cost savings, a 47% electricity savings, and a 47% savings in water and sewer bills is demonstrated.

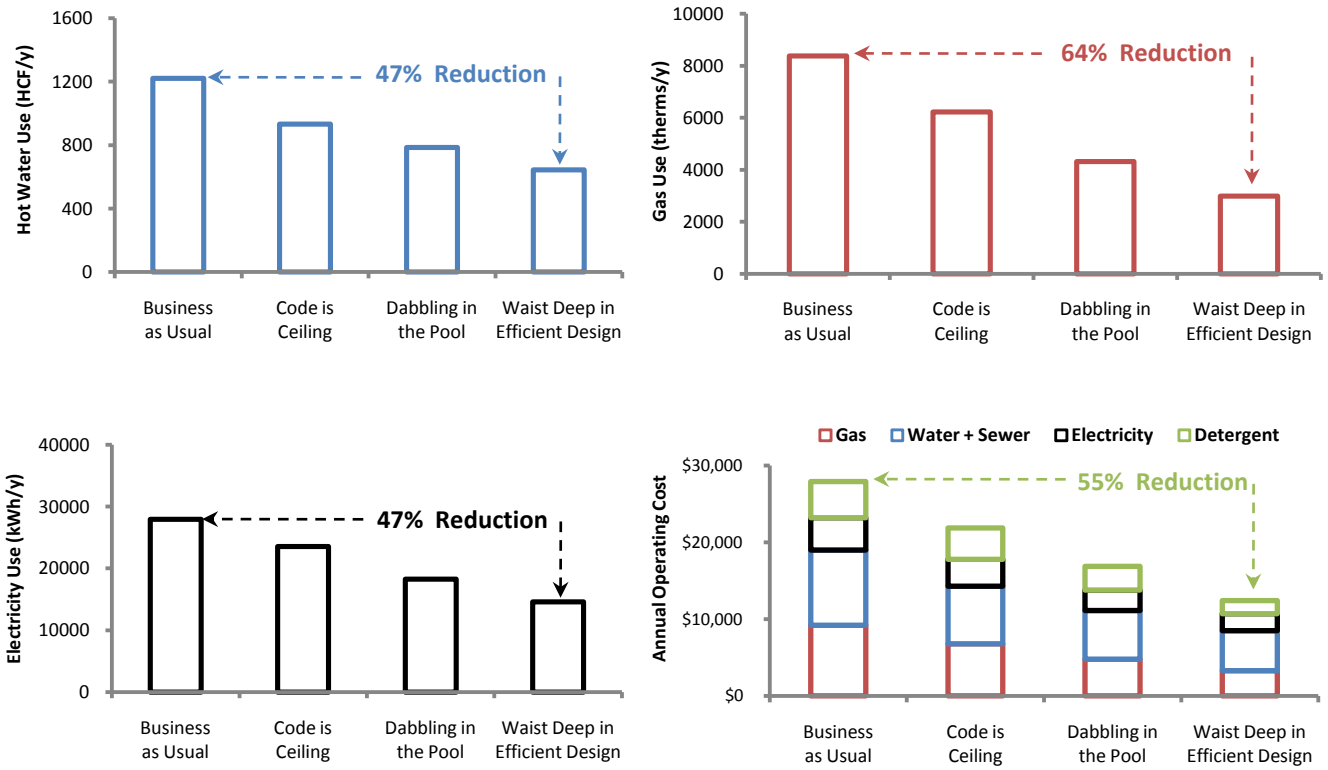


Figure 41. Gas, electricity, hot water use reductions and associated annual savings.

In summary, annual operating cost is reduced by 55%, saving $15,400 per year in the most efficient scenario from the *Business-as-Usual* case (Table 9), while improving hot water wait times. In analyzing cost savings from reducing hot water use or making system efficiency improvements separately (from the worst- to best-case scenario), the savings associated with water use reductions is estimated at $14,200 per year. The savings associated with just improving the system efficiency is estimated at $2,400 per year. This illustrates the importance of reduced hot water use for energy, water and overall cost savings.

Table 9. Annual operating costs associated with the four design scenarios.

