Design Guide

Advanced Water Heating for Foodservice

Improving Operational Performance of Commercial Foodservice Water Heating Systems

Advanced Water Heating for Foodservice will help you achieve optimum performance as well as water and energy efficiency in your commercial foodservice hot water system. The information presented is applicable to new construction and, in some instances, retrofit construction.

This design guide is intended to augment comprehensive design information published in previous design guides as well as the *Sizing Dishroom Ventilation* design guide.

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Introduction

This design guide discusses strategies to implement an advanced commercial foodservice hot water system that adequately meets all the hot water and sanitation needs of the facility while optimizing performance and water and energy efficiency.

Hot water systems can account for as much as half of a commercial foodservice facility's energy use as well as most all its water use, so proper hot water system design is paramount for the performance and operating cost of any facility.

This guide builds on previous design guides and adds information and lessons learned from lab and field research including projects on hot water distribution systems in commercial buildings, heat pump water heater demonstrations and hybrid condensing water heater demonstrations.

Background

Hot water is the lifeblood of restaurants. The hot water system provides the service of hot water to clean hands, wash dishes and equipment, and cook food. 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.

Conventional hot water systems for foodservice are comprised of three fundamental component groups: water heater(s) with or without storage, distribution piping, and an array of hot water-using equipment and fixtures.

Most water heaters installed in restaurants are storage (or tank) type units designed to hold water at a preset temperature until 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, use 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 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 equipment and fixtures. Otherwise, it can take minutes for hot water to arrive at its intended temperature at important fixtures such as hand sinks and dishmachines, jeopardizing proper sanitation. In foodservice, 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 pre-rinse operating equipment, dishmachines, and faucets. The use of this equipment varies throughout the service 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 floor hose for wash down can also be a major hot water draw.

Table 1 shows the typical hot water system costs of conventional designs for quick-service (QSR) and full-service restaurants (FSR). These designs conform to 20th century standards in that they use a continuous recirculation system fed by a standard-efficiency tank-type water heater, run their hot water systems at 140˚F, have either door-type or undercounter dishmachines (either high- or low-temperature rinse models) and deliver hot water to faraway points-of-use such as lavatory sinks. These costs consider the water and gas use of the hot water system at the water heater as well as auxiliary electricity usage, as would come from a high-temperature dishmachine with a booster heater and electric point-of-use heaters. The table below shows a QSR that uses a three-compartment sink to wash their kitchen wares and a FSR that uses reusable wares for the dining room and has two dishmachines (an undercounter at the bar and a door-type in the dishroom).

Table 1. Typical Hot Water System Use and Utility Costs for Restaurants.

	Water Use (gal/d)	Natural Gas Use (therms/y)	Electricity Use (kWh/y)	Water & Sewer Cost	Natural Gas Cost	Electricity Cost	Annual Utility Cost*
Quick-Service Restaurant (QSR)	500	1,600	-	$2,700	$1,800	-	$4,500
Full-Service Restaurant (FSR)	2,000	8,400	73,340	$10,900	$9,200	$13,900	$34,000

*Based on $11.25/HCF, $1.10/therm, $0.19/kWh

The savings potential for a best-in-class hot water system design is substantial. Best-in-class technologies include heat recovery dishmachines, low-flow pre-rinse spray nozzles, hybrid condensing water heaters, demand recirculation controllers and distributed heat generation through point-of-use heaters. In addition to saving energy, many best-in-class technologies can also save water. Table 2 details the utility costs for best-in-class systems as well as their savings over the conventional systems in Table 1. Since most hot water systems for foodservice are installed once and kept in place for decades, the lifetime savings for best-in-class systems can be in the tens to hundreds of thousands of dollars.

Table 2. Best-in-Class Hot Water System Savings Potential.

	Water Use (gal/d)	Natural Gas Use (therms/y)	Electricity Use (kWh/y)	Water & Sewer Cost	Natural Gas Cost	Electricity Cost	Annual Utility Cost*	Annual Savings over Conventional
Best-in-Class QSR	400	1,000	-	$2,160	$1,100	-	$3,260	$1,240
Best-in-Class FSR	1,600	5,500	63,870	$8,720	$6,050	$12,100	$26,870	$7,130

* Based on $11.25/HCF, $1.10/therm, $0.19/kWh

Design Path for Savings: A Systems Perspective

Specifying the hot water system in a reverse direction — starting with the hot water using equipment and moving back toward the water heater — is an effective process to achieve high system efficiency and performance. Reducing hot water consumption not only results in lower water and sewer costs, but it is the most effective way to reduce water heating energy.

1. **Specify Efficient Hot Water Using Equipment** — Start by selecting high-performance and efficient equipment and accessories. The best location in a commercial kitchen to achieve savings is the dishroom, which is where the largest portion of hot water is used. Reducing hot water use of the pre-rinse equipment and the dishmachine is the foundation of an optimized system. Consider specifying point-of-use heaters for far-off fixtures such as lavatory sinks and/or bar sinks, as well as an integrated heat recovery dishmachine, so that these fixtures can operate standalone with only cold-water supply connections. These equipment choices would size down the main water heater and distribution system, increasing overall system efficiency.

2. **Build an Efficient Distribution System** — Incorporate an efficient distribution scheme to minimize hot water delivery time. Key factors for distribution system efficiency and performance are (1) the placement of sinks and equipment in relation to the water heater, (2) the distribution pipe size, layout and insulation, and (3) the recirculation pump and controls. If a recirculation system is required, specify a properly-sized (low-flow or variable speed ECM) pump with smart controls that turn off the pump during hours of non-operation. This will reduce system heat losses and maintain higher water heater efficiency.

3. **Specify High-Efficiency Water Heater(s)** — To fully optimize the water heating system design, specify high-efficiency condensing water heaters or advanced heat pump water heaters when applicable. Before the hot water system design is finalized, consider integrating other pre-heating technologies such as refrigerant or drain water heat recovery, or solar.

4. **Commission & Maintain the System** — Proper installation and simple monitoring equipment can help commission and maintain the hot water system.

Equipment & Fixtures

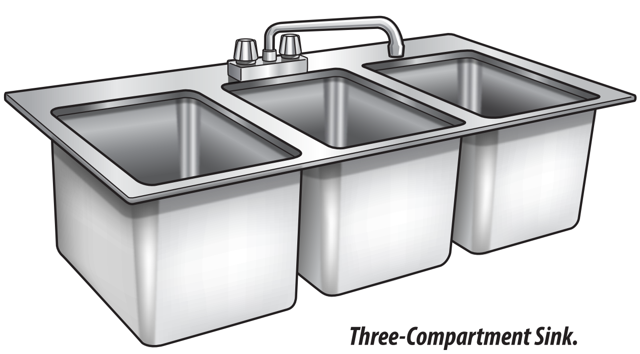
Selecting hot water-conserving equipment and fixtures is critical to an optimized hot water system in foodservice facilities. These are the only parts of the system that regularly interface with staff and are the easiest to remove and replace — namely the dishmachine, the pre-rinse spray valve, and the aerators on sink faucets. Efficient equipment or fixtures, as long as they offer equal performance to conventional models, will translate into long-term savings.

Pre-Rinse Operating (PRO) Equipment

The most important piece of pre-rinse operating equipment is the pre-rinse spray valve (PRSV). The pre-rinse spray valve is a handheld device designed for use with commercial dishwashing equipment and multi-compartment sinks for removing food residue off dishes and flatware. 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. Realizing that efficient spray valves have equivalent performance to inefficient or conventional higher flow counterparts, the federal government passed laws limiting their flow rate. Prevailing efficient pre-rinse spray valves (with flows in the 1 to 1.2 gpm range) have been proven in a wide variety of kitchen applications, encouraging manufacturers to develop advanced models that use less than one gallon per minute. A busy, full-service restaurant can clock three hours total of pre-rinse use per service day. At just one hour of use per day, a best-in-class 0.65 gpm spray valve can save **70 therms** and **$260 annually** when compared to a federally regulated 1.2 gpm spray valve.

The pre-rinse spray valve is usually the only piece of pre-rinse equipment installed in most quick-service and full-service restaurants, but it does not tell the whole story for large, cafeteria-style dishrooms. Corporate campuses, hotels and educational facilities can use scrappers, disposers and troughs that can significantly contribute to an operation's hot water consumption. The following pieces of equipment are typically only suitable for operations with a very large throughput.

Pre-Rinse Spray Valve (PRSV)

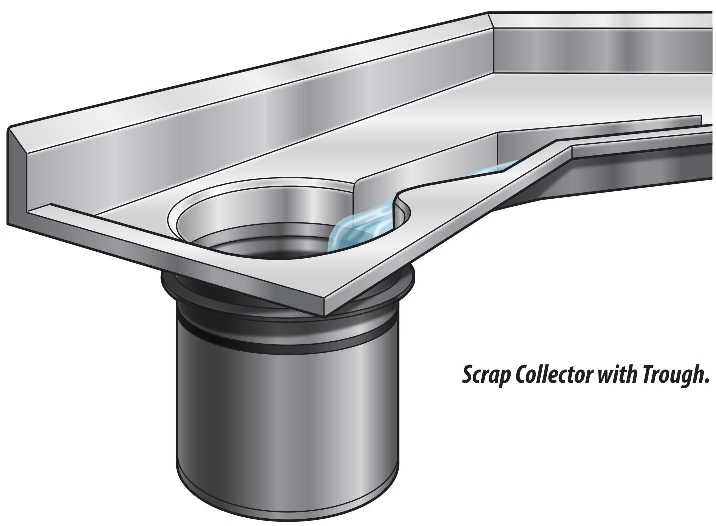


Three-Compartment Sink.

Scrap collectors, or "scrappers", have a recirculating pump that operates an 8 – 30 gpm waterfall. Scrappers use between 1 and 2 gpm of fresh hot water. When dishes are placed under the waterfall stream, scrappers collect solid debris in a mesh basket, which are periodically removed and emptied into a waste bin. Standard models flow at a constant rate during dishroom operating hours regardless of whether anyone is actively scrapping dishes. Advanced models have timers and occupancy sensors that are designed to turn the scrapper off when not in use, saving water.

Disposers use between 3 and 10 gpm of fresh water and essentially work like an upsized garbage disposer with a spinning blade inside to grind food scraps going down the drain. Unlike a residential disposer, water is automatically injected into the grinding cavity during the process. Disposers typically have low durations of operation because water only flows when the disposal button is pressed, resulting in a lower total water consumption than scrappers and other PRO equipment.

