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Technical Design Guide for Advanced Water Heating within the Foodservice Industry

Improving Operating Performance of Hot Water Systems in Commercial Kitchens

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. It will also help you identify best practices towards building net zero energy commercial kitchens. 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 Dish Room Ventilation design guide. You can also review the Operating Guidelines for Advanced Water Heating within the Foodservice Industry for information on how commercial kitchen owners and users can optimize equipment use through commissioning needs, operating best practices, and maintenance plans.

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Introduction

This design guide discusses strategies to implement an advanced commercial foodservice hot water system that meets the health department's hot water sanitation requirements of the facility while optimizing equipment performance, water efficiency, energy efficiency, and decarbonization.

Hot water systems can account for as much as a third of a commercial foodservice facility's energy use as well as most of its water use, so proper hot water system design is paramount to meet performance requirements and keep operating costs manageable for any facility. Efficient hot water system design is also paramount to meeting net zero energy goals as every efficiency opportunity is one step closer to supporting a net zero energy 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 (HPWH) demonstrations and hybrid condensing water heater demonstrations. For information on how commercial kitchens can use and maintain equipment efficiently, please view the Operating Guidelines for Advanced Water Heating within the Foodservice Industry (referred to as the "Operator's Guide" within this document).

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.

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 and shrinking 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.

The second fundamental part of a water heating system is the distribution system, which consists of a network of piping wrapped in insulation to reduce heat loss. In moderate to large systems such as those commonly found in full-service restaurants, a recirculation loop and pump are usually 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 dish machines, 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 tempered to 100°F.

The third component to the hot water system are the hot water-using equipment and the fixtures. Hot water-using equipment includes dish machines and cooking equipment, such as steam tables or steam cookers. Hot water fixtures include hose bibs, pre-rinse operating equipment, and hand sink and prep sink faucets. The use of equipment and fixtures 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 washdown can also be major hot water draws.

Commercial kitchens are highly energy intensive. Based on energy modeling published in the Zero Net Energy Commercial Market Characterization report (TRC 2019), restaurants have a much higher EUI than other commercial building types. Much of that energy intensity is due to hot water use, which is typically heated by natural gas water heaters. According to Energy Efficiency Potential of Gas-Fired Commercial Water Heating Equipment in Foodservice Facilities (Delagah and Fisher 2009), water heating for foodservice applications represents 340M Therms of gas consumption annually in California, representing 16 percent of commercial gas usage statewide. With so many kitchens relying on natural gas to heat hot water, major design shifts need to occur to support these facilities becoming zero net energy by 2030, as defined by the state's decarbonization goals. Simply transitioning from gas to electric heaters, however, is not cost effective and therefore assessing the full design and finding energy efficiencies throughout the water heater system is a crucial first step towards decarbonizing full-service restaurants.

To better understand how energy and water efficiencies in commercial kitchens impact the bottom line, one needs to first understand how much energy and water are used by hot water systems. Table 1 presents typical hot water system costs of conventional designs for quick-service (QSR) and full-service restaurants (FSR). These designs conform to early 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 dish machines (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 and electricity usage from a high-temperature dish machine with an electric booster heater. Both restaurants have some common fixtures such as mop, compartment, and hand sinks. The difference is a QSR uses disposable containers and cutlery for the dining area and a three-compartment sink to wash kitchen wares and a FSR uses reusable wares for the dining room and has two dish machines (an undercounter at the bar and a door-type in the dish room).

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	500	1,600	-	$3,400	$2,900	-	$6,300
Full-Service Restaurant	2,000	8,400	73,340	$13,700	$15,100	$23,600	$52,400

*Based on $14.13/HCF, $1.80/therm, $0.32/kWh.

The savings potential for a best-in-class hot water system design is substantial. Best-in- class technologies include heat recovery dish machines, 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 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	-	$2,700	$1,800	-	$4,500	$1,800
Best-in-Class FSR	1,600	5,500	63,870	$11,000	$9,900	$20,600	$41,500	$10,900

*Based on $14.13/HCF, $1.80/therm, $0.32/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 and support net zero energy building practices.

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 dish room, which is where the largest portion of hot water is used. Reducing hot water use of the pre-rinse equipment and the dish machine 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 dish machine, 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 the placement of sinks and equipment in relation to the water heater, the distribution pipe size and layout, the installation of continuous pipe insulation and use of best insulation installation practices, and proper installation of pipe hangers. Consider distributed generation for remote bars and other fixtures far from the mechanical room.
3. **Optimize the Control of the Recirculation Loop from Both Ends -** Larger buildings require hot water to be pumped in a distribution loop around the building, known as the recirculation loop, to ensure hot water is available nearby to all hot water using fixtures. It is important to install a master mixing valve (MMV) at the start of the distribution system to precisely control the supply temperature. MMVs offer higher efficiency water heater operation from improved water temperature stratification in the tank, distribution loop pipe heat loss savings, and the ability to safely increase storage heating capacity. On the end of the recirculation system is the recirculation pump and controls. Specify a properly sized variable speed ECM pump with constant-temperature controls that operate at much lower power levels while maintaining a precise recirculation return temperature for energy savings.
4. **Specify High-Efficiency Water Heater(s) -** To fully optimize the water heating system design, specify high-efficiency condensing water heaters or heat pump water heaters. Before the hot water system design is finalized, consider integrating other pre-heating technologies such as refrigerant heat recovery, drain water heat recovery, or solar preheating. To decarbonize existing facilities, consider hybrid electric resistance heat pump water heaters for low hot water load applications such as quick service restaurants, and heat pump assist to maximize the benefits of gas and heat pump water heating for larger loads. Various water heater configurations with controls can also help facilities manage when the facility uses the water heating system and to increase the temperature of the storage tank when renewable energy is plentiful and cheap, and then be able to count on that stored energy to help limit use during peak periods. These controls are especially important for electric resistance water heaters.
5. **Commission & Develop a Maintenance Plan -** Proper installation and simple monitoring of equipment can help maximize efficiencies of the hot water system. Refer to the Operator's Guide for commissioning and maintenance recommendations.

1. Equipment & Fixtures

As described in the Design Path for Savings, specifying 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 dish machine, the pre-rinse spray valve, and the aerators on sink faucets. Efficient equipment or fixtures, as long as they offer equal or better performance than conventional models, will translate into long-term savings. This section presents guidelines for selecting the following key components of kitchen equipment: pre-rinse operating equipment, dish machines, utility sanitation fixtures, and bars and auxiliary fixtures.

PRE-RINSE OPERATING (PRO) EQUIPMENT

The most important and common 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.

Pre-Rinse Spray Valve (PRSV)

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 dish rooms. 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 large throughput, such as a cafeteria that needs to serve many people in the dining room at once.

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 dish room 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.

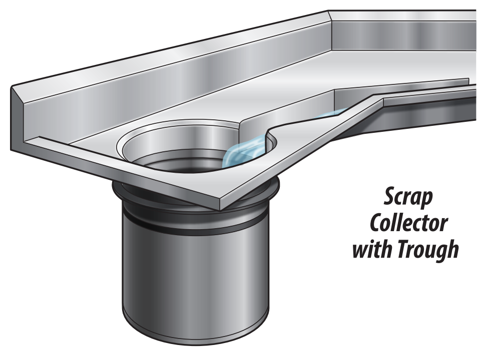
Commercial disposers use between 3 and 10 gpm of fresh water and essentially work like an upsized garbage disposer with a spinning blade inside to grind food scraps going down the drain. Unlike a residential disposer, water is automatically injected into the grinding cavity during the process. Disposers 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 it allows a larger channel for operators 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 two to three nozzles and allows multiple staff members to work simultaneously. These nozzles each use between 2 to 3 gpm of fresh water.

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

A field evaluation of 15 sites with PRO (Delagah and Karas 2018) has shown the most water and energy efficient methods are the use of dry scraping and PRSVs independently or in combination. The second-best methods are using dry scrapping or PRSV with manually operated disposer. Field testing has shown these methods use 0 to 200 HCF of water and 0 to 1,000 Therms of natural gas to heat water annually. Continuously flowing scrappers and trough collectors, and floor spraying hoses as installed and operated, are much more wasteful and use 800 to 1,800 HCF and 4,000 to 8,000 Therms annually.

Lastly, if the facility is large enough, consider specifying room to dry scrap wares and multiple PRSVs in the PRO area that can allow more workers to scrap dishes at the same time. This will reduce the misuse of non-PRO equipment like floor hoses, which can lead to large inefficiencies in water consumption.



Scrap Collector with Trough

COMMERCIAL DISH MACHINES

The most important piece of equipment in a commercial foodservice facility is the dish machine. The dish machine most likely consumes more hot water than any other appliance in the building. Every part of a commercial foodservice operation depends on the dish machine to function correctly. Additionally, health departments regulate the operation of dish machines (target rinse temperatures) and can shut restaurants down for running a malfunctioning machine.

Dish machines are also important from an energy and water perspective. In addition to using between 25 percent and 75 percent of a facility's hot water, dish machines 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 dish machine. Dish machines come in six main classes: undercounter, glass-washers, upright door-type, pot and pan, 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 dish machines 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. Other specialized types of commercial dish machines include glass washers that may be used at the bar and pot and pan dish machines that are taller and sometimes double wide versions of the door-type dish machine that are suited to handle bakery and heavy-duty kitchen wares. To explore the efficiencies of these models, this section first presents information on conventional hot water-fed dish machines, and then presents information on heat recovery dish machines.