System Components	Business as Usual	Regulatory Code as Threshold	Dabbling in the Efficiency Pool	Waist Deep in Efficient Design
Hot Water Use (gal/d)	2500	1910	1610	1320
Temperature Rise (°F)	75°F	75°F	75°F	75°F
System Efficiency	68%	70%	85%	90%
Gas Use (therms/year)	8380	6220	4320	2990
Electricity Use (kWh/year)	27570*	23310*	18040*	14580**
Gas Cost	$9,200	$6,800	$4,800	$3,300
Water + Sewer Cost	$9,800	$7,500	$6,300	$5,200
Electricity Cost	$4,100	$3,500	$2,700	$2,200
Dishwasher Detergent Cost	$4,700	$4,100	$3,100	$1,700
Total Operating Cost	**$27,800**	**$21,900**	**$16,900**	**$12,400**
Annual Savings		**$5,900**	**$10,900**	**$15,400**

*Includes electricity used for the recirculation pump and electric booster heater with 40°F temperature rise, 97% efficiency
**Includes electricity used for the demand circulation pump and electric booster with 58°F temperature rise, 97% efficiency

Design Example 2: Quick-Service Restaurant

From the perspective of a quick-service restaurant owner, the design priorities are to minimize both the footprint of the water heater and its installed cost, while meeting food safety regulations. Factors typically overlooked include the operating efficiency of the primary water heater and the customer experience at the hand-washing sinks. This design example demonstrates methods to reduce the hot water wait time, minimize the heater footprint and lower the purchase and installation costs of the distribution system. The additional funds saved may be used to help offset the costs of higher-efficiency heaters or distribution system components. In *Configuration A*, illustrated in Figure 42, is the layout of a conventional hot water system for a quick-service restaurant.