A trough is similar to a scrapper, but allows a larger channel for people to deposit dishes into the trough. Recirculated water from the trough washes over the dishes with their debris flowing into the scrapper at its terminal. The trough usually has 2-3 nozzles and allows multiple people to operate it. These use between 2-3 gpm of fresh water each.



Scrap Collector with Trough.

For all types of PRO equipment, continuously recirculating units can consume over 90% more water and energy than intermittent cycling units or those outfitted with occupancy sensors. As a result, is recommended to specify actuated PRO equipment whenever possible.

Staff training is the most important water and energy saving measure for pre-rinse operations. The most wasteful situations observed in the field involve the improper use of PRO equipment or the use of broken equipment by dishroom staff. For example, it is a common occurrence for floor hoses to be used in place of a PRSV. Floor hoses can use as much as 10 gpm and still not provide enough pressure to properly rinse. If the facility is large enough, consider specifying multiple PRSVs in the PRO area that can allow more workers to scrap dishes at the same time and reduce the misuse of non-PRO equipment like floor hoses.

Commercial Dishmachines

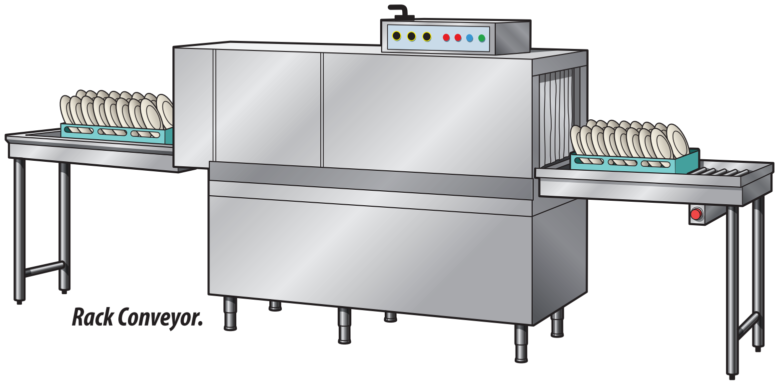
The most important piece of equipment in a commercial foodservice facility is the dishmachine. The dishmachine most likely consumes more hot water than any other appliance in the building. Restaurants can't cook without clean cookware and can't serve without clean dishes, which means that every part of a commercial foodservice operation depends on the dishmachine to function correctly. Additionally, health departments regulate the operation of dishmachines (target rinse temperatures) and can shut restaurants down for running a malfunctioning machine.

Dishmachines are also important from an energy and water perspective. In addition to using between 25% and 75% of a facility's hot water, dishmachines with electric booster heaters and tank heaters can rival entire cooklines in terms of electric energy consumption. This is especially true of the larger classes of dishmachine. Dishmachines come in four main classes: undercounter, upright door-type, rack conveyor and flight-type (rackless conveyor) machines. Undercounter and door-type units typically wash and rinse one rack at a time, functioning in a "batch-type" operation. Rack conveyor dishmachines continuously wash wares placed in a rack on a conveyor belt, while flight-type conveyors have integrated pegs for placement of wares directly on the conveyor.

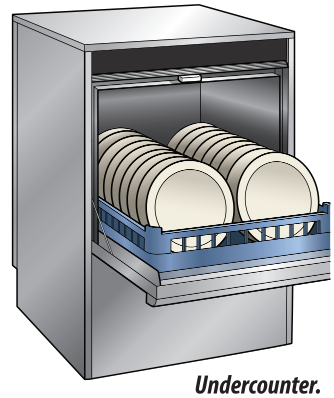
There are two types of commercial dishmachines based on sanitation method: ***low-temperature chemical-sanitizing*** and ***high-temperature sanitizing***. Low-temperature (or "low temp") chemical-sanitizing machines wash at 120-140°F and final rinse at 140°F with the aid of chemical sanitizing agents. A low-temp dishmachine uses three chemicals: (1) a washing agent, (2) a rinse aid and (3) a sanitizer. Normally, low-temp machines are not required to be installed under a ventilation hood (check with your local authority having jurisdiction).

High-temperature (or "high temp") machines wash dishware at 150-160°F with a final rinse at 180°F, which is a high enough temperature to sanitize wares without the need for chemical sanitization. High-temp machines only use a washing agent and a rinse aid. The high rinse temperature is achieved by either an internal or external booster heater that "boosts" the incoming 140°F water supply from the facility's main water heater to achieve the minimum 180°F rinse temperature. Due to the intense heat generation, high-temp dishmachines are required to be direct vented or installed under a ventilation hood.

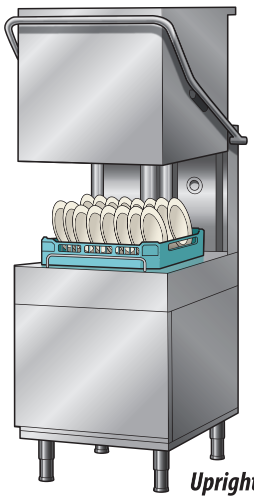
This guide will focus on high-temperature machines as they offer better washing performance and lower water and chemical use than low-temperature models. Most conveyor machines can only be specified in a high-temp configuration, while low temperature models are often seen in undercounter and door-type configurations.



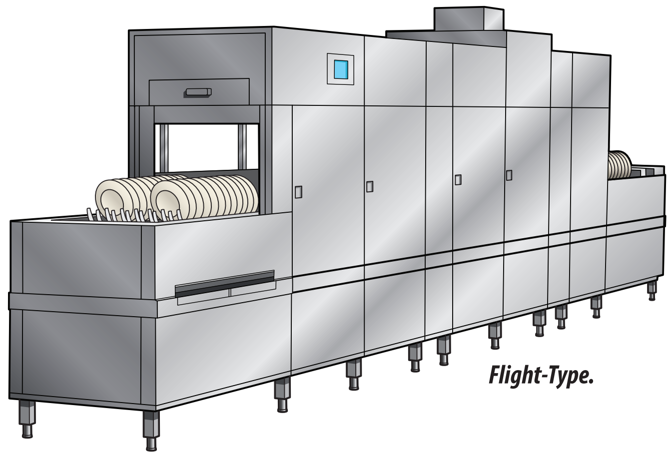
Rack Conveyor.



Undercounter.



Upright Door-Type.



Flight-Type.

Specifying a high-performing, high-temperature dishmachine from the outset or retrofitting an old, low-temperature dishmachine with a new, high-temperature dishmachine is one of the fastest ways to ensure water and energy savings on a foodservice facility's hot water system. The biggest deterrent of high-temp machines is higher amperage service required for the booster heater, higher initial machine purchase price and required dedicated ventilation. Energy consumption at the machine is also higher, however, that can be mitigated by specifying a heat recovery dishmachine that reduces water heating costs and may be installed unhooded in some areas. Field data on 20 machines has demonstrated that high-temp units consume about 20% less water and energy at the water heater as their low-temp counterparts.

The Food Service Technology Center (FSTC) validated water and energy saving features of dishmachines in controlled laboratory testing and the field. Historically, manufacturers with efficiency-driven designs have focused on reducing the rinse water use to comply with the ENERGY STAR® program requirements. Recently, manufacturers are introducing innovative technologies that may differentiate their products in a saturated market. Water and energy use per rack for conventional, ENERGY STAR, and Best-In-Class undercounter and door-type dishmachine categories are shown in Table 3. The rated rinse water use is compared to the measured real-world water use per rack (including tank fill and top-off operations). The real-world energy use (total building water heater energy used to heat water for rinse and fill, and electricity use to maintain idle, run pumps, motors & controls) is shown to provide perspective on resource intensity.

Table 3. Rating vs. Real World Water & Energy Use Per Rack for Batch-Type High-Temp Dishmachines.

Type	Conventional	ENERGY STAR®	Best-in-Class
Undercounter (Rating)	0.8 gal/rack	0.7 gal/rack	0.6 gal/rack
Undercounter (Real World)*	2.5 gal/rack 4,750 Btu/rack	1.1 gal/rack 3,000 Btu/rack	0.7 gal/rack 1,370 Btu/rack
Door-Type (Rating)	1.0 gal/rack	0.7 gal/rack	0.6 gal/rack
Door-Type (Real World)*	1.4 gal/rack 3,000 Btu/rack	1.3 gal/rack 2,500 Btu/rack	0.7 gal/rack 2,000 Btu/rack

*includes dishmachine fills and top-offs.

Similar data is presented in Table 4 below based on gallons per hour of rated and real-world rinse operations for conveyor dishmachines. This data is based on field monitoring of 16 rack and nine flight-type conveyor dishmachines.

Table 4. Rating vs. Real World Water & Energy Use Per Hour for Conveyor-Type High-Temperature Dishmachines.

Type	Conventional	ENERGY STAR®	Best-in-Class
Rack Conveyor (Rating)	260 gal/h	130 gal/h	80 gal/h
Rack Conveyor (Real World)*	660 gal/h 960,000 Btu/h	300 gal/h 590,000 Btu/h	130 gal/h 350,000 Btu/h
Flight-Type Conveyor (Rating)	280 gal/h	85 gal/h	85 gal/h
Flight-Type Conveyor (Real World)*	1,100 gal/h 1,800,000 Btu/h	280 gal/h 685,000 Btu/h	140 gal/h 395,000 Btu/h

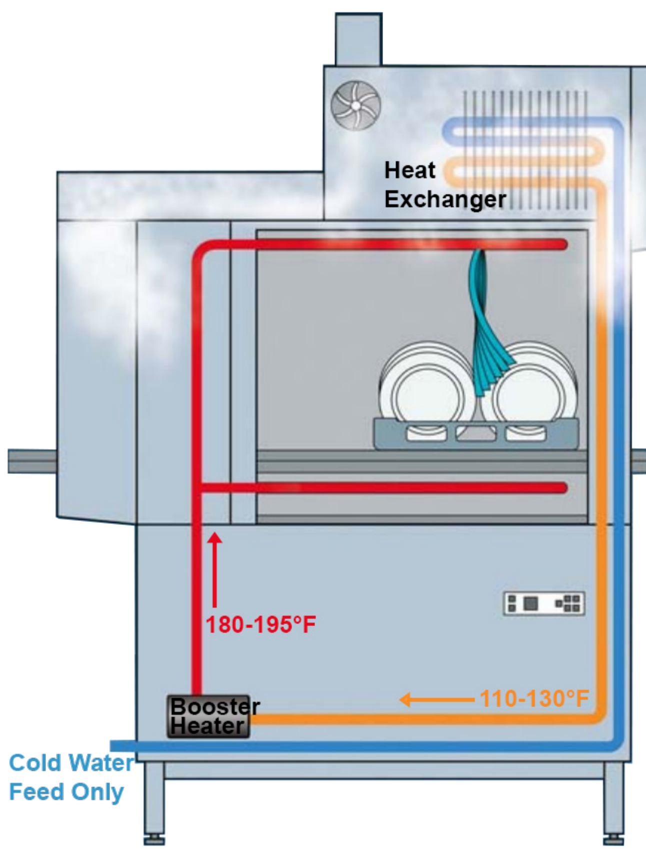
*includes dishmachines fills and top-offs.