CONVENTIONAL DISH MACHINES

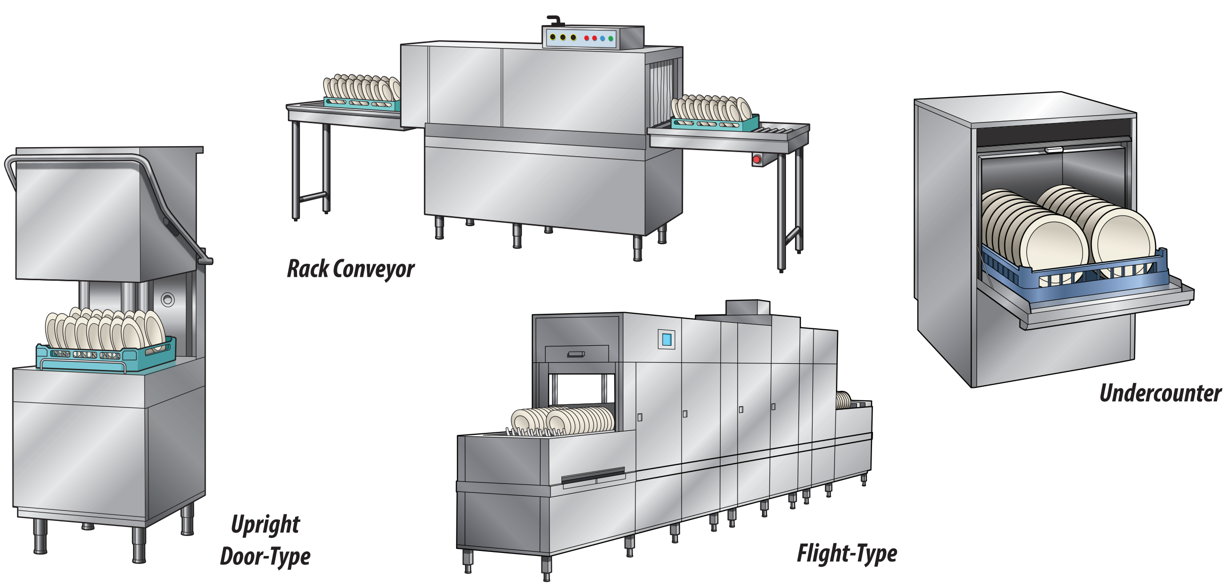
Traditionally, there are two types of commercial dish machines based on sanitation method: low-temperature chemical-sanitizing and high-temperature sanitizing. Low-temperature (or "low temp") chemical-sanitizing machines wash at 120 – 140°F and final rinse at 140°F with the aid of chemical sanitizing agents. A low-temp dish machine uses three chemicals: a washing agent, a rinse aid and 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 dish machines 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.

Specifying a high-performing, high-temperature dish machine from the outset or retrofitting an old, low-temperature dish machine with a new, high-temperature dish machine is one of the fastest ways to ensure water and energy savings on a foodservice facility's hot water system. The biggest deterrents of high-temp machines are 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 dish machine 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 percent 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 dish machines 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 dish machine 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, and 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 Dish machines.

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 3,800 Btu/rack	0.95 gal/rack 2,600 Btu/rack	0.75 gal/rack 2,000 Btu/rack

*includes dish machine 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 dish machines. This data is based on field monitoring of 16 rack and nine flight-type conveyor dish machines.

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

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

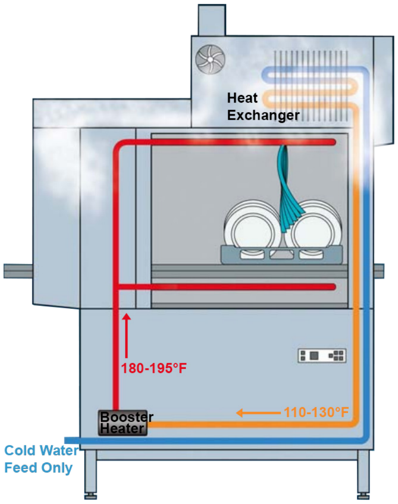
*includes dish machines fills and top-offs.

There is a clear difference between conventional, ENERGY STAR®, and best-in-class dish machines 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 dish machines regardless of size is that these machines tend to operate much closer to the manufacturer's specifications in the real world than conventional machines. This is because door-type machines utilize pumped rinse operations and conveyor-type machines utilize advanced communication and monitoring systems and advanced tank filtration technology to reduce fill and top-off water consumption as well as pumped rinse operation. Best-in-class exhaust air heat recovery conveyor machines also minimize fouling of the heat exchanger through a specialized cleaning cycle and managing clean air flow through the unit.

HEAT RECOVERY DISH MACHINES

By capitalizing on waste heat to preheat incoming hot water, energy recovery systems reduce both water heating and ventilation loads associated with dish machine 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 percent 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 dish machines 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. It is recommended, that the specified dish machine with exhaust-air heat recovery system employ a hot water automatic washdown of the heat exchanger to minimize fouling and maintain proper heat exchange funtion. 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 dish machine'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 Dish machine 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 dish machine heat recovery technologies and HVAC implications, please refer to the Sizing Dish Room Ventilation design guide.

Table 5 compares three dish machines installed at a restaurant in Northern California. The baseline machine was a seven-year old ENERGY STAR® high-temp dish machine monitored for water and energy use. This unit was replaced with a current ENERGY STAR® dish machine, then replaced again with an exhaust-air heat recovery dish machine. Of the three machines, the exhaust-air heat recovery dish machine 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 Dish Machine 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	1.40	$0.28	$22,800
ENERGY STAR Dish machine	12	247	0.95	$0.23	$18,500
Exhaust-Air Heat Recovery Dish machine	Pumped Rinse	201	0.75	$0.20	$16,600

*Based on $14.13/HCF, $1.80/therm, $0.32/kWh.

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

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. 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. This high flow rate has many implications for hot water systems — during cleanup, these sanitation fixtures 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 dish room 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.

A water broom, 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.

BARS & AUXILIARY FIXTURES

Considerations should be made for restaurants with auxiliary hot water fixtures in the front-of-house like bar areas. Bars require the use of a three-compartment sink and a hand sink for sanitation and may include a undercounter dish machine and utility sink to support bartending functions. Other auxiliary cleaning devices that may be used include 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 dish machines 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 typically are not major users of hot water.

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 (IAPMO 2022) 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.

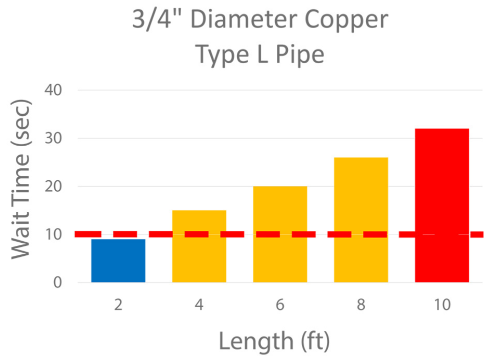
The figures to the right show the effects of pipe size on reducing hot water delivery time. A strategy to improve delivery performance is to reduce the diameter of the branch and/or twig piping leading from the trunk line to the hand sink(s). To simplify the wait time estimation, it is assumed that the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

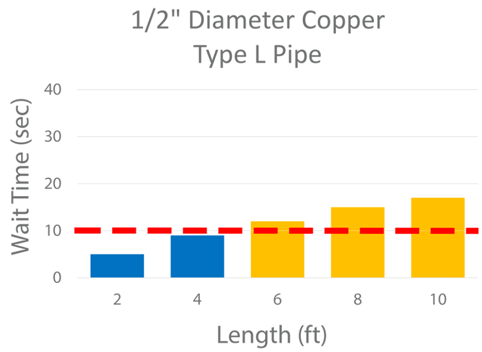
A common practice is to specify ¾-inch diameter branch piping for two or more lavatories. With 10 feet of ¾-inch diameter branch piping and a 0.5 gpm aerator installed, the wait time would be 33 seconds before the 0.28 gallons of water is purged and hot water reaches the faucet.

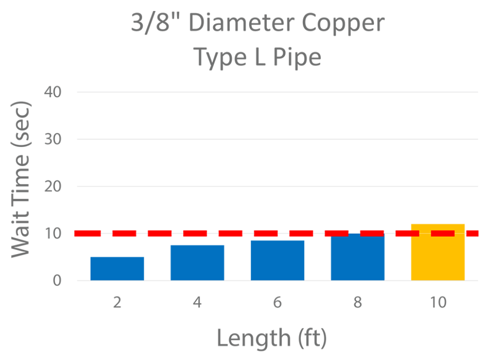
For better delivery performance, ½-inch branch piping will effectively serve up to four lavatories that have a maximum total flow rate of 2 gpm. ¾-inch branch piping should be used to service five or more lavatory sinks. 3/8-inch branch piping would provide the best delivery performance when paired with 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 point-of-use (POU) heater installed with one 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







2. 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 building design process, and many constraints already exist. These constraints include the locations of the dish room, 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 system 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 dish room on a wall opposite the front-of-house and place any auxiliary bar fixtures or restrooms on the other side of the dish room wall.
- Centrally locate the utility room near major points-of-use.

In thinking about distribution systems, there are two main considerations: the distribution design and pipe insulation. This section first presents information on the distribution design, it then identifies considerations for pipe insulation.

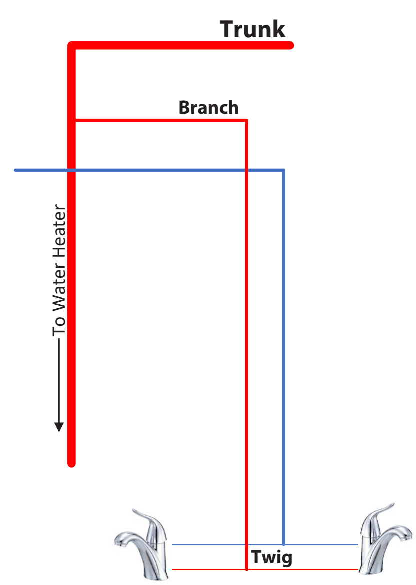
DISTRIBUTION SYSTEM DESIGNS

There are four main types of distribution systems that can be used in a commercial foodservice application, which are each explained in this section:

1. **Simple Distribution** – supply piping with no return loop.
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 Systems

A simple distribution system uses a trunk, branch and twig configuration 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 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 cold 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 dish machine, while a second tempered line delivers tempered water to hand sinks to prevent scalding.