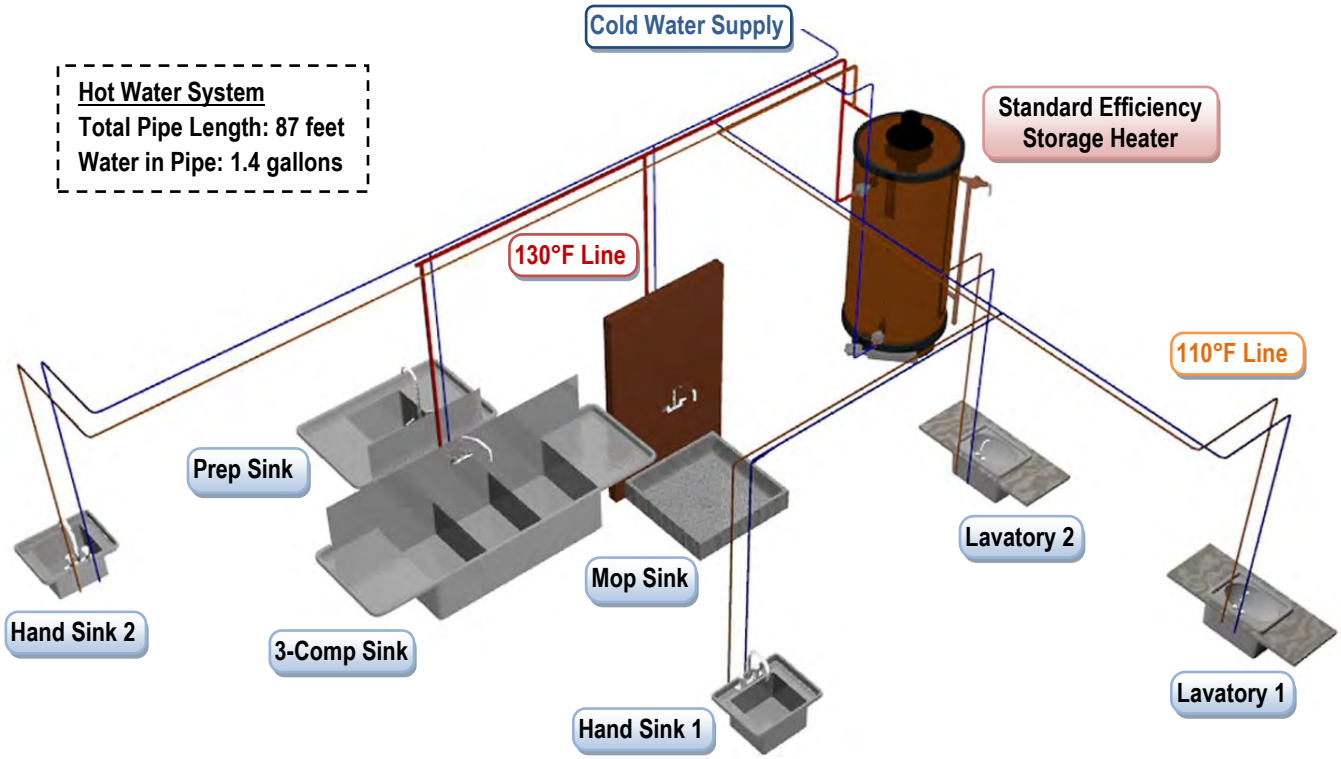


Figure 42. Configuration A: Hot-water-system design of a conventional quick-service restaurant.

Hot water is delivered from the heater (at a set temperature of 130°F) directly to the 3-comp, mop and utility sinks. A central mixing valve installed near the outlet pipe of the heater provides 110°F water to all hand sinks and lavatories. The design specifies ¾-inch thick insulation on all hot water pipes. A recirculation system is not required as the distribution line lengths of 30 feet for the hot water and 57 feet for the tempered water are within maximum guidelines of 60 feet.

The first issue with this system is elevated water heating costs due to the standard efficiency heater. The second performance issue relates to the extended hot water wait times at hand sinks and lavatories, particularly when specifying low-flow aerators. The wait times are based on operation at the start of the day or whenever use is infrequent throughout the day causing the 110°F water line to cool to room air temperature. To estimate the wait time at each hand-washing sink, the volume of water in the pipes in between the heater and each individual faucet has to be quantified. The results show that the volume of water that has to be purged (aerator flow rate of 0.5 gpm) ranges from 0.38 gallons to 0.45 gallons. Wait times modeled for *Configuration A* ranges from 45 to 55 seconds (Figure 43). The wait times are unacceptable because users will not wait for hot water and will choose to wash hands in the flowing room-temperature water. From an overall system efficiency standpoint at all hand washing sinks, the users will ask for but won't receive hot water for a large part of the operating day, meaning that the overall system efficiency is very low (where efficiency is defined as the hot water delivered divided by energy consumed by the water heater).