There is a clear difference between conventional, ENERGY STAR, and Best-In-Class dishmachines based on real-world water use. All categories demonstrated a strong benefit for specifying best-in-class units that utilize heat recovery technologies and other features to drive down use and operating costs as well as allowing for sizing down and simplifying the hot water system design for additional savings. One major case for best-in-class dishmachines regardless of size is that these machines tend to operate much closer to the manufacturer's specifications in the real world than conventional machines.

Heat Recovery Dishmachines

By capitalizing on waste heat to preheat incoming hot water, energy recovery systems reduce both water heating and ventilation loads associated with dishmachine operation. Manufacturers offer energy recovery models for all types and sizes of high-temp machines (heat recovery is not a cost-effective option on a low-temp machine due to a lower difference between incoming cold water and rinse water temperatures). Energy recovery machines typically cost about 25% more up front than an ENERGY STAR unit of the same size category, but they can use as little as half the total energy (at the water heater and the machine) of a standard machine.

The most common energy recovery technology for dishmachines is ***exhaust-air heat recovery*** (figure below) where incoming cold water is preheated by captured heat and steam produced in the normal high-temp dishwashing cycle. Usually found on larger conveyor machines, other heat recovery machines use ***heat pump technology*** to capture the operating exhaust heat and vapor and convert it into usable energy to heat the wash and fresh rinse water. Although energy recovery machines reduce energy use at the water heater significantly, the trade-off is a higher load on the dishmachine's booster heater. Whereas a booster heater for a standard machine can accommodate a 40°F temperature rise, the booster heater for an energy recovery machine needs to accommodate a 50-70°F rise.



Conveyor Dishmachine with Exhaust Air Heat Recovery. (Source: Winterhalter)

During normal operation, a properly commissioned energy recovery machine will use only cold water, effectively eliminating the load on the building hot water system. Compared to conventional designs, this means that the hot water system can be reduced from 140˚F to 125˚F and the water heater downsized, which is both beneficial from a first cost and operating cost perspective.

For more discussion on dishmachine heat recovery technologies and dishroom HVAC implications, please refer to the ***Sizing Dishroom Ventilation*** design guide.

Table 5 compares three dishmachines installed at a restaurant in Northern California. The baseline machine was a 7-year old ENERGY STAR high-temp dishmachine monitored for water and energy use. This unit was replaced with a current ENERGY STAR dishmachine, then replaced again with an exhaust-air heat recovery dishmachine. Of the three machines, the exhaust-air heat recovery dishmachine performed the best, used the least amount of water per rack and exhibited the lowest overall cost to operate.

Table 5. High-Temperature Door-Type Dishmachine Field Comparison.

Machine	Rinse Pressure (psi)	Racks per Day	Water Use (gal/rack)	Cost per Rack*	Annual Operating Cost*†
Baseline (fed by water heater)	Est. 20 psi	227	1.4	$0.17	$14,200
ENERGY STAR Dishmachine	12	247	0.9	$0.15	$12,500
Exhaust-Air Heat Recovery Dishmachine	Pumped Rinse	201	0.74	$0.12	$11,000

*based on 11.25/HCF, $1.10/therm, $0.19/kWh

†annual operating costs based on an average 225 racks per day.

Regular commissioning and maintenance of dishmachines is critically important to maintain the machine's performance and low water consumption. The dishroom staff is the first line of defense against water waste and should be trained to point out maintenance problems before they can lead to catastrophic failures. Staff should immediately report any visible problems like water leaks, faulty doors, ripped curtains or drain valves that do not completely close.

For recommendations on dishmachine commissioning and maintenance, please refer to the ***SoCalGas® Natural Gas Foodservice Equipment Cleaning & Maintenance*** user's guide.

Utility Sanitation Fixtures

Floor sanitizing equipment can include mop sinks, water brooms and/or floor hoses. Mop sinks and floor hoses are typically fed directly by the hot water system without any flow or pressure regulation — running between 8 gpm and 20 gpm. This high flow rate has many implications for hot water systems — during cleanup, the mop sink can cause concentrated hot water demand that can quickly deplete a hot water tank, or overdraw a tankless water heater and starve other end-uses such as hand sinks and dishroom equipment. Whether hot water is supplied by a tank-type or tankless water heater, this scenario can lead to longer wait times and drops in supply temperatures, impacting building sanitation.

Staff can be trained to only clean floors at night or during down periods between meal services, using the mop sink to fill 5-15 gallon buckets with hot water. A full-service restaurant can require staff to refill the mop bucket many times throughout a shift ranging from 10 to 50 gallons per day. This is not always feasible given that some spills requiring immediate mopping usually occur during meal service, especially in a restaurant's service and seating area. Floor hoses typically use much more water (with flow rates up to 10 gpm) than mop sinks because staff tend to use more water than the 10-15 gallons required to fill a mop bucket.

A water broom (right), which is a device that uses a high-pressure hose attached to a broom head to sanitize floors, can address the flow rate problem because they typically operate at about half of the flow rate of a floor hose/mop sink while sometimes increasing the rinse pressure to clean the spill. This reduces the overall and instantaneous hot water loads and can potentially replace a mop sink. Based on one hour of use per day, a water broom can reduce the total hot water demand by 50 gallons per day compared to a floor hose.

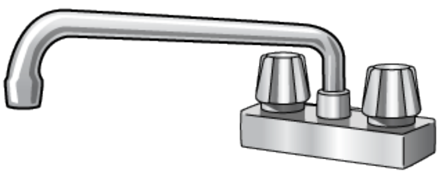
Water Broom. (Source: General Pump)

Bars & Auxiliary Fixtures

Considerations should be made for restaurants with auxiliary hot water fixtures in the front-of-house like bar areas. Bars commonly use an undercounter dishmachine, a three-compartment sink, a hand sink and a few other cleaning devices such as pint glass rinsers and pitcher sinks. These fixtures should be properly sized before deciding on a distribution system type or specifying the water heater as they can represent a substantial load on the hot water system. Consider the glass and service ware washing needs of the bar; generally, one rack of dishes will require washing per 15-20 drinks served at the bar. To overcome chemical smells, heat and steam pouring into the bar service area, specify exhaust-air heat recovery undercounter dishmachines to reduce the load on the overall hot water system and increase patron comfort.

Prep Sinks

Prep sinks typically require higher flow rates and can be installed without the use of aerators. Prep sinks need to be installed relatively close to the kitchen's food preparation and cooking areas and can be major users of hot water. The location is often far from the building's primary water heater. If the floorplan is already decided and the prep sink needs to be placed farther than 60 feet from the utility room, consider installing a dedicated point-of-use (POU) water heater to supply hot water to these fixtures. This will have the benefit of reducing the amount of hot water piping and providing better delivery performance.



Prep Sink Faucet.

Hand Sink Aerators.

Hand Sinks

California Title 24 requires all hand sinks be outfitted with aerators to control their maximum flow rates. Aerators reduce the volume of water flow from faucets and increase the velocity of the exit stream, saving water and creating a better hand washing experience. The standard flow rate in the California Plumbing Code (2019) for aerators is **0.5 gpm**. New systems need to use aerators rated at 0.5 gpm to comply with code. The requirement to use low-flow aerators can extend the time needed to clear the "cold slug" of water from the branch and/or twig line before hot water can be delivered at the faucet.

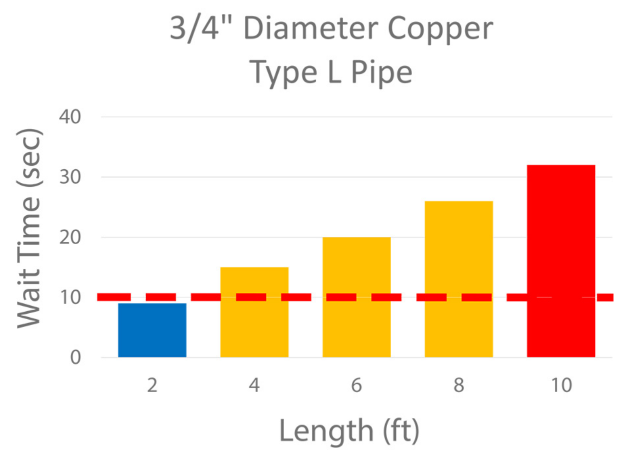
The figures to the right show the effects of pipe size on reducing hot water delivery time. A strategy to improve delivery performance is to reduce the diameter of the branch and/or twig piping leading from the trunk line to the hand sink(s). To simplify the wait time estimation, it is assumed that the 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.

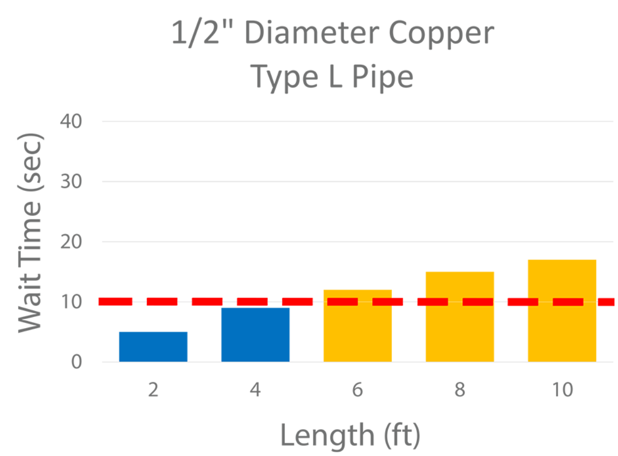
A common practice is to specify ¾-inch diameter branch piping for two or more lavatories. With 10 feet of ¾-inch diameter branch piping and a 0.5 gpm aerator installed, the wait time would be 33 seconds before the 0.28 gallons of water is purged and hot water reaches the faucet.