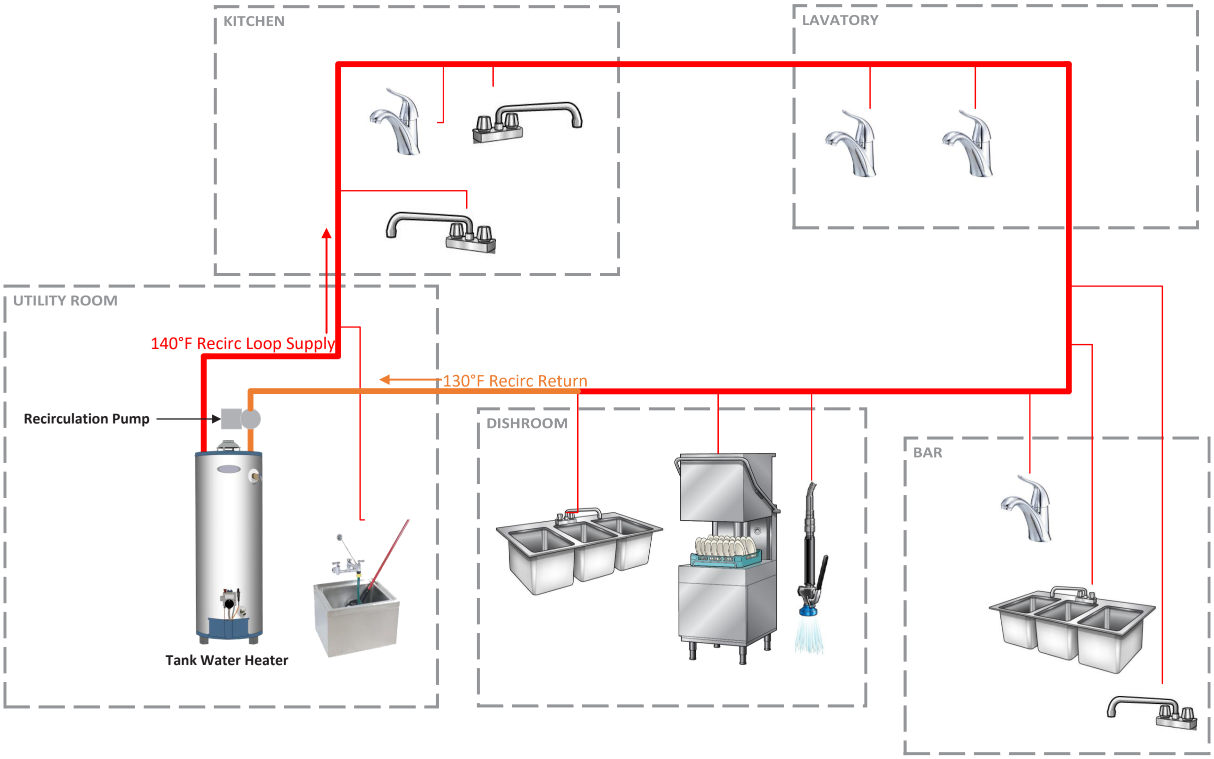


Simple Distribution with Trunk, Branch, and Twig Configuration.

Continuous Recirculation Systems

Continuously circulating hot water through the main distribution line and back to the heater, as seen in the figure below, ensures that there is hot water near the system temperature setpoint in the trunk line at all times, in essence moving the water heater closer to points-of-use. 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 requires 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.

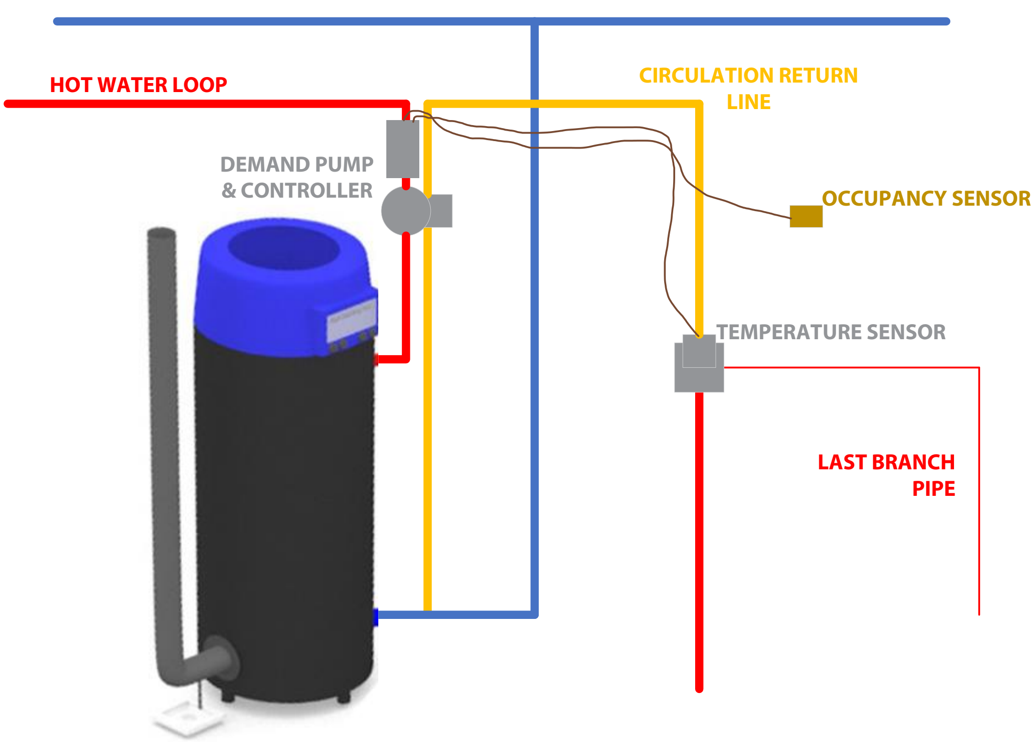


A Conventional, Continuous Recirculating Hot Water System

Demand Circulation Systems

A demand circulation system, illustrated in the figure below, 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 percent 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.

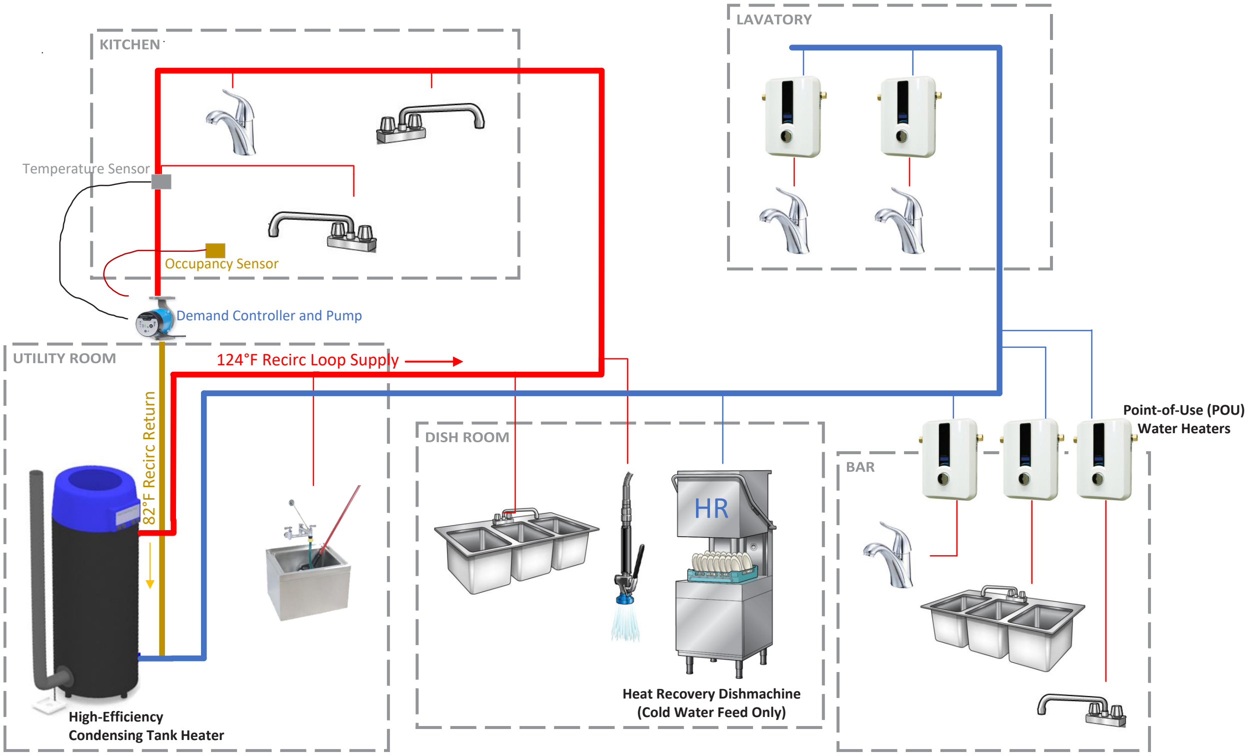


A Demand Recirculation Hot Water System with Controller, Pump, Occupancy Sensor and Temperature Sensor.

Distributed Generation Systems

Distributed generation can either comprise a 100 percent distributed system (i.e., multiple simple distribution systems) 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, illustrated in the figure below, 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 (Frontier Energy 2018).

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 percent hot/50 percent 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.

Pipe Insulation

Pipe insulation requirements for commercial DHW systems are located in the Title 24 building energy efficiency standards, Part 6, Section 120.3. Piping for domestic hot water systems shall be insulated to meet the pipe insulation thickness requirements of Table 120.3-A, shown in Table 6.

Table 6. Pipe Insulation Thickness Requirements.