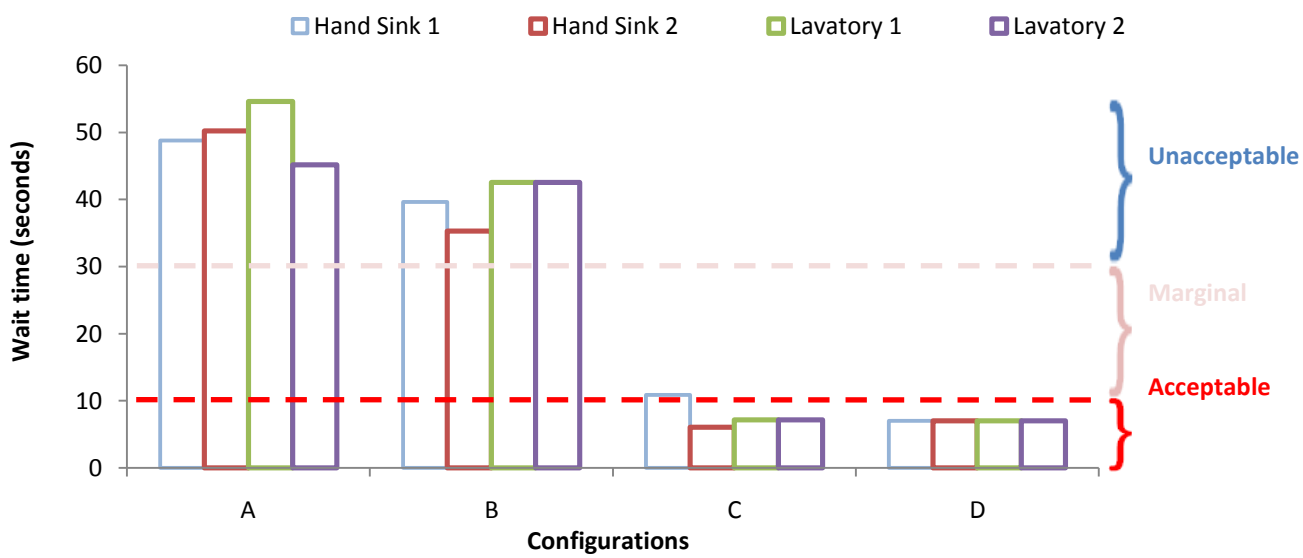


Figure 43. Estimated initial wait time for hot water at hand washing sinks.

In *Configuration B*, illustrated in Figure 44, the standard efficiency storage heater (80% T.E.) is replaced with a 199,000 Btu/h standard efficiency (82% T.E.) tankless heater. This tankless model has a lower installed cost and saves kitchen space. The heater is installed on the wall above the mop sink, further increasing usable kitchen space. Furthermore, it is centrally located in the kitchen next to a cluster of sanitation sinks. The generation of hot water is now closer to points of use resulting in shorter distribution lines that reduces the amount of copper piping, insulation material, and associated installation costs. However, its efficiency is not much higher than the standard efficiency storage heater and thus does not reduce the gas consumption significantly.