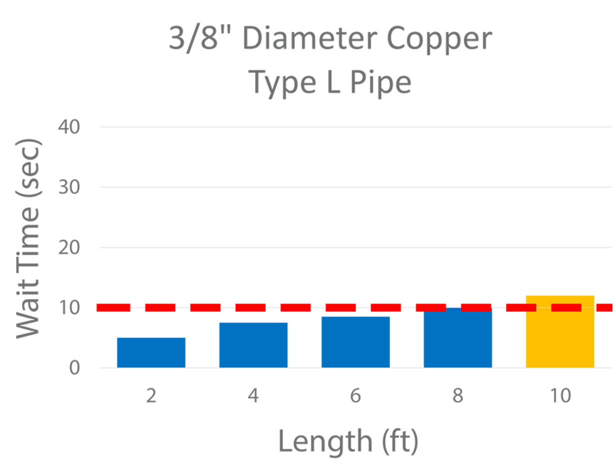
For better delivery performance, ½-inch branch piping will effectively serve up to four lavatories that have a maximum total flow rate of 2 gpm. ¾-inch branch piping should be used to service five or more lavatory sinks. 3/8-inch branch piping would provide the best delivery performance when paired with a 0.5 gpm hand sink aerator, however, current plumbing codes do not allow the specification of 3/8-inch diameter tubing or piping for use with potable commercial hot water systems. For this approach, a variance for its use would have to be granted by a local buildings department with approval from a professional engineer.

The other way to reduce the delays in hot water delivery to hand sinks is to use a POU heater installed with 1 foot or less piping from the faucet (i.e., under the sink). This approach is especially useful when hand sinks are located far away from the primary water heater.

Hot Water Wait Time.
Unacceptable 31+ sec
Marginal 11-30 sec
Acceptable 1-10 sec







Distribution Systems

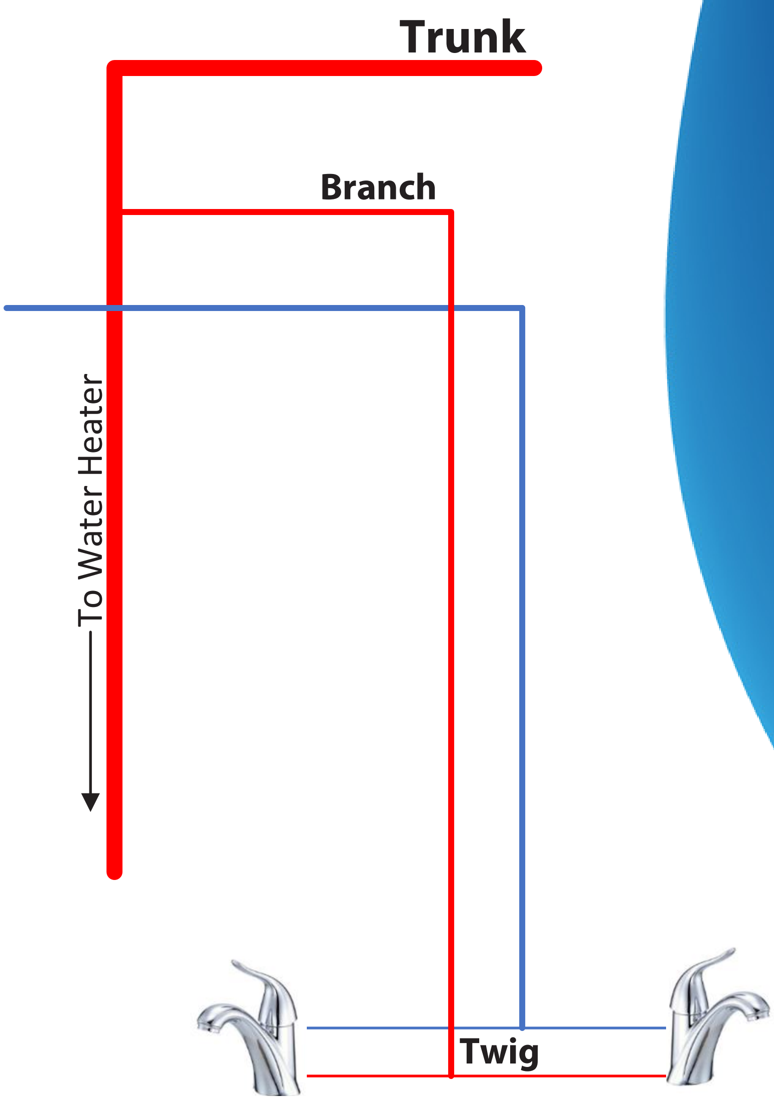
The hot water distribution system is often overlooked as a component of the hot water system that affects both water and energy use. In many cases, the shape of the distribution system is dictated by the building's floorplan. The hot water system is often one of the last energy systems to be specified in the design process, and many constraints already exist. These constraints include the locations of the dishroom, the location of any major auxiliary water uses (such as a bar) and the placement of the restrooms. This is one of the primary reasons why hot water systems designs with continuous recirculation are often oversized.

One method of optimizing the design of a hot water recirculation system is to locate all the fixtures as close to each other, and as close to the utility room (water heater), as possible. This approach requires hot water specification to occur earlier in the building design process than is currently standard practice. The following floorplan recommendations will aid in designing a smaller, more efficient hot water system:

- **Mirror men's and women's restrooms.**
- **Locate the dishroom on a wall opposite the front-of-house and place any auxiliary bar fixtures or restrooms on the other side of the dishroom wall.**
- **Centrally locate the utility room near major points-of-use.**

There are four main types of distribution systems that can be used in a commercial foodservice application:

1. **Simple Distribution** — Supply piping with no return loop (right).
2. **Continuous Distribution** — Supply piping with return loop and pump.
3. **Demand Circulation** — Pump, controller, and sensors with return loop.
4. **Distributed Generation** — Primary distribution loop and point-of-use heating.



Simple Distribution with Trunk, Branch, and Twig Configuration.

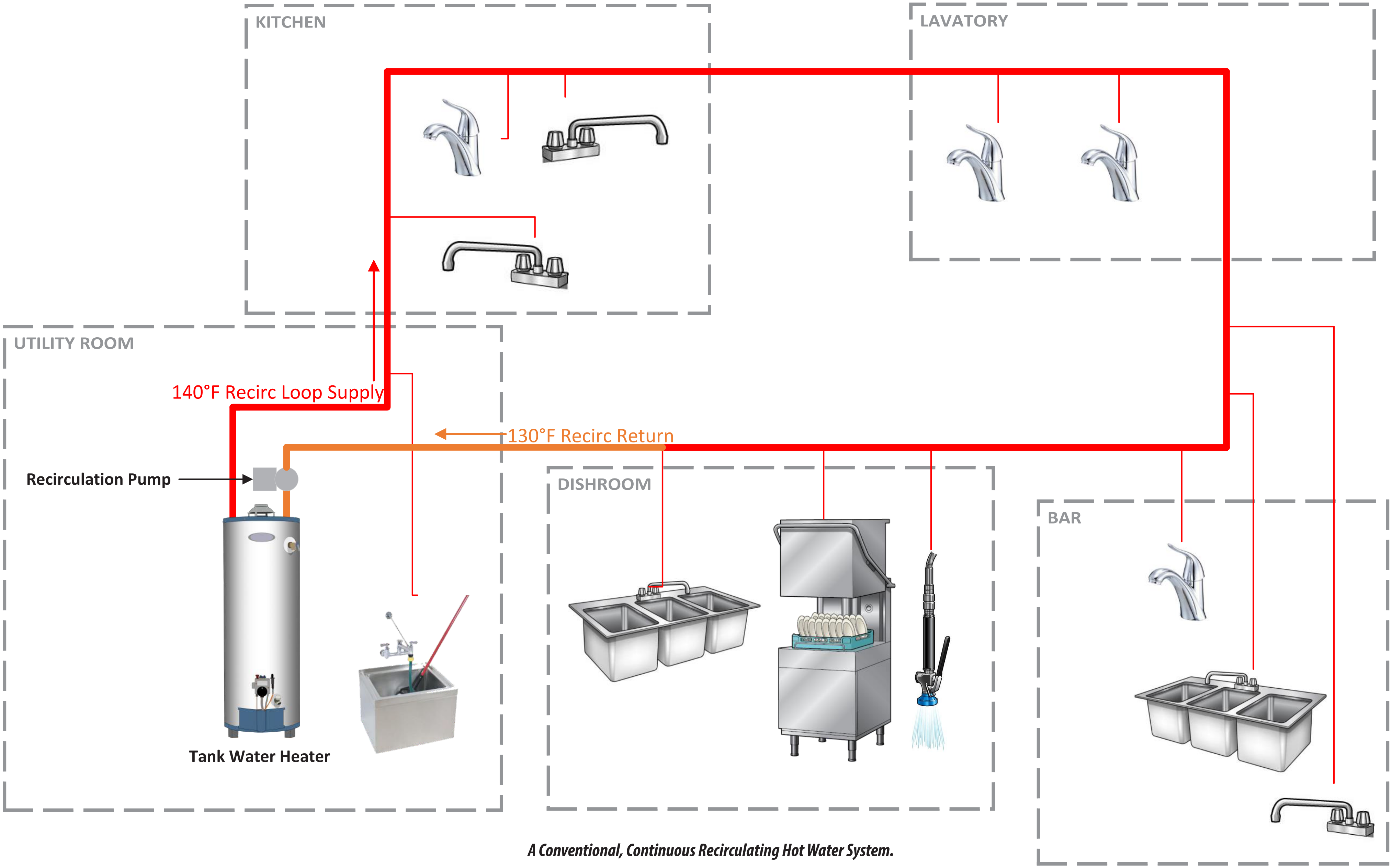
Simple Distribution Systems

A simple distribution system uses a trunk, branch and twig configuration (pg. 13) to deliver water from the heater to the points-of-use. The benefit of this system is that it is simple, reliable and compatible with all water heaters. The drawback is a potentially long wait time for hot water, especially at first use or after long periods when water in the pipes has cooled down. Increasing the length or increasing the diameter of the distribution line increases wait times at the farthest fixtures because a larger volume of water must be purged before hot water arrives. Simple distribution systems are typically used in small quick-service restaurants and specialty shops where distribution lines are less than 60 feet. The two most popular configurations include (1) a single-line distribution system that feeds all sinks and equipment, and (2) a double-line distribution system that provides hot water (typically at 140°F) to the sanitation sinks and dishmachine, while a second line delivers tempered water to hand sinks to prevent scalding. Supplying water to a system with two different temperature setpoints requires the use of two water heaters either running in parallel or in series.