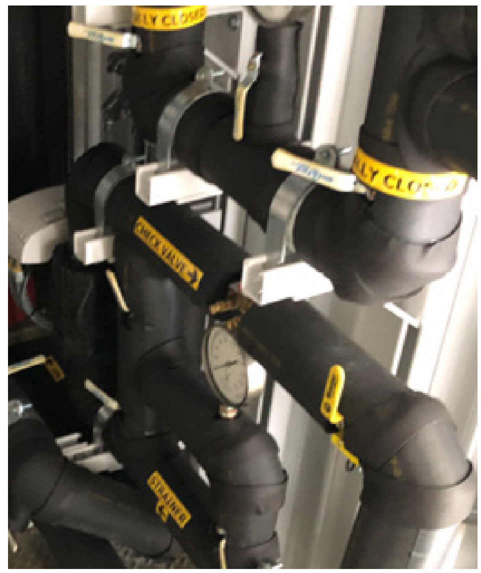
FLUID OPERATING TEMPERATURE RANGE (°F)	INSULATION CONDUCTIVITY			NOMINAL PIPE DIAMETER (in inches)				
	Conductivity (in Btu•in/ h•ft2•°F)	**Mean Rating Temperature (°F)**		**< 1**	**1 to <1.5**	**1.5 to < 4**	**4 to < 8**	**8 and larger**
Space Heating and Service Hot Water Systems				**Minimum Pipe Insulation Required (Thickness in inches or R-value)**				
141—200	0.25—0.29	125	Inches	1.5	1.5	2.0	2.0	2.0
			R-value	R11.5	R11	R14	R11	R10
105—140	0.22—0.28	100	Inches	1.0	1.5	1.5	1.5	1.5
			R-value	R7.7	R12.5	R11	R9	R8

The building energy code is unclear whether the requirements extend to insulating the piping connected to the water heaters or storage tanks, and appurtenances in series with the hot water piping. However, the intention is that the pipe insulation should be continuous throughout the system, from the water heater, storage tank, distribution system and through to each piece of equipment. Benefits of insulating pipes are energy savings, cost savings, minimal to no maintenance needs, and improved hot water delivery performance. The below bullets provide a list of insulation best practice specifications that the plumbing system designer needs to include on plumbing plans to ensure that pipe heat losses are further minimized. Hot water piping includes the pipe or tube and the fittings (elbows, tees, couplings, etc.). Plumbing appurtenances include all elements that are in series with the hot water piping, such as: flanges, pumps, valves (isolation, mixing, balancing, check, etc.), strainers, hose bibs, meters, sensors, heat exchangers and air separators.

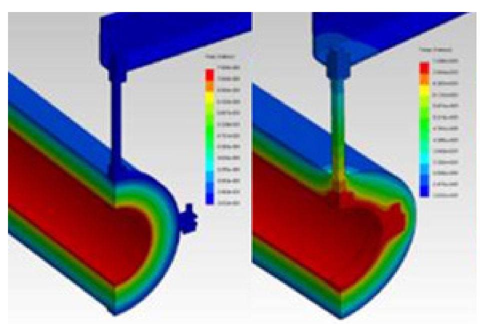
Insulation best practice specifications:

- Insulate inlet cold water piping from the expansion tank to the storage tank or storage heater.
- Continuously insulate the piping and appurtenances.
- To prevent thermal bridges, attach pipe supports, hangers, and pipe clamps on the outside of rigid pipe insulation to prevent heat from transferring to pipe support assembly through conduction.
- Seal all pipe insulation seams.
- Install insulation for pipe elbows that are mitered, preformed, or site fabricated with PVC covers.
- Install insulation for tees that are notched, preformed, or site fabricated with PVC covers.
- Install extended stem isolation valves.
- Meet the following requirements for insulation on all plumbing appurtenances on piping from a heating source to storage tanks, piping connected to tanks, and piping throughout the distribution system:
    - » Where the outer diameter of the appurtenance is less than the outer diameter of the insulated pipe that it is attached to, insulate the appurtenance flush with the insulation surrounding the pipe.
    - » Where the outer diameter of the appurtenance is greater than the outer diameter of the insulated pipe that it is attached to, insulate the appurtenance with a minimum thickness of 1”.
    - » Allow the insulation to be removable and re-installable to ensure maintenance or replacement services can be completed.
    - » Ensure insulation does not impede the functionality of the valve (e.g., opening and closing an isolation valve).

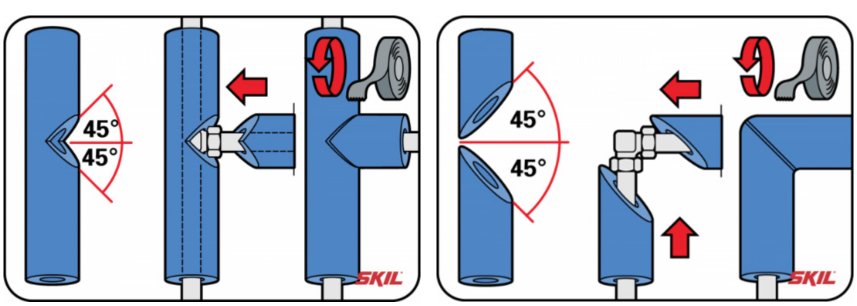
Cold Water Pipe Insulation Leading Back to Expansion Tank. (TRC 2023)



Continuous Pipe Insulation with External Pipe Supports. (Ecotope 2021)



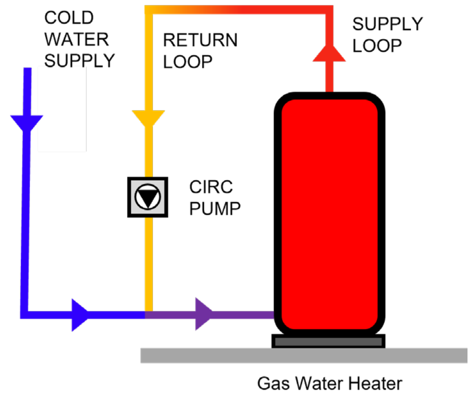
(Left) No Thermal Bridge with Pipe Hanger and Clamp on Outside of Pipe Insulation. (Right) Thermal Bridge with Hanger and Clamp on Inside of Insulation. (Walraven 2023)



Examples of Notched Tee and Mitered Elbow. (SKIL 2023)

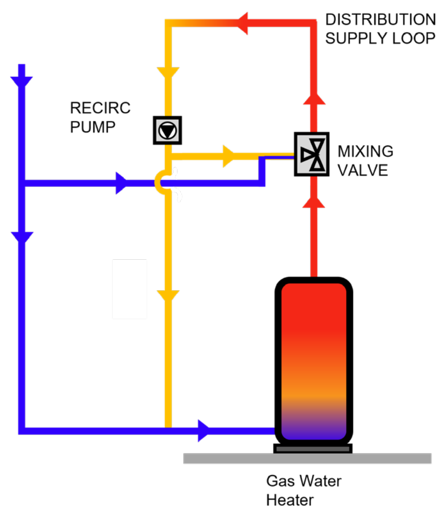
3. Water Recirculation Controls

Once the type of distribution system has been specified, the next step is to consider hot water delivery performance to fixtures in larger DHW systems. There are three ways to control the recirculation loop to save energy, to mitigate scalding and pathogen risks, and to minimize long term erosion in the piping. The designer has the option to control the supply and return temperature in the recirculation loop, the water flow rate, and the use of continuous or intermittent water pumping. Optimizing the control of the recirculation system by precisely controlling the supply temperature at the start of the recirculation system and controlling the pump flow rate and operation at the end of the distribution loop are the most viable options.



Continuous Recirculation System

Master mixing valves and recirculation pumps with electrically commutated motor (ECMs) and/or demand controllers are useful technologies in maximizing the performance of the hot water system. Master mixing valves do this by increasing storage capacity, and these technologies provide distribution piping heat loss savings and increase hot water stratification in the storage tank. These are each described in this section.



Continuous Recirculation System with Mixing Valve

MASTER MIXING VALVES

Large kitchens require continuous recirculation systems to ensure hot water is available close to points of use at specified temperatures, commonly 120°F and 140°F. Both mechanical and digital master mixing valves (MMV) are types of thermostatic mixing valves defined by the capability to sense the water heater or storage tank outlet temperature and actively mix the right ratio of incoming hot and cold water to maintain the desired output temperature. The MMV must be installed on the central heater or storage tank hot water supply outlet header leading to the hot water distribution supply piping. MMVs are traditionally not installed in restaurants, but they are installed for pathogen and scalding mitigation in hospitality, healthcare, multifamily and other building segments.

The valve ensures most of the hot water returns to the cold side of the MMV and bypasses the storage tank, which promotes water temperature stratification in gas-fired or heat pump-based indirect storage tank systems or integrated water heaters, leading to higher efficiency operation. The MMV provides distribution loop pipe heat loss savings by better controlling the outlet temperature from the water heater. Outlet temperatures typically have a deadband range of ±5 to 10°F for activation and deactivation of the heater, which can vary the outlet temperature to the distribution system. MMVs can safely increase stored energy capacity by raising the temperature of the storage tank without raising the temperature of the distribution system. Laboratory testing to mimic the operation of a DHW system in a multifamily building at PG&E's Applied Technology Services Hot Water System Laboratory showed a 10 percent reduction in energy use when an MMV was installed on a hot water outlet supply line of a heat pump water heater (HPWH) compared to when mixing occurred manually at fixtures, such as sinks or other equipment. With gas-fired water heaters that also rely on tank stratification to improve thermal efficiency of the heater, there is significant savings especially from condensing models, but these savings have not been researched in the laboratory at the time this guide is being written.

MMV performance can vary even with established performance standards set. MMVs should be installed and commissioned in accordance with manufacturer's instructions. While mechanical MMVs have been around since 1911, more innovative products under the digital MMV category were introduced starting in 2005 (Contractor 2010) that better deal with pumped recirculation hot water systems and offer modern features such as remote control and monitoring capabilities.

Digital MMVs require less maintenance and offer higher accuracy, performance, and versatility. Additionally, they are more responsive to temperature fluctuations and pressure changes in the hot water system. Digital MMVs more accurately maintain the setpoint temperature to ±1 to 3°F, and they are designed to operate with modern DHW systems with recirculation and wide variation in water draws. Digital MMVs also offer energy savings for the systems' pumps due to reduced pressure drops, reduced temperature fluctuation between low and high demand periods, and increased ability to maintain loop temperatures during minimum demand periods (Ali Rahmatmand et al. 2020).

Compared to mechanical MMVs, they minimize energy waste by limiting cold water intrusion into the distribution loop during draws (Ali Rahmatmand et al. 2019). Furthermore, digital MMVs can direct up to 100 percent of the return flow back to the distribution system by fully closing off the hot inlet port to prevent temperature creep, thus reducing scalding risk and pipe heat loss. Most digital MMVs reduce routine maintenance through daily exercise functions of the valve to minimize scale build-up. They also ensure smooth operation compared to mechanical MMVs that are impacted by hard water, which affects the mixing accuracy and operation. With the advance of central HPWH systems, the use of faster response digital MMV offers greater load shifting capabilities and improves the reliability of single pass heat pumps in certain recirculation return to primary tank design configurations.