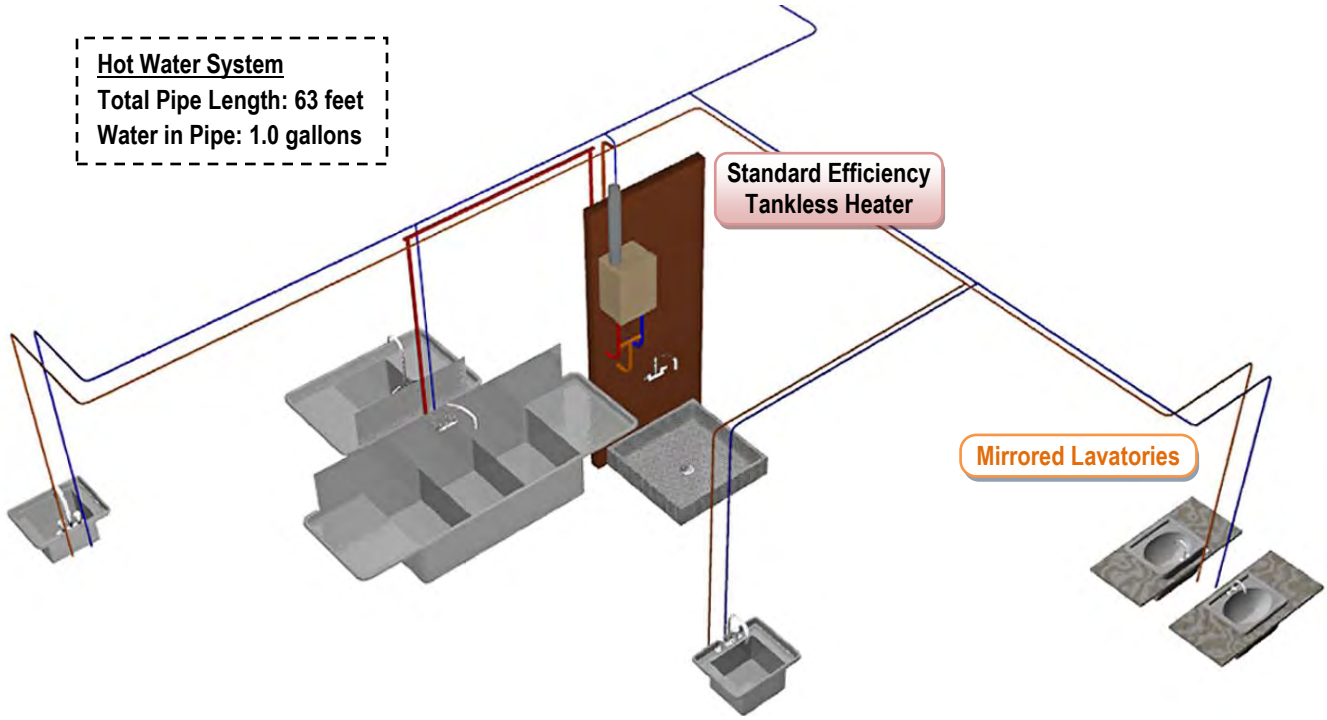


Figure 44. Configuration B: Compact system design.

In this configuration, there is one gallon of hot water being stored in the pipes that can cool to room temperature. Thus, less water needs to be purged, reducing wait time at the hand-washing sinks and improving system performance. The second change to *Configuration B* involves relocating the lavatories to a common wall. This allows for a single branch pipe to lead from the tempered water line down to both fixtures. This further reduces the distribution line length and doubles the frequency of hot water flow through the branch, improving the probability that water is hot for the next user in either lavatory. A potential operational problem is that the 200 kBtu tankless heater can only flow 5.2 gpm at a 65°F temperature rise. Therefore, filling the wash sink of the 3-comp sink with hot water would take approximately 3 times longer than it would take with the storage heater.

Configuration C, shown in Figure 45, is designed to significantly reduce wait times at hand sinks and reduce the fill time at the 3-comp sink. To achieve the latter, two high-efficiency condensing tankless heaters are specified, increasing the peak flow rate (at a 65F temperature rise) to 11.5 gpm from the 5.2 gpm in *Configuration B*. The additional heater provides a safety net should one of the heaters fail. To improve delivery performance at hand sinks, two strategically placed demand-circulation pumps at the furthest hand sinks (Sink 2, Mirrored Lavatories) effectively lowers the wait time to ten seconds or less. An effective passive strategy to lower the weight time at Hand Sink 1 is to reroute the tempered line to minimize the length of the connecting twig and reduce pipe diameters. Since the demand pump placed at the mirrored lavatories ensures that there is hot water in the main distribution line, the wait time is reduced from 43 seconds in *Configuration B* to only 11 seconds in *Configuration C*. This configuration is a balance of maximizing performance and minimizing operating costs.