Continuous Recirculation Systems

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 (pg. 17). 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 installed. Regardless of how well the strategy works, water is being circulated at 140°F (or more), continuously losing heat to the surroundings and being reheated by the water heater. The hotter the water is in the lines, and the poorer the insulation, the greater the heat loss and the 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." Although it is possible to design without recirculation, it will require cooperation from the county plan checker to allow a variance from this rule (based on an engineered design of an alternative and equally effective distribution strategy). California Title 24 states that recirculation loops need to have air release valves or vertical pump installation, that there is backflow prevention, equipment for pump priming, isolation valves and cold water supply backflow prevention, which essentially means that there needs to be check valves installed on the cold water supply and the recirculation return. Title 24 also specifies that water heater storage tanks need external insulation with an R-value of at least R-12 or internal and external insulation with a combined R-value of at least R-16. Title 24 requires insulation with an R-value ≥ 3 on all hot water piping in commercial buildings.

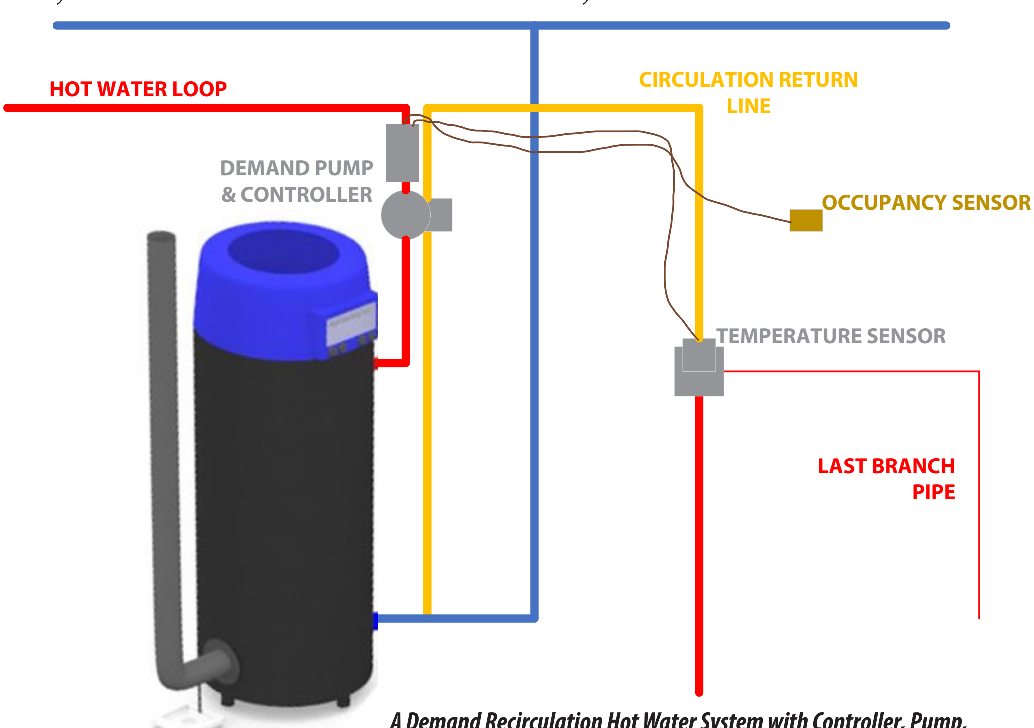


A Conventional, Continuous Recirculating Hot Water System.

Demand Circulation Systems

A demand circulation system incorporates a controller and sensors that operate the pump only when there is need for hot water. After a period of inactivity, the pump purges room temperature or slightly elevated (70°F or 90°F) water from the hot water supply line and transfers it back to the water heater via the hot water circulation return line. The system works by having an occupancy sensor placed in a common area in the kitchen. The sensor triggers the pump controller to check the temperature sensor placed at the start of the return line after the last branch pipe. If it senses that the water in the line has cooled down and that there are people in the facility, it activates the pump until a temperature rise is seen. When the temperature sensor measures an increase in water temperature, it assumes that hot water (120°F or 140°F) is just about to arrive. The controller then shuts off the pump, ensuring that hot water is close to every fixture on the hot water supply line, but preventing hot water from being pumped into the return line. Every time the occupancy sensor is triggered, the controller first checks the water temperature. If it senses that the water in the pipe is still warm, it does not activate the pump. The figure below shows a sample installation setup diagram. In the diagram, the occupancy sensor and temperature sensor are installed on the last branch pipe.

Demand recirculation systems ensure that hot water is delivered quickly to fixtures (similar to a continuous recirculation system), but only lukewarm water is returned back to the water heater. Furthermore, the pump only runs when needed, saving 95% of the gas used to keep a continuous recirculation system operating around the clock. Pump run-time drops from 24 hours to 30 minutes per day, saving electricity. In addition, gas storage heaters can operate at higher efficiencies as temperature stratification in the tank is maintained. Demand systems can easily be designed in new facilities and retrofitted onto existing hot water systems that have a continuous recirculation system.

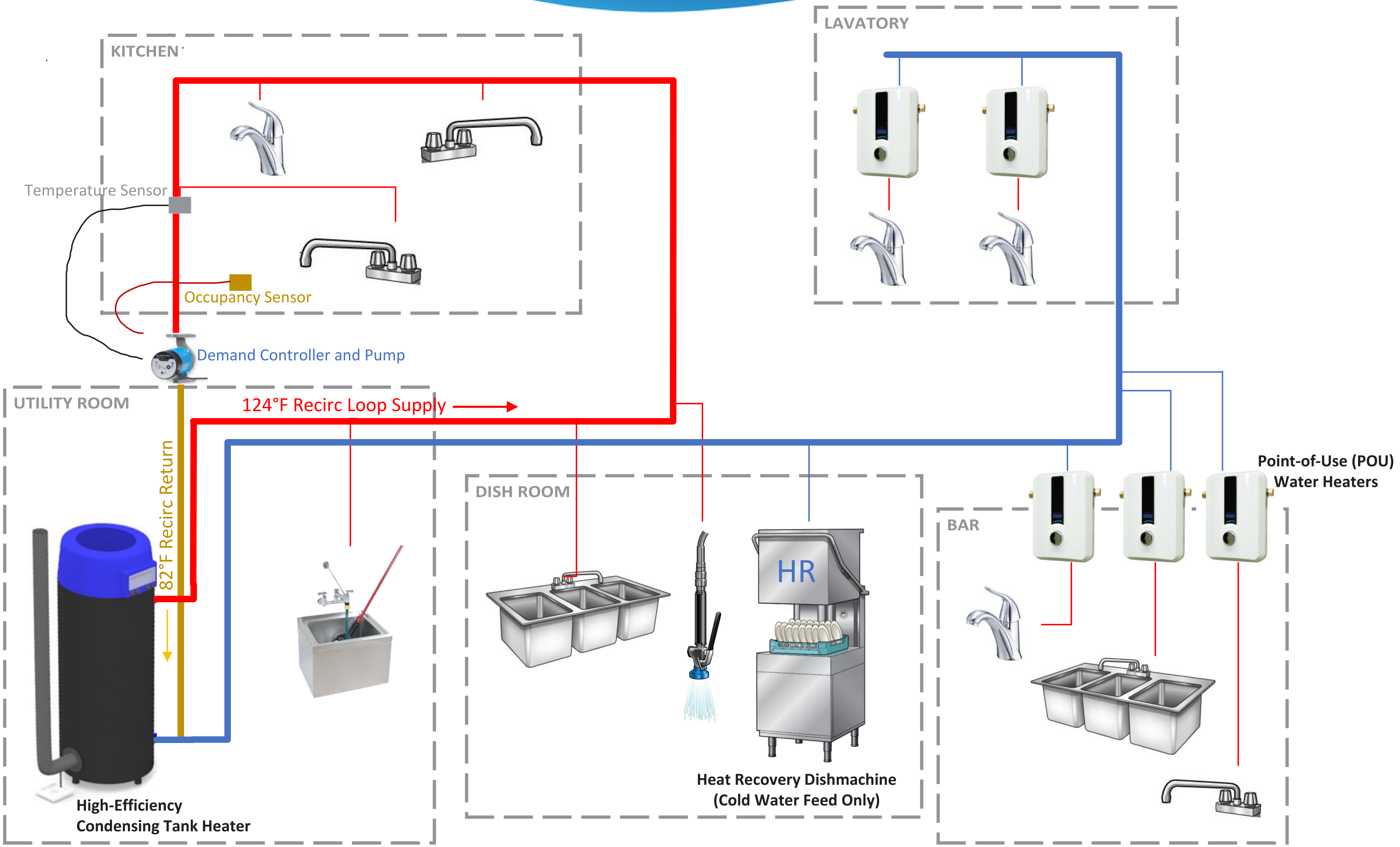


A Demand Recirculation Hot Water System with Controller, Pump, Occupancy Sensor and Temperature Sensor.

Distributed Generation Systems

Distributed generation can either comprise a 100% distributed system (i.e., a simple distribution system) utilizing point-of-use water heaters as might be found in a small café or convenience store, or a hybrid hot water system that combines a central water heater (storage type or tankless) with POU heaters. In the hybrid configuration (pg. 20), a simple distribution system delivers hot water to sanitation equipment and kitchen sinks clustered near the primary water heater and POU heaters are strategically placed near remote fixtures in lavatories or bars. The POU heaters that are sized appropriately for the end use flow rate and temperature rise can be plumbed to the cold-water line, thus eliminating the need for a separate hot water line to these areas. Using distributed electric POU heaters for hand-washing sinks is a cost-effective option, especially when specifying the "best-in-class" 0.38 gpm aerator for a public lavatory faucet in combination with point-of-use heaters that have an industry lowest activation rate of 0.2 gpm. Many manufacturers carry models that run on 120V and an amperage draw under 15A. This approach minimizes water and energy use while enhancing the customer experience by reducing the wait times for hot water.

Specify a dual handle faucet for best results with a POU heater. This ensures that the user doesn't passively choose the neutral single faucet handle position of 50% hot/50% cold, which could produce a hot water draw (~0.19 gpm) that falls below the activation rate of the POU heater. When utilizing a single-handle faucet, the aerator should be at least 0.5 gpm flow rate to ensure a sufficient draw when the handle is used in the neutral position.



A Best-in-Class, Hybrid Distributed Generation Hot Water System.