RECIRCULATION PUMPS

Domestic hot water circulators are simply water pumps used in many foodservice applications including restaurants, cafeteria, and other buildings where the water heater is more than 60 feet away from the last hot water using equipment or sink. Conventional inline pumps powered by standard induction motors operating at constant speed are found in 90 percent of field installations, and they are typically oversized. A comparison of pump operating costs between standard and advanced electrically commutated motor (ECM) based pumps is shown in Table 7.

ECM Pump with Constant Temperature Control Mode. (Grundfos 2023)

Table 7. Recirculation Pump Operating Cost Comparison.

	Avg. Power (W)	Max Head (ft.)	Annual Energy Use (kWh)	Pump Cost	Install Cost	1st Year Operating Cost	Annual Maintenance Cost	1st Year Cost	15th Year Cost
1/6 HP 3 Speed Pump (Low speed)	150	24	1314	\$700	\$450	\$420	\$1001	\$1,700	\$10,600
1/8 HP ECM Pump in Constant Temp. Mode	12	20	88	\$1,770	\$750	\$30	\$0[1]	\$2,600	\$3,100
1/6 HP Pump with Demand Control	150	24	99	\$1,100	\$750	\$30	\$100	\$2,000	\$3,900

[1] Maintenance costs for standard and ECM pumps referenced from NREL report (GSA 2018)

An ECM pump offers more efficient motors and intelligent speed control that adjust their power output to changing demand. Switching from a conventional pump to ECM pump operated at fixed speed can provide approximately 20% savings. Installing a stainless-steel ECM pump with constant temperature control mode uses an internal temperature sensor in the pump to automatically maintain a constant return temperature, which is ideally suited for DHW recirculation return applications. This set point is typically set to 10°F below the distribution supply temperature. With advanced ECM pumps in constant temperature mode, the savings are much higher at above 90% (Dean 2018) (GSA 2018). Recirculation pumps are typically operated 24 hours a day to ensure there is hot water available during preparation, operating hours, and after-hours cleanup. Advanced ECM pumps for restaurant applications have less than three-year payback periods and may offer \$7,500 savings in their 15-year effective useful life (Putnam 2017) not accounting for additional savings from improving water temperature stratification in the tank.

Operating a conventional pump with a demand controller that is set up to activate the pump on flow and deactivate the pump when the recirculation return temperature sensor senses hot water is also a cost-effective option in terms of pump costs. It reduces pump run time significantly to an estimated 1.8 hours per day.

4. Water Heaters

Now that the distribution system has been designed, the last step is to design for the water heating equipment and hot water storage. This section discusses how to select and size water heaters for various applications in keeping with the California Department of Public Health sizing guidelines. It starts by characterizing the primary water heater technologies. It then compares these technologies to each other, reviews sizing guidelines for each technology, and explores cost and space requirements of heater types. Finally, it considers hot water storage to help manage peak demand.

PRIMARY WATER HEATER TECHNOLOGIES

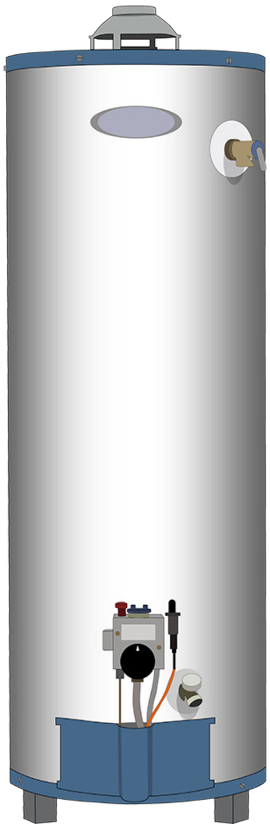
The most common type of water heater in restaurants is gas-fired tank-type water heaters, followed by gas tankless heaters. These two technologies comprise 90 percent of the installed water heaters in California (Delagah and Fisher 2009) and these technologies will be discussed in depth with regards to technology and sizing guidelines. Next, electric resistance tank-type water heaters are commonly found in smaller facilities such as coffee shops, sandwich shops, or quick-service restaurants in all electric strip malls. Some small restaurants including a prominent sandwich chain restaurant elect to use a distributed generation model that utilizes a small storage heater for compartment and mop sinks and POU electric tankless heaters or mini-tank heaters at kitchen hand sinks and lavatories. The last technology that is at its infancy in the commercial foodservice segment is electric or gas HPWHs. Currently, there is no established health department sizing guideline for HPWHs, thus their specification requires local county health department approval on a case-by-case basis. Electric HPWHs are more widely available on the market and support local community and California's goals for decarbonization. Each of these water heater types is described next.

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 percent 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 $9,000. The prices have gone up for the California market as the burners have to be specially designed to meet regional air quality departments ultra-low NOx guidelines (HD Supply 2023). 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 percent depending on how often the water heater's burner cycles on and off.

A storage water heater can run out of hot water during heavy usage if it is undersized for water volume or burner input rate, which is a sanitary concern in foodservice operations. Moreover, emptying a whole tank of hot water in a



Standard Gas-Fired Tank-Type Water Heater.

short 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. Gas-storage water heaters are priced based on sales volume, thus a 100-gallon integrated storage water heater with 200,000 Btu/hr rated burner, which is the most commonly purchased unit, will have the lowest cost per Btu/hr, and likely cost the same as a 150,000 Btu/hr heater. Generally, gas storage water heaters have high input rates versus storage volumes and heat water quickly when compared to electric heaters. The venting costs for standard efficiency heaters may be higher because they use metal galvanized piping to handle the higher exhaust temperatures.

CONDENSING WATER HEATERS

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

High-efficiency, condensing water heaters achieve their rated efficiencies by condensing water vapor contained in the exhaust gases, which produces liquid condensate as a byproduct. To condense, the water temperature in the tank must be stratified so the coldest water at the bottom of the tank makes contact with the hottest exhaust gases that travel through the heat exchanger and up the flue. 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 percent and 95 percent. An important caveat is that the operating efficiency depends on the temperature of the recirculation return, the recirculation return flow rate to the tank, and volume of hot water use.

For a condensing water heater to achieve higher operating efficiencies, the recirculation return pipe shall be controlled for either temperature and/or flow rate coming back to the water heater. Two methods to maintain condensing operation include demand recirculation control to lower the return recirculation temperature, and the use of master mixing valves to reduce the return flow rate by nominally 75 percent back to the water heater. 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 percent on top of the initial cost of a standard efficiency water heater.

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, while condensing water heaters are more expensive to purchase than standard efficiency heaters, they can be less expensive to install, 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 more favorably. Nevertheless, it is recommended to specify condensing water heaters over their conventional counterparts, when applicable.

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 less expensive PVC piping in certain applications.

GAS-FIRED TANKLESS WATER HEATERS

A tankless heater is an attractive option with respect to its lower purchase cost and ability to be wall hung, saving floorspace. Multiple heaters can be installed in parallel to meet flow rate requirements and offer redundancy so the restaurant can still operate even if one heater goes down. It is offered in standard efficiency and high efficiency condensing models.

Tankless water heaters have become more popular for smaller foodservice facilities because of their space saving benefits, but other than for very small facilities such as small QSRs, sandwich shops and cafes, they are overwhelmingly likely to cause hot water delivery problems in most scenarios and generally shouldn't be used in larger restaurants unless the installation of a storage tank is not possible.

Tankless heaters have limitations when used in larger commercial kitchens. The primary challenge associated with tankless heaters is proper sizing to accommodate sufficient supply of hot water to all the fixtures during a peak demand scenario such as clean-up at the end of shift. If a commercial dish room was fed by tankless water heaters only, the heaters would need to supply hot water for a fill cycle of a dish machine 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 supply temperature and starve the system of hot water. This flow rate reduction and water pressure loss can have a devastating impact on a dish machine'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.

Integrating a tankless heater with a recirculation system generally requires an investment in a more complex system. Other limitations of a tankless heater are 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 to go through safety sequence and on average 15 seconds before the heated water is near the setpoint temperature. The cold-water sandwich and hot-water lag issues create an incompatibility especially with door-type and undercounter dishwasher and its need for immediate hot water in a short duration.

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.

Other considerations are that steel venting must be used with standard efficiency tankless heaters. Less expensive PVC piping can be used with condensing tankless water heaters. Gas piping for tankless 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.

GAS-FIRED INDIRECT WATER HEATERS

Indirect water heaters are typically installed in very large restaurants and cafeterias and have a water pump to circulate water through the heat exchanger in the heater and supply and return piping connected to a storage tank. They offer an extended life operating period and redundancy as they typically use multiple sets of burners per unit and are separated from the storage tank. They are expensive to purchase and install and take up a larger footprint.

ELECTRIC RESISTANCE WATER HEATERS (ERWH)

Although still utilized, discussion of centralized tank integrated ERWH will be limited due to their expensive operating costs in restaurants at roughly three to five times that of gas or electric heat pump alternatives. ERWH 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. As the first costs and the health department regulatory barriers to installation of electric heat pumps fall in the coming years, ERWH will almost certainly lose market share because split HPWHs and hybrid WHs with both resistance element and heat pumps integrated into one tank will offer much lower operating costs.

ELECTRIC RESISTANCE TANKLESS WATER HEATERS

Centralized electric tankless heaters require higher amperage wires and larger subpanels compared to electric tank-type heaters. It may require a larger amp service panel, which usually carries a hefty fee from the utility. After installation, it also drives up peak demand charges on the monthly bill. The only viable use of this technology is as a backup heating source when using conventional refrigerants for a heat pump based DHW system during the winter periods when the temperature falls below 40°F and the HP cannot operate or when the unit fails.

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 and transfer it into water. Only air-source heat pumps that draw heat from outdoor or indoor air will be discussed in this guide. These units have effective thermal efficiencies greater than 100 percent, i.e., coefficients of performance (COP) greater than one.

The efficiency and capacity of a HPWH 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). The larger the storage volume also ensures higher operating efficiencies by minimizing heating cycles and the ability to heat a larger volume of lower temperature water depending on the location of the temperature sensor and setpoint.