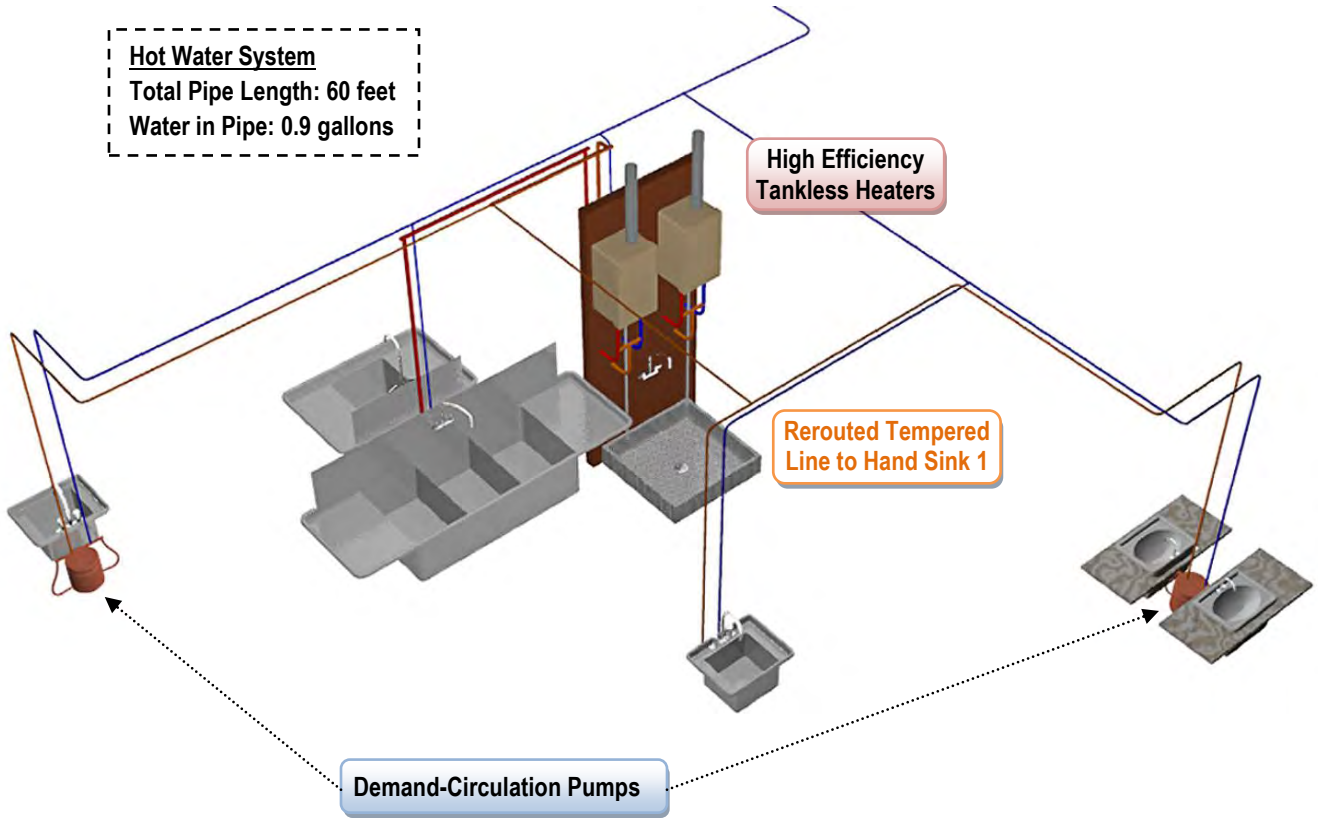


Figure 45. Configuration C: Demand-circulation pump based system design.

Configuration D, shown in Figure 46, eliminates one of the tankless heaters and completely removes the tempered supply line to all hand-washing sinks by incorporating small, on-demand electric tankless heaters. These heaters are installed on the cold water line. A small electric heater is located under each hand sink and a larger capacity electric heater is placed under the mirrored lavatories. This hybrid water heating system, with a central gas heater and decentralized electric heaters, reduces the length of the hot water distribution system from *Configuration A* by 75% (from 87 to 19 feet) and reduces the volume of hot water in the pipes from 1.4 to 0.4 gallons.

The electric heaters will generate and supply hot water to the tap within seconds, depending on the model selected. Some tankless electric heaters have the capability to function at flow rates as low as 0.2 gpm. In this case, the installation of a 0.375 gpm aerator on the faucet would produce water and energy savings while easily satisfying the user's desire for hot water delivery in less than 10 seconds. Furthermore, since all the hand sinks are disconnected from the central heater, the full water heating capacity of the tankless unit can be dedicated to one task at a time, such as filling the 3-comp sink. The distribution system in this configuration has a low installed cost. The cost savings for labor and materials associated with eliminating the tempered hot water line (partially or fully) offset the added capital and installation cost of the three point-of-use electric heaters.