Water Heater Sizing & Selection

After the fixtures have been specified and the distribution system has been designed, the next step is to size the POU and primary water heaters. Sizing POU heaters is simpler than sizing the primary water heater as they are generally used to feed fewer fixtures. Table 6 lists common health department guidelines for fixture flow rate for sizing water heaters by fixture type. The table lists the minimum flow ratings for both tankless and tank-type water heaters. To size a water heater, the specifier must account for the number of fixtures the water heater will supply and multiply them by the values in Table 6 to get the total flow rate (tankless type) or recovery rate (tank type). When using this table to specify POU heaters, the gpm rating of each fixture supplied should be used to determine the required capacity. Once the POU heaters have been sized and specified, it is good practice to ensure that there is an adequate energy supply to the locations where POU heaters will be installed. One design consideration when choosing the fuel type for a POU heater is that electric heaters do not require venting. As such, electric POU heaters are the most common choice for remote application.

Table 6. Sample Flow Rates for Sizing a Water Heater.

Fixture Type	Tankless Flow Rate (gpm)	Tank Recovery Rate (gal/h)
Restroom Sinks	0.5	5
Hand Sinks w/ Aerator	0.5	5
3-Compartment Sink (18" x 18")	3	42
3-Compartment Sink (bar)	3	18
Door-Type Dishmachine	See Spec Sheet	See Spec Sheet
Conveyor Dishmachine	See Spec Sheet	See Spec Sheet
Pre-Rinse Spray Valve	1.2	45
Mop Sink	2	15
Utility Sink	3	5
Utensil Pre-Soak Sink	5	5
Dipper Well	0.5	30

Tankless Water Heaters

Tankless water heaters have a small footprint and can be installed in a variety of spaces—if the utility room is low on floorspace, tankless heaters can be a good option to save space. Also, multiple heaters can be installed in parallel for redundancy so the restaurant can still operate even if one heater goes down. The primary challenge associated with tankless heaters is proper sizing to accommodate sufficient supply of hot water to all of the fixtures during a peak demand scenario such as clean-up at the end of shift. If a commercial dishroom was fed by tankless water heaters only, the heaters would need to supply hot water for a fill cycle of a dishmachine at the same time as the compartment sinks and mop sinks are running at their maximum flow rates. If the heaters are undersized, the flow rate will throttle to maintain the hot water system temperature and starve the system of hot water. This can have a devastating impact on a dishmachine's ability to provide the requisite hot water for the sanitizing rinse, as well as slowing down water flow to other fixtures such as hand sinks, leading to significant delivery performance problems.

Table 7 shows a fixture count for various sizes of restaurants that the FSTC has monitored in the field. Because compartment sinks, mop sinks and dishmachines are all high-flow rate hot water users, using a tankless water heater as the building's main water heater is inappropriate for any site other than a deli or a small quick-service restaurant. Tankless water heaters need to have an input rate of at least three times that of a tank-type water heater for similar demands. Gas piping for tankless heaters is also 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. Similarly, electric tankless heaters require higher amperage wires and larger subpanels than electric tank-type heaters, which increases installation costs.

Table 7. Fixture Count for Various Restaurant Sizes.

Fixture Type	Deli	Quick-Service Restaurant	Small Full-Service Restaurant	Large Full-Service Restaurant
Restroom Sinks	1	2	2	4
Hand Sinks	1	2	3	6
3-Compartment Sinks	1	1	1	2
Dishmachine	-	-	Door-Type	Conveyor
Pre-Rinse Spray Valve	-	-	1	1
Mop Sink	1	1	1	1
Utility & Prep Sinks	-	1	1	2
Dipper Well	-	-	-	1

Storage Tank Water Heaters

Storage tank-type water heaters are sized by their hourly recovery rating, or how fast the water heater can refill its tank with hot water. The tank acts as a buffer between the heating source and the fixture and allows the heater to run at much lower input rates than for tankless water heaters without a storage buffer. Sizing a tank-type water heater involves adding up all of the fixtures in the proposed design, multiplying by the values shown in Table 6, then finding the minimum input rate based on that recovery rate and rounding up to the nearest commercial water heater input rate class. Water heater manufacturers publish both the input rate and recovery rates for tank-type water heaters as part of their specifications sheets. Table 8 shows the result of multiplying tables 6 and 7 to size a tank-type water heater.

Table 8. Sizing a Tank-Type Water Heater for Various Restaurants.

Fixture Type	Storage Heater Minimum Recovery Rate (gal/h)			
	Small Quick-Service Restaurant	Medium Quick-Service Restaurant	Small Full-Service Restaurant	Large Full-Service Restaurant
Restroom Sinks	5	10	10	20
Hand Sinks	5	10	15	30
3-Compartment Sinks	42	42	42	60
Dishmachine	-	-	30	126
Pre-Rinse Spray Valve	-	-	45	45
Mop Sink	15	15	15	15
Utility or Pre-Soak Sinks	-	5	5	10
Dipper Well	-	-	-	30
Minimum Recovery Rate (gal/h)	**54***	**66***	**162**	**336**
Minimum 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 gal/h * 0.8 = 54 gal/h

Primary Water Heater Technologies

Conventional Gas-Fired Tank-Type Water Heaters

— These water heater designs are relatively simple with a burner mounted beneath a tank of water with the flue going through the center of the tank. Gas-fired storage tank-type heaters have thermal efficiencies of 80% or lower and lifespans in commercial kitchens of about five years. The cost scales directly with tank and burner size, but most conventional commercial water heaters can be purchased for between $2,000 and $5,000. Some conventional water heaters come equipped with active flue dampers designed to close the flue when the burner is not running. This traps heat in the flue, which is then reabsorbed into the tank water over time instead of being exhausted. Automatic flue dampers can increase the efficiency of these water heaters by up to 5% depending on how often the water heater's burner cycles on and off. The venting costs for standard efficiency heaters may be higher because they use metal piping to handle the higher exhaust temperatures. Stainless steel venting must be used with standard efficiency tankless heaters and high input rate storage heaters above 100 kBtu/h that must comply with the ASME code. Less expensive galvanized steel can be used with smaller storage heaters.

Standard Gas-Fired Tank-Type Water Heater.

Hybrid Condensing Water Heaters — High-efficiency, hybrid condensing water heaters condense water vapor contained in the exhaust gases, producing liquid condensate as a byproduct. A pipe must be connected from the base of the exhaust flue to route the condensate to a drain in proximity to the heater. Alternately, a condensate pump can be used to discharge the liquid to a remote drain. Gas-fired condensing water heaters typically have thermal efficiencies between 90% and 95%. An important caveat is that the operating efficiency depends on the temperature of the recirculation return. As the recirculation return temperature approaches the water heater's setpoint temperature, the heater loses its condensing function and essentially works like a conventional gas water heater. Because demand recirculation control lowers the return recirculation temperature, condensing water heaters should only be used on either non-recirculating or controlled-recirculating distribution systems. For continuous recirculation systems with high recirculation flow rates, the operator has effectively paid for a more efficient water heater that, in practice, operates at standard efficiency because condensing can't occur in the flue due to the high return temperature. Typical first costs for condensing water heaters vary by manufacturer, but specifiers can expect to pay roughly 20% on top of the initial cost of a standard efficiency water heater.

Hybrid Condensing Tank-Type Water Heater. (Source: A.O. Smith)

High-efficiency, condensing storage heaters installed in new facilities or as replacement units in existing restaurants reflect a payback of one year or less when allowed to fully utilize their condensing function. In new installations, condensing water heaters may be less expensive to install than standard efficiency heaters because of flue piping (although condensing water heaters are more expensive to purchase), presenting an immediate payback. Even for a voluntary changeout in a full-service restaurant, the payback period is in the four- to six-year range. There is a good case for changing out an inefficient water heater as soon as possible because changing out the water heater in an emergency may significantly increase the replacement cost. Quick-service restaurants have longer paybacks because they typically use much less hot water than full-service restaurants. If the reduced liability of a voluntary or planned changeout is considered, a longer payback period can be viewed in more favorably. Nevertheless, it is recommended to specify condensing water heaters over their conventional counterparts, when applicable.

Heat Pump Water Heaters (HPWH) — Available in both gas-fired and electric-powered versions, these water heaters employ heat pump technology to draw heat from the environment. These units have effective thermal efficiencies greater than 100%, i.e., coefficients of performance (COP) greater than one.

A gas absorption HPWH utilizes a heat pump cycle to transfer energy from the ambient air to preheat incoming water to a storage tank. The storage tank is heated directly with gas burners to bring the water to the final system operating temperature. In addition to the heat pump cycle, gas HPWHs have integrated heat recovery, capturing the remaining useful heat from gas combustion to heat water. Gas heat pumps are emerging technologies in commercial foodservice applications and have an opportunity to lower utility costs by offering higher efficiencies than either conventional or condensing gas storage water heaters, while providing auxiliary HVAC benefits. Commercially available gas HPWHs have nominal COPs around 1.4-1.8 depending on operating conditions with higher efficiency products coming to market in the near term. Recent field studies have demonstrated reductions of gas consumption over baseline ranging from 18% to 50% when serving commercial water heating loads.

The efficiency and capacity of a gas HPWHs depends on the hot water demand and the ambient temperature of the environment where the heat pump unit is placed. When ambient temperatures around the evaporator are low, or when hot water demand is low, the system will have lower operating efficiencies. Outdoor heat pump unit locations are recommended for milder climates. Locations with cold winters and hot summers can have the evaporator ducted outside with a damper that can be closed during the winter months. Another efficiency consideration is that the HPWH has a limited recovery rate compared to a conventional water heater. This requires a sizing adjustment when specifying HPWHs to ensure that the highest hot water demand during the day can be handled without depleting the tank(s). This is similar to sizing conventional tank-type water heaters according to their hourly recovery rate. Smaller tank sizes (where the space is limited) for high-demand applications may require auxiliary heating.