Unfortunately, sizing HPWHs is similar to sizing indirect gas water heaters and conventional tank-type water heaters according to their hourly recovery rate. The existing health department sizing guidelines do not depend on the storage volume, thus sizing with 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 greatly undersized with the use of a conventional backup heater, there will be limited energy savings over a conventional water heater; if the HPWH is oversized for heating rate, 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.

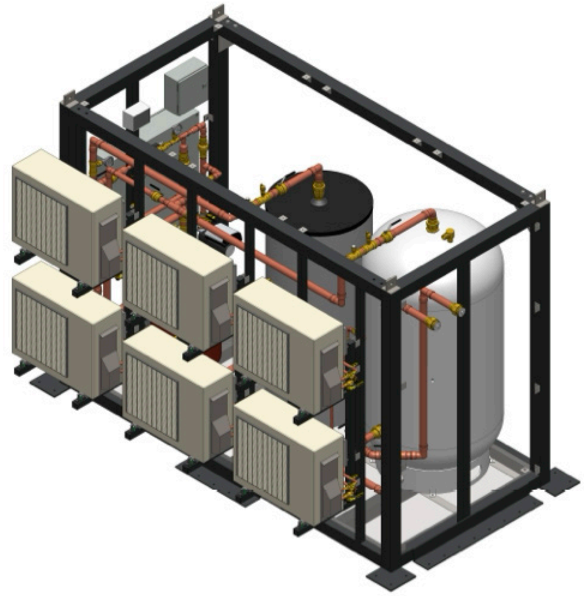
With accurate sizing and planning, it is possible to optimize the size and water storage capacity of the HPWH for the load and achieve the maximum benefit. The initial cost of HPWHs increases with size. As a result, the most cost-effective approach is to optimize end use with efficient equipment to accommodate a smaller capacity water heater. Research in a recent CEC study suggests that sizing the HPWH to meet 30 percent to 60 percent 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. However, 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 siphon energy from the surrounding ambient air via a refrigeration cycle and transfer this energy to preheat incoming water. Electric HPWHs may 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 or utilize HPs to meet the primary load from hot water draws and ER heater to meet some or all the recirculation system hot water load from pipe heat losses and ensure adequate loop temperatures are maintained in the recirculation loop.

Electric HPWHs are available in multiple configurations but not limited to light-commercial standalone hybrid systems, residential custom engineered split systems, and 'plug n play' skid systems. Lower cost light commercial standalone units where the heat pump unit is conveniently located above the electric resistance water heater as one integrated unit may be used in a light-duty application such as a café or small quick-service restaurant. Typical input rates for light-commercial units are around 13 kW, which includes 1 kW for the heat pump compressor and 12 kW for the backup electric resistance heating element. Rated COP of hybrid heaters is nominally 4.0, but operating COP can range from as low as 1.5 COP with systems with continuous recirculation to upwards of 3.0 with no recirculation or with optimized recirculation system controls. Split systems are generally more efficient with operating COPs ranging from 2 to 4 since they can take advantage of single pass heating and have much larger technologically advanced condensing units. Split systems that utilize modern refrigerants a working fluid, such as 744a, better known as CO2 can operate at full capacity at much lower ambient temperatures and can produce hot water at lower capacity all the way down to -20°F, than conventional refrigerant 134a. Commercial units are generally engineered systems with the heater and storage tank are selected independently and the system designed specifically for the facility and can be placed indoors or outdoors.

HPWH with Packaged Evaporator, Compressor and Hot Water Storage

Commercial units are starting to be offered as a plug and play skid system, where the unit is pre-designed, installed and commissioned at the manufacturer's site prior to shipping to the site, which reduces overall cost and startup time.



HPWH Split System Skid Installation Schematic

Colmac Split HPWH System with Hot Water Storage Rooftop Installation

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 still an emerging technology and carry much higher installed costs with limited efficiency savings as compared to condensing gas storage water heaters, while they can be set up at an additional cost to provide auxiliary HVAC space cooling benefits. Commercially available gas HPWHs have operating COPs in the 1.1 to 1.4 range. Recent field studies have demonstrated reductions of gas consumption over baseline ranging from 18 percent to 50 percent when serving commercial water heating loads (ETCC 2021). Gas HPWHs are currently not economically viable based on installation and operating cost and footprint versus other gas products and commercial indirect HPWHs. Additionally, regulatory barriers may put a full stop to the potential emergence of gas heat pumps as the current rule making processes may ban commercial gas-fired water heating products with an California Air Resources Board implementation date for zero emission water heaters (GHG, NOx) anticipated for 2030 and Bay Area and South Coast Air Quality Management District rule for Zero-NOx standard in 2031 (SCAQMD 2023). Lastly, California is currently looking to electrify as many building systems as possible. Thus, the rest of this guide will mainly focus on electric heat pumps and their applications, except for the design examples that include gas heat pump examples.

HPWH considerations in the commercial kitchen environment are mainly related to space and electrical capacity requirements. Other considerations include ducting, refrigerant type, condensate drain requirements, and noise concerns. A key barrier to a HPWH in a retrofit application is sufficient available electrical capacity (electrical panel and/or service). A HPWH may require a panel upgrade in approximately 80 percent to 100 percent of existing foodservice facilities and additional wiring and subpanel costs to the HP installation location. Additionally, physical space for breakers is a secondary limiting factor above and beyond electrical panel capacity. A second key barrier is space requirements. Space for additional storage volume and HP units is a limiting factor especially in quick service restaurants that pack in a lot of equipment already in their kitchen and rooftops and offer limited installation capability on the perimeter mainly due to drive throughs and outdoor seating.

Of less concern is the noise generated from a HPWH. HPWHs operating at 60 dBA or below for this application are considered to be quiet. Generally, the larger the heat pump, the higher the dBA rating, and likelihood that the unit is designed for an exterior or rooftop application. Restaurant interiors are already noisy with dining areas typically registering at 75 dBA. Thus, heat pumps are not a deterrent since they are typically installed far away from the dining area and many units operate at a dBa level below this rating. A noisy HPWH can be problematic if installed in the kitchen, as prolonged periods of any sound at or above 85 dBA are more likely to cause damage to staff members' hearing overtime if they are working next to the unit (A Noisy Planet 2019). The last consideration is if the restaurant has a patio where normal conversation is at 60 dBA; anything louder may be considered noisy. Designers would have to factor in the proximity of the HPWH and the direction of the fan. Note: acoustic materials can be used to shield or redirect the noise.

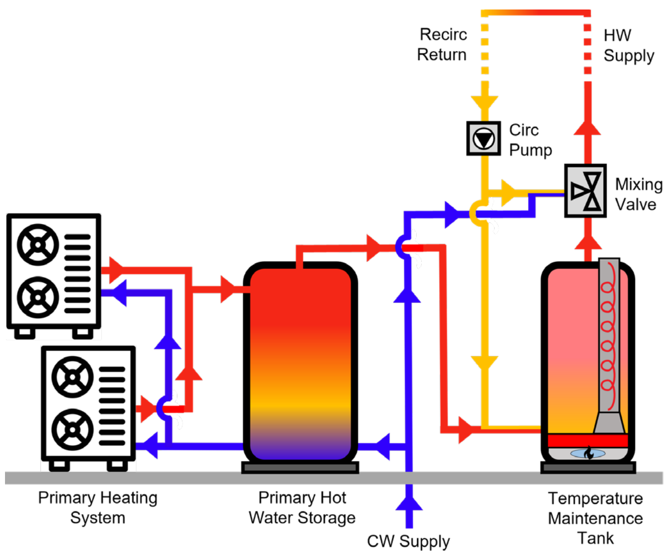
Restaurants will one day have to search for refrigerants with lower global warming potential (GWP) to reduce their carbon footprint and meet regulatory requirements. Examples of low GWP refrigerants for water heating applications are CO2, which sets the benchmark for low GWP at one. Also, R-513a is a medium GWP refrigerant at a lower GWP and has been developed as a direct replacement to R-134a. Propane is another refrigerant used around the world to consider once it passes US flammability rules. Propane has a low GWP and HPWH with this refrigerant are less costly to manufacturer.

Ventilation requirements are a concern with indoor HPWH applications as commercial HP's have high air flow rates ranging from 800 CFM with residential split HP to 16,000 CFM for large commercial HPs. Small enclosed spaces such as an indoor water heater closet may not be suitable. This is not an issue in most restaurants, since water heaters typically are not enclosed and there is heat producing equipment all around to scavenge heat such as cooking equipment, dishwashers, refrigeration equipment and ice machines. Some HP units have options for ducting to the outdoors that will add flexibility to some indoor applications. Lastly, HPs produce condensate which is not acidic and easier to plumb to landscaping or sanitary drain using gravity feed or with a condensate removal pump (NEEA 2022).

HEAT PUMP ASSIST

This concept adds a HPWH upstream in series configuration with an existing conventional storage heater. This strategy isolates the primary tank to safely operate a single-pass HP and at high COP. The small HP can be placed on the roof or outside or elevated on interior wall. The existing gas heater in this illustration maintains the recirculation loop temperature and acts as a swing tank, which fluctuates in temperature based on the volume and duration of higher temperature water it receives from the primary storage tank. A master mixing valve would ensure safe outlet water temperatures and additional energy savings.

Since it is not a replacement, HP Assists do not require significant design assistance from a water heating system standpoint. The HPWH would purposely be undersized for output capacity and storage volume to minimize cost and meet existing building space and electrical requirements. The benefits are that the HP can operate near rated COP in this application, while the



existing heater is retained to meet existing health department water heater sizing requirements. The HP Assist design would add redundancy and resiliency when paired with gas backup heaters. Because the heat pump is purposefully undersized, it can operate at its peak COP with long 19-hour duty cycles, essentially constant use that avoids peak demand pricing. This strategy maximizes cost effectiveness and provides a decarbonization strategy for the 95 percent of restaurants operating today with conventional gas and electric heaters that do not have the space, electrical capacity or cannot afford to complete a HP replacement project based on the current health department sizing requirements that cause the HP to be oversized by a factor of 3 or 4, if allowed at all.