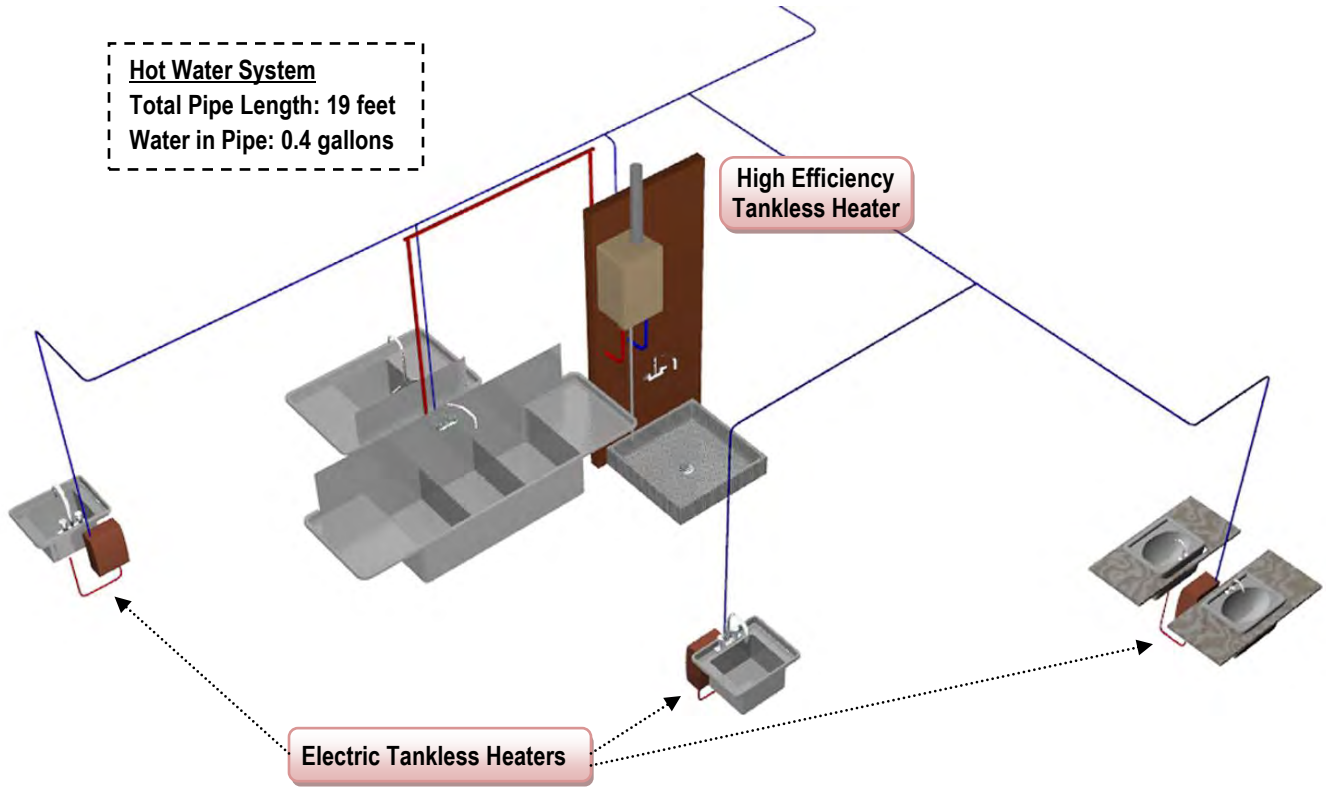


Figure 46. Configuration D: Hybrid system design.

To increase flow rate to the 3-comp sink without having to add a second heater, the installation of a low-cost freeze-protected solar preheating system that stores pre-heated water inside the solar collector on the roof in advance of the tankless heater was specified. In such a scenario, for a significant portion of the operating day, the solar preheating system will raise the temperature of the incoming supply water by 25°F, which further reduces the gas used for water heating. By reducing the average temperature rise required by the condensing tankless heater from 65 to 40°F, the maximum flow rate of the tankless heater is increased from 5.8 to 9.3 gpm of 130°F water.

To summarize, by changing system designs from *Configuration A* to *Configuration D*, the performance of the hot water system is greatly improved and the user will receive hot water at all the hand-washing sinks within ten seconds. Overall, the distribution is downsized and the total cost for the design, purchase, installation and operation of the system remained unchanged.

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Funding

Pacific Gas and Electric Company
P.O. Box 770000 MCN6G
San Francisco, CA 94177
(415) 973-0106
www.pge.com

Research Team

Fisher-Nickel, inc.
12949 Alcosta Boulevard, Suite 101
San Ramon, CA 94583
(925) 866-5265
www.fishnick.com

Research Labs

PG&E Food Service Technology Center
12949 Alcosta Boulevard, Suite 101
San Ramon, CA 94583
(925) 866-2844
www.pge.com/fstc

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