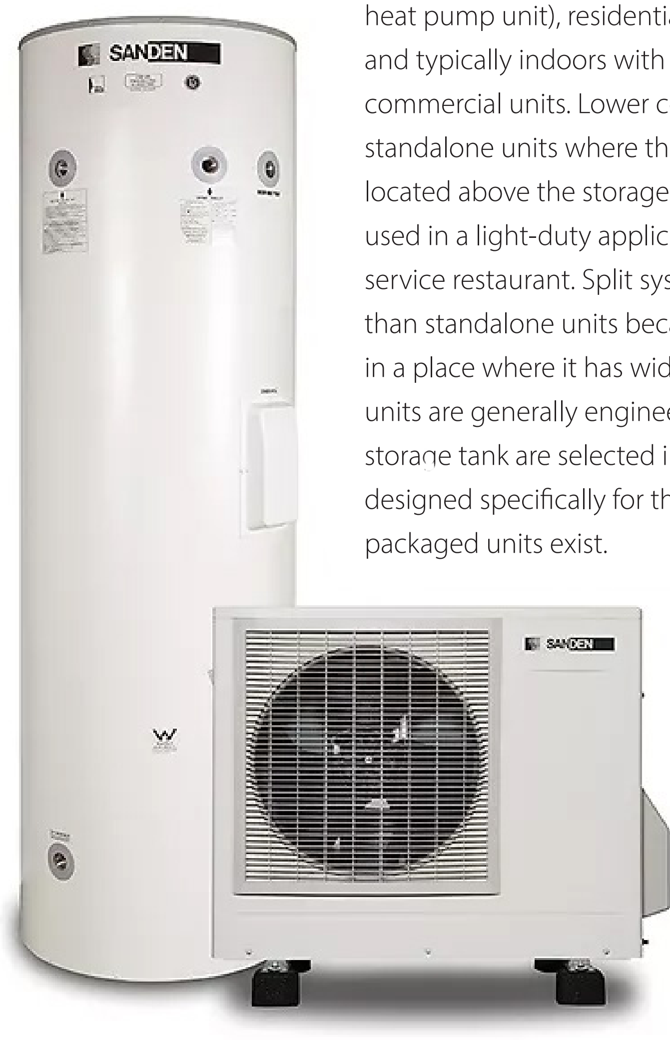
Sizing HPWHs presents additional challenges. If the HPWH is undersized, there will only be minimal energy savings over a conventional water heater; if the HPWH is oversized, it will mostly run at part load, limiting the performance potential as full COP cannot be realized. The COP drops at part load due to compressor cycling. Every time the compressor first cycles on after being off, the refrigerant has not yet absorbed heat from the environment and the system takes time before effectively preheating the incoming water.

With accurate sizing and planning, it is possible to optimize the size and capacity of the HPWH for the load and achieve the maximum benefit. The initial cost of HPWHs increase with size. As a result, the most cost-effective approach is to optimize end uses with efficient equipment to accommodate a smaller capacity water heater. Research in a recent CEC study suggests that sizing the gas HPWH to meet 30% to 60% of the peak load may be optimal for most full-service restaurants. As an emerging technology, HPWHs are currently about twice the initial cost of conventional water heaters. It is anticipated that the incremental cost difference for HPWHs will decrease as the technology builds momentum due to the combination of decreasing manufacturing costs and increasing demand.

Electric HPWHs operate similarly to gas absorption HPWHs: they siphon energy from the surrounding ambient air via a refrigeration cycle and transfer this energy to preheat incoming water. Electric HPWHs also use a supplementary electric resistance heating element to provide the final water heating when the energy from the heat pump is insufficient for the hot water load. Typical input rates for commercial units are around 15 kW, which includes 3 kW for the heat pump compressor and 12 kW for the electric resistance heating element.

Electric HPWHs are available in three configurations including residential standalone (tank is integrated with heat pump unit), residential split system (tank is separate, and typically indoors with heat pump unit outdoors), and commercial units. Lower cost residential/light commercial standalone units where the heat pump unit is conveniently located above the storage tank as one integrated unit may be used in a light-duty application such as a café or small quick-service restaurant. Split systems are generally more efficient than standalone units because the evaporator can be installed in a place where it has wider operating parameters. Commercial units are generally engineered systems with the heater and storage tank are selected independently and the system designed specifically for the facility, although some standalone packaged units exist.

Custom designed systems offer much larger water heating capacities and are matched to supply space cooling capacity, which can be used to ventilate hot kitchens, but with narrower operating parameters at a cost proportional to the heating requirements.



Heat Pump Water Heater.
(Source: Sanden)

Electric Resistance Water Heaters — Although still utilized, centralized electric resistance storage tank heaters will not be discussed further due to their expensive operating costs in restaurants at roughly three to four times that of gas or electric heat pump alternatives. Electric resistance storage heaters are typically only specified in facilities that are not plumbed with natural gas and/or low-usage facilities (300 gal/d) such as small specialty or coffee shops where the space and installation savings of electric heaters outweighs the potential increase in operating costs. From an environmental standpoint, the source-to-site energy comparison shows a significantly larger energy footprint of the centralized primary electric resistance heater versus the other heating systems.

Dual Fuel Water Heaters — An upcoming technology solution for commercial kitchens is a hybrid gas water heater with an electric heat pump. This hybrid system combines the very high COP of the electric HPWH with the low cost of using gas as a primary fuel source for supplemental heating. This approach provides a bridge toward grid-integration by operating primarily in electric heat pump mode, while using the gas source as a backup during high hot water demand situations (such as end of shift clean up) and grid demand response events. Prototypes are being evaluated, but no commercial units are currently available on the market.

Primary Water Heater Comparison

Table 9 shows the operating characteristics of the five tank-type water heaters viable for commercial foodservice applications.

Table 9. Site/Source Energy and Cost Comparison of Primary Water Heaters.

Heating System	80% TE Gas Heater	95% TE Gas Heater	Gas Heat Pump COP 1.8	95% TE Electric Resistance	Air Source Electric Heat Pump COP 3.5
Industry Efficiency Characterization	Conventional	Efficient	Efficient	Conventional	Efficient
Heat Absorbed by Water (Btu/d)	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Daily Operating Efficiency	70%	85%	1.25	90%	2.5
Energy Consumed: Site Energy (Btu/d)	1,428,600	1,176,500	800,000	1,111,100	400,000
Source-Site Energy Ratio	1.05	1.05	1.05	3.14	3.14
Source Energy (Btu/d)	1,500,000	1,235,300	840,000	3,488,900	1,256,000
California Utility Cost* ($/d)	$16	$13	$9	$62	$22

*based on $11.25/HCF, $1.10/therm, $0.19/kWh

In the previous table, the industry efficiency characterization describes whether the water heaters use modern technological advances to achieve a better operating efficiency or whether the unit should be classified as conventional relative to its fuel source. The heat absorbed by the water is the daily load presented by the facility and is consistent with a small full-service restaurant's needs. The heat absorbed by water (or the output of the water heater) has been set to a constant to show the differences in input between the water heaters. The daily operating efficiency calculated from field studies is always lower than the manufacturer's rated thermal efficiency because it includes distribution and standby losses.

The energy consumed (site energy) is the load divided by the efficiency, or how much energy the water heater consumes downstream of the utility meter. The source-site energy ratio is a correction factor that shows how many units of energy a utility must consume (at the source) to deliver one unit of energy to the water heater. The source-site energy ratio is higher for electricity than gas because of transmission and generation losses and will depend on the fuel source mix to generate electricity. The California utility cost is the site energy multiplied by the average energy rate for either gas or electricity (2020 rates).

The gas heat pump water heater uses the least amount of source energy and boasts the smallest daily utility cost, meaning it is the most inexpensive to run based on current utility rates. It is also important to note that an electric heat pump and a condensing gas water heater have about the same source energy consumption, meaning that the high COP for the electric heat pump makes up for the electric generation and transmission losses.

Design Example: Full-Service Restaurant

The following hot water system design example for a full-service restaurant is based on real world kitchen layouts. This example will apply the design process and potential for optimization discussed in this guide. The example presents three options for distribution systems and three options for the central water heater for a typical full-service restaurant.

The full-service restaurant has a dedicated dishroom with a pre-rinse spray valve, a door-type dishmachine and a three-compartment sink as well as various hand sinks located throughout the facility, utility sinks in the food preparation area, and a mop sink in the utility room. This design also includes a separate bar area with a hand sink and a prep sink in the front-of-house. This site was designed with adequate gas service in the utility room and 120V electrical service distributed throughout the facility. This site washes about 200 racks of dishes per day. The hot water load of the remaining equipment was estimated based on FSTC field studies of commercial foodservice hot water systems. The three hot water design options are as follows:

1. **A Conventional Fully Recirculating Hot Water System.** The hot water distribution system is fed by a standard-efficiency gas tank-type water heater. This approach roughly corresponds to the conventional system layout presented on page 17. This system would have 500 feet of hot water piping, 250 feet recirculation line, and a continuously running recirculation pump. The typical operating setpoint is 140˚F to feed hot water to conventional high-temperature door-type dishmachine with an integrated electric booster heater and a 1.2 gpm PRSV.

2. **A Partially Distributed Generation System.** The hot water system can be partially distributed using a combination of high-efficiency dishroom equipment and fixtures and demand-controlled recirculation. Utilizing an advanced energy recovery dishmachine allows the machine to be removed from the distribution system. The dishmachine is fed by cold water and utilizes a combination of energy recovery and integrated booster heaters to provide the high-temp sanitizing rinse. The addition of a high-performance PRSV operating at 0.8 gpm further reduces the dishroom's hot water load. The elimination of the dishmachine from the distribution system accommodates upgrading to a smaller (or right-sized) high-efficiency condensing tank-type water heater with about half the input rate of the conventional system's water heater. This demand recirculation system operates for an average of 12 hours per day (instead of 24/7). The resulting distribution system would still have 500 feet of piping (minus the branch to the dishmachine) and 250 feet of recirculating piping. With a reduction in the average flow rate of the water in the distribution system, pipe diameter can be reduced in strategic locations.

3. **A Fully Distributed Generation System.** The hot water system can be fully distributed by utilizing POU heaters at remote fixtures to reduce the length of the main recirculation system. The POU heaters are combined with a larger water heater located closer to the kitchen and dishroom to feed heavy use fixtures such as the pre-rinse station, three-compartment sink and mop sink. This fully distributed system reduces the amount of recirculation piping from 250 feet to 125 feet and reduces the total amount of hot water piping from 500 to 200 feet. The main water heater is much smaller in Option 3 than the other two options because it feeds fewer fixtures. The remote POU heaters are all small enough to be run on 120V service. The lavatories each have a 2 gpm heater, and the bar has three 4 gpm heaters. The fully distributed system accommodates a smaller primary water heater and allows for upgrades to more efficient, smaller-scale technologies such as a hybrid condensing water heater or a natural gas-fired or electric-powered heat pump water heater. This approach roughly corresponds to the system layout presented on page 20 of this guide.

Table 10. Operating Costs for Different Hot Water Systems in a Full-Service Restaurant.