PRIMARY WATER HEATER COMPARISON

With so many water heating options, it can be helpful to compare key operating characteristics across the heaters. Table 8 shows the operating characteristics of six tank-type water heaters viable for commercial foodservice applications in a generalized way. 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 (TE) because it includes recirculation piping heat losses and water heater 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 has to 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 (PG&E 2023).

Table 8. Site/Source Energy and Cost Comparison of Primary Water Heaters.

Heating System	80% TE Gas Heater	95% TE Gas Heater	Gas Heat Pump COP 1.4	95% TE Electric Resistance	Integrated Hybrid Electric COP 4.2[2]	Single Pass Electric Heat Pump COP 5.5[2]
Industry Efficiency Characterization	Conventional	Efficient	Efficient	Conventional	Efficient	Efficient
Heat Absorbed by Water (Btu/d)	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Daily Operating Efficiency	70%	85%	1.1	90%	2.5	4.3
Energy Consumed: Site Energy (Btu/d)	1,428,600	1,176,500	909,100	1,111,100	400,000	232,600
Source-Site Energy Ratio	1.05	1.05	1.05	3.14	3.14	3.14
Source Energy (Btu/d)	1,500,000	1,235,300	954,600	3,488,900	1,256,000	730,400
California Utility Cost[1] ($/d)	$26	$21	$16	$104	$37	$22

[1] Based on $14.13/HCF, $1.80/therm, $0.32/kWh. [2] COP calculated at indoor average temperature of 70°F

As shown in Table 8, the standard efficiency gas water heater at 80 percent TE is the most expensive gas water heater to operate and has the highest source energy. The condensing unit at 95 percent TE provides significant utility cost savings and has a competitive source energy use. The gas heat pump water heater uses the least amount of source energy for a gas unit and boasts the smallest daily utility cost, meaning it is the most inexpensive to run based on current utility rates. Unfortunately, gas heat pumps are expensive, don't payback, and are not readily available. At the time of writing, there was only one major manufacturer of gas HPWHs and the first costs and payback period is detailed in Design Example 1.

With the electric units, the big outlier is the electric resistance water heater that is up to 5 times more expensive to operate and up to 5 times the source energy use as the most efficient HP. The integrated commercial HP is comparable in source energy use to a gas-condensing heater, but energy cost is significantly higher as operating COP suffers versus its rated COP as it relies on some electric resistance heating. The best electric HP technology that is cost competitive with gas-condensing heaters is the single pass split HP installed indoors where it can scavenge the warmer kitchen temperatures year around for a high operating COP. The split HP also has the best source energy use of all water heaters, and the product is mature in the market.

WATER HEATER SIZING

After the fixtures have been specified and the distribution system has been designed, the next step is to size the primary water heater. To do this, one needs to tally up the number of fixtures, then calculate either the flow rate or recovery rate depending on whether the heater has a tank, and then size the water heater accordingly. These steps are each described next.

Fixture Needs

The first step is to tally up all the fixtures in the facility. Table 9 shows a typical fixture count for hot water using equipment for various sizes of restaurants ranging from deli to large full-service restaurant.

Table 9. 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 Sink	1	1	1	1
Bar 3-Compartment Sink	-	-	-	1
Dish machine	-	-	Door-Type	Conveyor
Pre-Rinse Spray Valve	-	-	1	1
Mop Sink	1	1	1	1
Food Prep Sinks	-	1	1	2
Dipper Well	-	-	-	1

Fixture Flow Rates and Recovery Rates

After tabulating the hot water using equipment, each piece of equipment must be characterized for its maximum hot water use in Table 10 to calculate the peak hot water demand per California CCDEH hot water sizing guidelines. Fixture counts are multiplied by the fixture flow rate in gallons per minute (gpm) to get the total flow rate required for tankless water heater sizing. Tank-type water heaters are sized by their hourly recovery rate, 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.

Table 10. Fixture Flow Rate and Recovery Rate Guidelines.

Fixture Type	Tankless Flow Rate (gpm)	Tank Recovery Rate (gal/h)
Hand Lavatories	0.5	5
Dump Sink	0.5	5
3-Compartment Sink (18" x 18")	4[1]	42
3-Compartment Sink (bar)	2[2]	18
Door-Type Dish machine	See Spec Sheet	See Spec Sheet
Conveyor Dish machine	See Spec Sheet	See Spec Sheet
Pre-Rinse Spray Valve	1.2	45
Mop Sink/Garbage Can Wash	2	15
Food Preparation Sink	2	5
Dipper Well	0.5	30

[1] Two faucets at sink. [2] One faucet at sink. (CCDEH 2020)

Dish machine flow rate and recovery rate is calculated based on manufacturer's equipment specifications. For a door type dish machine that uses 0.74 gallons of hot water per rack and has a 10 second rinse operation, the rinse flow rate is calculated by taking the gallons per rack specification and dividing it by the rinse time in seconds and multiply it by 60 seconds per minute. The rinse flow rate is 4.4 gpm, which is then used for sizing a water heater (CCDEH 2020). The same dish machine washes 58 racks per hour and uses a maximum of 43 gph if washed back to back.

Tankless flow rate requirements in Table 10 can also be used to specify energy input rates for individual tankless POU heaters based on the temperature rise required for the connected fixture(s). Sizing POU heaters is simpler than sizing the primary water heater as they are generally used to feed fewer fixtures, commonly single fixtures. 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.

Sizing Tank-type Water Heaters

Sizing a tank-type water heater involves adding up all the fixtures in the proposed design, then multiplying that by the fixture recovery rate to calculate the minimum tank-type heater recovery rate. A discount factor of 0.8 is applied for quick-service restaurants or any facility with single service utensils. This discount factor may vary from one municipality to another. The next step is to calculate the minimum gas or electric input rate based on that recovery rate and rounding up to the nearest commercial water heater input rate class. The source used to calculate BTU and kW input rate is Formula 1 (for gas water heaters) and Formula 2 (for electric water heaters) from the CCDEH water heater sizing guidelines. Local health departments may use these exact formulas or simplified versions based on fixed values for thermal efficiency and/or temperature rise to calculate input rate. Table 11 shows the result of multiplying tables 9 and 10 to calculate recovery rates, and then using the CCDEH formulas to calculate input rates for conventional gas and electric tank-type water heaters. Table 11 also shows input rates for electric HPWHs using the 98 percent thermal efficiency value for an electric resistance heater as the value for HP coefficient of performance (COP). This is based on interviews with plan checkers in several county health departments that allow HPWH. Additionally, the nominal 2.5 COP value typically used by designers for representing operating COP of a HP is used for calculating input rate.

Table 11. Sizing a Tank-Type Water Heater for Various Restaurant Types.

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	5	15	30
3-Compartment Sinks	42	42	42	60
Dish machine	-	-	51	126
Pre-Rinse Spray Valve	-	-	45	45
Mop Sink	15	15	15	15
Food Preparation Sinks	-	5	5	10
Dipper Well	-	-	-	30
Minimum Recovery Rate (gal/h)	54[1]	621	183	336
Minimum Gas Input Rate (Btu/h)	30,000	34,000	142,000	261,000
Minimum Electric Resistance Input Rate (kW)[2]	6.7	7.7	31.9	58.6
Minimum Electric HP Input Rate Using 98 percent TE as Efficiency Value (kW)[3]	6.7	7.7	31.9	58.6
Minimum Electric HP Input Rate Using 2.5 COP as Efficiency Value (kW)[4]	2.6	3.0	12.5	23.0

[1] 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.

[2] Based on existing electric resistance input rate requirements using 98% value for thermal efficiency.

[3] Interpretation by local county health departments for sizing HPs based on existing electric resistance input rate requirements using 98% value for thermal efficiency.

[4] Adjustment to the CCDEH sizing requirements for sizing HPs based on heating capacity output rate requirements using nominal value of 2.5 for standard electric HPWH operating COP.

The minimum input rate requirements for the various water heaters are used to specify the water heater by rated input rate and suggested storage volume. Table 12 shows that conventional gas and electric water heating load is easily met with a single integrated commercial gas or electric resistance water heater. For the quick-service restaurant examples, one hybrid storage heater can exceed the input rate requirements, but for the small and large full-service restaurant, three and six units would need to be used to meet the recovery rate requirements using 98 percent TE. If the health department requirements for HPs are updated to recognize the output rate at a nominal operating COP of 2.5, then only two units are required for the small FSR and three hybrid units for the large FSR. Sizing is more stark, when sizing for split HPWHs which can be configured without ERWHs. Further discussion into sizing for these restaurant types is included in the design examples section.

Table 12. Volume and Input Rate of Tank-Type WH and Quantity to meet Recovery Rate for Various Restaurant Types.

Water Heater Type	Small Quick-Service Restaurant	Medium Quick-Service Restaurant	Small Full-Service Restaurant	Large Full-Service Restaurant
Gas Storage	75 Gal. 75,000 Btu/h	75 Gal. 75,000 Btu/h	81 Gal. 154,000 Btu/h	100 Gal. 275,000 Btu/h
Electric Resistance Storage	80 Gal. 12.2 kW	119 Gal. 12.2 kW	120 Gal. 36 kW	120 Gal. 60 kW
Electric HP/ER Hybrid Storage	112 Gal. 11.3 kW	112 Gal. 11.3 kW	112 Gal. 11.3 kW	112 Gal. 11.3 kW
Electric HP/ER Hybrid Storage (0.98 Eff.)[1]	1	1	3	6
Electric HP/ER Hybrid Storage (2.5 COP)[2]	1	1	2	3

[1] HP sizing based on interpretation of CCDEH sizing guidelines using 98% value for thermal efficiency.

[2] Deviation to the CCDEH sizing requirements for sizing HPs based on heating capacity output rate requirements using nominal value of 2.5 operating COP for electric HPWH.