	Option 1	Option 2	Option 3		
	Conventional System	Partially Distributed System	Fully Distributed Generation w/ NG Heater	Fully Distributed Generation w/ Electric HPWH	Fully Distributed Generation w/ Gas HPWH
Install Cost	$27,780	$29,850	$25,300	$27,800	$27,800
Water Use (gal/y)	294,000	199,000	199,000	199,000	199,000
Gas Use (therms/y)	3,257	542	453	0	395
Electricity Use (kWh/y)	29,200	40,051	44,052	48,936	44,052
Annual Operating Cost*	$12,600	$10,100	$10,700	$11,000	$10,600
First Year Cost	**$42,400**	**$40,000**	**$36,000**	**$38,800**	**$38,400**
10-Year Cost	**$155,800**	**$130,900**	**$132,300**	**$137,800**	**$133,800**

*based on $11.25/HCF, $1.10/therm, $0.19/kWh

Table 10 compares the 10-year life cycle cost for the three options. An efficient design utilizing modern energy recovery and control technologies can save the operator over $20,000 over a 10-year span.

Installation cost includes the equipment cost as well as the labor necessary to install hot water piping, gas piping and electrical service. The smaller distributed generation systems resulted in a lower installation cost, which offsets the higher initial costs of the fixtures and water heaters.

Annual water use for the three options demonstrates that water savings is primarily driven by efficient fixtures and equipment — the dishmachine and PRSV upgrades account for the most water savings.

Removing the dishmachine from the hot water loop accounts for the significant reduction in gas use between Options 1 and 2 with a slight increase in electric consumption to accommodate local hot water heating at the dishmachine. Further gas use reductions were achieved by a combination of reduced heat loss from the controlled recirculation system and a boost in water heater efficiency.

Option 2 results in a reduction of $2,500 in annual operating costs compared to Option 1. All the measures in Option 2 are retrofittable — energy recovery dishmachines and recirculation controls can be installed in existing buildings with conventional water heating systems. The caveat is that energy recovery dishmachines generally require a larger electric service than conventional dishmachines (due to the added condensing fans and a larger booster heater). This may require upgrades (panels, wiring) to the electrical service. A high-temp door-type dishmachine may require 60A service whereas a comparable energy recovery version may require 80-100A service. Some energy recovery conveyor dishmachines may require separate electrical connections for the different subsystems.

Option 3 has the lowest installation cost and the lowest energy consumption of the three options. The increase in annual operating cost between Option 2 and Option 3 were due to the shift from natural gas to electric heating sources — the 19¢/kWh electric energy rate is approximately five times greater per unit of energy than the $1.10/therm gas energy rate. One significant benefit of Option 3 is downsizing the primary water heater, which accommodates the adoption of advanced HPWH technologies and their associated space conditioning benefits.

Disclaimer: The design example is 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 this example. Close coordination with local code officials, manufacturers, engineers and contractors is recommended for all kitchen hot water system projects.

Key Takeaways

- *Design a hot water system for foodservice operations in reverse order: (1) specify efficient hot water using equipment, (2) build an efficient distribution system, (3) specify high efficiency water heaters, and (4) ensure proper installation and monitoring to ease commissioning and ongoing maintenance.*
- *Specify high-performance pre-rinse spray valves rated below 0.8 gpm.*
- *Train dishroom staff to properly operate pre-rinse operating equipment. Train staff to identify and report malfunctioning PRO equipment.*
- *For larger pre-rinse operations, specify actuated PRO equipment (scrap collectors, troughs) over continuously recirculating units.*
- *Specify ENERGY STAR®-certified or better dishmachines with heat recovery systems and only cold water supply connections.*
- *Train dishroom staff to properly identify and immediately report a malfunctioning dishmachine.*
- *Specify ultra-low flow aerators on hand sinks at 0.5 gpm or below and select (if applicable) a commercial grade point-of-use heater at hand sinks.*
- *Reduce the hot water system load to the extent possible by designing for a distributed generation system using demand recirculation controls, point-of-use heaters at remote fixtures, and heat recovery dishmachines.*
- *Design with short branch lines or eliminate unnecessary pipe drops to fixtures.*
- *Mirror the men's and women's restroom lavatories on both faces of the same wall.*
- *Specify insulation with an R-value of at least 3 on all hot water supply, return and branch lines.*
- *Position the water heater as close to the dishroom and other sanitation sinks as possible.*
- *Specify a high-efficiency hybrid condensing water heater or heat pump water heater.*

Glossary

ASME — American Society of Mechanical Engineers.

Btu (British thermal unit) — A unit of heat energy. Defined as the energy required to raise the temperature of 1 pound of water 1°F.

Btu/h — A unit of power. Describes the power or maximum input rating of water heaters.

Door-Type Dishmachines — Door-type machines typically have a one rack capacity and most utilize a manual lever that opens/closes the dishwashing cavity for loading and washing. A standard door-type machine has a wash tank of 10-15 gallons. Door-type dump and fill machines do not have a wash tank and use the rinse water from the previous cycle as wash water for the next, which is held in a sump with a 1-2 gallon capacity. Pot and pan washing machines are specifically designed to wash large, bulky items and have a cavity sized to accommodate 1-2 racks.

Exhaust-Air Heat Recovery Dishmachine — Dishmachine designs that can capture and transfer the heat and steam produced from the dishwashing process. The incoming cold water passes through a network of thin copper pipes while a fan extracts and forces steam across attached aluminum plates. The steam condenses on the cold fins and the latent heat is transferred to preheat the incoming water.

Flight-Type Conveyor Dishmachines — Found in very large institutional facilities, these machines use a conveyor belt to feed items placed directly on the belt (without a dish rack) through prewash, wash, and rinse sections. Wider and longer in size than rack conveyors, flight-type machines consist of several sections and may have several tanks with individual water inlets. Some flight-types have the option of a heater blower dryer section that dries wares after the final rinse.

FSTC — Food Service Technology Center.

HCF (or CCF) — One hundred cubic feet; 1 HCF = 748 gallons of water.

Heat Pump Water Heaters (HPWH) — Heat pump water heaters use a heat pump cycle to absorb low-grade energy from the outside air ("air-source") or a ground-coupled water loop ("water-source") and transfer that energy to heat incoming water. While electric heat pump water heaters drive a refrigerant compressor with electricity, gas absorption heat pump water heaters come in three primary categories: (1) engine-driven type gas HPWHs drive the refrigerant compressor mechanically, (2) sorption type gas HPWHs use a secondary fluid or material (absorbent) and raise refrigerant pressure with applied heat, and (3) thermal compression type gas HPWHs are an emerging category that employ a Stirling-type engine.

kWh or kilowatt-hour— A unit of energy, commonly used as a measure of electrical energy. Expressed as the product of power in kilowatts multiplied by time in hours.

Point-of-Use (POU) Water Heaters — A small, tankless water heater supplying hot water to one fixture or appliance. POU water heaters are typically installed as close as possible to the fixture to provide instantaneous hot water.

Pre-Rinse Spray Valve (PRSV) — Pre-rinse spray valves (or "nozzles") are simple spray heads attached to a manual valve operated by a staff member. Food debris is sprayed off the plate into the sink prior to being loaded into a dishmachine or three-compartment sink. PRSVs are characterized by water flow rate and spray force; lower flow rate and higher spray force are associated with higher "cleanability" efficiency. Flow rates typically range from 0.65 to 4 gallons per minute (gpm); however, a 2018 Department of Energy (DOE) regulation limits the maximum flow rate of pre-rinse spray valves to 1.2 gpm. PRSVs are designed to provide maximum cleaning pressure while minimizing water consumption.

Psi— Pounds per square inch.

Rack Conveyor Dishmachines — Machines that use a conveyor belt to feed racks of dishes through separate wash and rinse sections. 44"-long conveyor machines are the most popular segment, while 60" versions add a prewash section before the wash section and 80" machines add an auxillary rinse section. Each section is separated by curtains. Conveyor wash tanks are usually 15-25 gallons, where prewash and auxillary rinse sections add 5-10 more gallons.

Recirculation Pump — A device that circulates hot water throughout the distribution system to keep hot water readily available at equipment and fixtures. Recirc pumps should be installed with a demand controller and sensors (temperature, occupancy) that operate the pump only when hot water is needed.

R-value — A measure of thermal resistance. The higher the R-value, the greater the insulation's effectiveness.

Recovery Rate — The number of gallons of water a storage water heater can bring to temperature per hour; it is a function of temperature rise (output temperature minus inlet temperature).

Scrap Collectors — A water fountain that is used to rapidly remove food debris from wares in a large deep well. Commonly referred to as "scrappers", scrap collectors are usually found in larger institutional kitchen dishrooms. Plates are placed under the fountain flushing debris down the drain, which either has a perforated basket or a grinder/disposer. The scrapper fountain is supplied with both fresh and recirculated water. Continuous fresh water is typically supplied at 2 gpm, while the recirculated water flow rate averages about 18 gpm.

Scrap Collectors with Troughs — A shallow "river" basin through which water flows to remove debris from dishware. Water flow is provided by multiple nozzles with a total flow rate of about 70 gpm (fresh + recirculated) when paired with a scrapper. The trough can be utilized by several people simultaneously as dishes are placed in the trough and cleaned as water flows over them. The trough usually feeds into a scrap collector at its endpoint.

Tankless Water Heaters — Also known as demand-type or instantaneous water heaters, tankless water heaters heat water instantaneously without the use of a storage tank.

Tank-Type Water Heaters — Also called storage water heaters, these heaters store hot water in a tank for use at any time. Cold water enters the tank from the bottom, where it is heated to replace the hot water that was previously used. Gas tank-type water heaters feature a burner at the bottom of the tank and a center flue. Electric tank-type water heaters feature elements inside the tank to heat water.

Therm — A unit of heat energy that is used for converting a volume of gas to its heat equivalent to calculate actual energy use; 1 Therm = 100,000 Btu.

Thermal Efficiency — A performance measure of a water heater expressed as a percentage of heat (energy) output divided by heat (energy) input.

Three-Compartment Sink — Each of the three compartments of these sinks is used for a separate purpose: (1) **Wash**, (2) **Rinse**, and (3) **Sanitize**. A chemical is added to each compartment for the cleaning process. These sinks are operated by hand and often used for pots and pans to soak before sanitization.

Twig, Branch and Trunk — Distribution system piping components. **Twigs** serve one water fixture; **Branches** serve two or more twigs; **Trunks** serve two or more branches and may be connected to a return line leading back to the water heater.

Undercounter Dishmachines — Similar in footprint to residential dishmachines, undercounter machines are primarily used for washing glassware. Undercounters can accommodate one rack of wares. These machines have a tank capacity of 3- to 5-gallons.

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Notes and Acknowledgments

Funding - Original Edition (2010)

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Funding - Updated Edition (2022)

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