COST AND SPACE REQUIREMENTS

As we transition from conventional gas and electric heaters to hybrid units and later HPWH systems with a separate heater and storage tank (illustrated in design examples), the cost and space requirements grow rapidly as shown in Table 13. A major hurdle for more efficient water heaters and HPWH in general is that they have higher first costs and larger footprints than their conventional counterparts. Another major hurdle for using HPWHs is sizing. It is four and half times more expensive to use a hybrid electric water heater than a gas storage water heater. Sizing tools have been developed for residential applications (Ecotope 2023) to balance the slow heating characteristics of HPs by incorporating more storage capacity, thus further reducing the number of HPs required for installation. There are no tools currently available for sizing HPWHs for commercial foodservice applications. Currently, health departments require input rates for water heaters to be sized for the second hour recovery rate and do not account for storage volume or heating output capacity. This presents an issue for HPWHs because their heating output capacities are much higher than their heating input capacities and they rely on storage volume since they heat water at a slower rate.

Table 13. Heater Cost and Footprint for Various Tank-Type Heaters for the Restaurant Types.

Water Heater Type	Small Quick-Service Restaurant	Medium Quick-Service Restaurant	Small Full-Service Restaurant	Large Full-Service Restaurant
Gas Storage WH Cost	$1.7k	$1.7k	$5.5k	$7.0k
Electric Resistance Storage WH Cost	$1.6k	$1.7k	$7.1k	$12.4k
HP/ER Hybrid Storage Cost	$7.3k	$7.3k	$15k-$22k	$22k-$44k
Gas Storage WH Footprint	Small	Small	Small	Small-Med
Electric Resistance Storage WH Footprint	Small	Small-Med	Small-Med	Small-Med
HP/ER Hybrid Storage Footprint	Small-Med	Small-Med	Med	Large

Design Examples

To help exemplify how efficiency opportunities can be applied in the real world, this section presents examples of designs for a quick-service restaurant and a full-service restaurant. Each design example presents a series of related design scenarios and their associated impacts on water, energy, and cost . These examples help exemplify how one can analyze potential solutions and explores how hot water system designs can have large impacts on resources and a facilities ability to meet net zero energy goals.

All of these scenarios show the viability of designs that can incorporate electric heat pumps, thereby reducing or even eliminating the need for a gas heater. For full-service restaurants, the examples also highlight the significant energy and cost savings achievable when using a distributed water system, rather than relying on one heating system for all fixtures. While the most efficient designs were sometimes less cost effective in the short-term, they tended to be cost-effective in the long-term and will be critical to meeting California's net-zero energy goals for new commercial facilities starting in 2030.

DESIGN EXAMPLE 1: QUICK-SERVICE RESTAURANT

Most quick service restaurants rely on disposable dishware, and so there is no or limited use of a dish machine for plates, glasses, and utensils. Because of this, their hot water systems are less complex and do not tend to have recirculation distribution systems. While there are opportunities to install efficient fixtures and insulate distribution pipes, the most complex energy efficiency feature to analyze for a quick-service restaurant is the water heater. Therefore, for the purposes of this example, the section focuses on analyzing the impacts of installing different types of water heaters and keeps all other variables constant.

The analysis shows that the 5.5 COP electric HP split system with ERWH backup is an energy efficient and cost-effective heater to install in this type of facility. Not only does that system provide a fully electric design, but it also had comparable costs to standard gas water heats in the long-term. The remainder of this section first compares water and energy use of selected heater types, and then it compares related estimated costs.

Quick-Service Kitchen Design Scenarios: Impacts

To determine the impacts of various water heaters on energy use and costs for quick service restaurants, the analysis first needs to define the water heater size required by the quick-service restaurant. A typical quick service restaurant uses 350 gallons per day of hot water and requires a minimum recovery rate for water heater sizing of 54 gph. This equates to a minimum input rate for gas-fired equipment at 36,000 Btu/h and a minimum input rate for electric equipment at 7.7kW. Table 14 shows the various types of heaters referenced earlier in this report (Table 8), their associated storage, input rate, efficiency levels, water use, and energy use.

As shown in Table 14, the heat pump split systems all show much greater source energy savings than the standard gas heater, condensing gas-fired heater, or electric resistance heater. After converting gas and electric consumption to BTUs for comparison purposes, the electric resistance heater was the worst option at 211,000 kBtu annually, followed by standard and condensing gas water heaters and gas HPs ranging from 97,700 to 79,400 kBtu, with electric heat pumps offering the lowest source energy ranging from 63,300 to 44,200 kBtu.

[1] The analysis did not factor in how first costs impact the value of money in subsequent years. Utility costs in subsequent years assume the following annual rates of increase: Electricity, 3.3%; Gas, 4.5%; Water and Wastewater, 6%.

Table 14. Energy and Water Impacts of Different Types of Water Heaters at Quick Service Restaurants

	#1 Standard Gas-Fired WH	#2 Condensing Gas-Fired WH	#3 Gas-Fired ASHP Split System	#4 Electric Resistance WH	#5 Hybrid HP/ ER WH	#6 Electric HP Split System with ERWH Backup	#7 Electric HP Split System with ERWH Backup
Water Heater Storage Volume	80% TE 75-gal 75,000 Btu/h	95% TE 45-Gal 100,000 Btu/h	1.43 COP 113-Gal Indirect Tank 54,500 Btu/h	99% TE 80 Gal. 12 kW at 208V	4.2 COP 112-Gal 11.3 kW at 208V	4.7 COP HP 0.95 kW at 208V with (2) 99% TE 80 Gal. 3.4 kW at 208V[1]	5.5 COP HP 0.95 kW at 208V with (2) 99% TE 80 Gal. 3.4 kW at 208V[1]
Required Minimum Input Rate (Btu/h or kW)	36,000	36,000	36,000	7.7	7.7	7.7	7.7
Operating TE or COP	68%	84%	1.4	95%	3.2[2]	3.7[3]	4.5[4]
Annual Water Use (HCF)	170	170	170	170	170	170	170
Annual Gas Use (therms)	930	756	465				
Annual Electricity Use (kWh)			490	19,694	59,08	5,064	4,122
Annual Source Energy (kBtu)	97,700	79,400	54,100	211,000	63,300	54,300	44,200

[1] Solar Booster ERWH specified offer only upper heating element, top and side HP supply and return connections, and are prewired for surface mount temperature sensor connection.

[2] COP calculated at indoor average temperature of 70°F.

[3] COP calculated at outdoor average temperature of 60°F.

[4] COP calculated at indoor average temperature of 80°F.

[5]Based on $14.13/HCF, $1.80/therm, $0.32/kWh.

Quick-Service Kitchen Design Scenarios: Cost Impacts

To better understand cost implications, the example also calculates the first year cost, simple payback period and tenth year cost estimate in Table 15. Note, the payback period (years) listed in the table is omitted in scenarios where it exceeds the expected useful life of the heater. The most cost-effective HP option is the Electric HP Split System with ERWH Backup. This heater is estimated to cost $53,900, which has cost parity with a standard gas heater. This HP has a 9.0 year payback period. In this scenario, the HP is mounted high where the hottest air resides to maximize efficiency as shown in the example photo mounted above the ice machine. The HP is connected to two backup electric resistance water heaters, which are required to be installed to meet current health department guidelines for the minimum kW input rate.

HP Mounted Near Ceiling. (Croton100 2020)

The resistance elements are installed at an elevated position in the tank and set to 120°F. The split HP would heat the tank with 150°F water from the top down with temperature sensor placed lower in the tank. All three HP options include the installation of a mechanical master mixing valve to ensure that the outlet temperature is tempered down to 120°F. In this configuration, the HP would meet all the hot water load for the facility and ER elements would provide backup on peak water use days, during malfunctions, or if maintenance was required with the HP to ensure hot water is available. This design considers an installation in a back room, which would have an estimated 80°F due to the sensible and latent heat loads from the 3-comp sink, undercounter dish machine and onboard condensing units from various refrigeration equipment. The higher HP COP is also attributed to the single-pass HP design and sufficient water temperature stratification in the tanks. This assessment may underestimate savings, because it does not factor refrigeration savings that would occur from operating in a cooler room.

Table 15. Cost Impacts of Different Types of Water Heaters at Quick Service Restaurants

	Standard Gas-Fired WH	Condensing Gas-Fired WH	Gas-Fired ASHP Split System	Electric Resistance WH	Hybrid HP/ ER WH	Electric HP Split System with ERWH Backup	Electric HP Split System with ERWH Backup
First Year Energy Cost[1]	$1,670	$1,360	$990	$6,290	$1,890	$1,620	$1,320
First Year Water Cost[1]	$2,400	$2,400	$2,400	$2,400	$2,400	$2,400	$2,400
Installed Cost[2,3]	$2,450	$4,340	$30,215	$3,190	$8,460	$6,970	$6,970
1-Year Cost	$6,520	$8,100	$33,605	$11,880	$12,750	$10,990	$10,690
Payback Period	0.0	5.4					9.0
10-Year Cost	$54,700	$52,700	$74,000	$108,000	$62,100	$57,400	$53,900
Percentage Increase in 10 Year Cost	0.0%	-3.7%	35.3%	97.4%	13.5%	4.9%	-1.5%

[1] Based on $14.13/HCF, $1.80/therm, $0.32/kWh.

[2] Water Heaters with HPs include the addition of a thermostatic master mixing valve to enable safe hot water storage at elevated temperature of 140°F+. Venting or condensate drain costs not considered when estimating installation costs.

[3] Plumbing Labor cost estimated at $150/h with the following labor hours estimated with each WH specification: 3h for standard gas and electric resistance, 5h condensing gas, 6h HP/ER Hybrid, 10h split electric HP, 16h split gas HP.

DESIGN EXAMPLE 2: FULL-SERVICE RESTAURANT WITH A GAS-FIRED PRIMARY WATER HEATER

This next section presents a design example for a full-service restaurant using a gas-fired primary water heater. Because full-service restaurants rely on dish machines, unlike Quick-Service Restaurants, this example explores all aspects of the hot water system. Similar to the last design example, it provides a comparison of different scenarios, based on various efficiency opportunities. Each scenario is described, followed by the water and energy impacts. It then also highlights estimated costs of each scenario.

Minimum input rate requirements and design input and output rate details are provided to show the extent of oversizing heat pump water heaters required to meet the health department's interpretation of their existing hot water sizing guidelines, which were not designed for HPs. As stated previously, the health department recovery rate sizing methodology is solely dependent on input rate and does not account for hot water storage capacity. There would be opportunity to reduce payback periods further if a flexible design approach becomes available that lets the designer balance storage water capacity and input rate to meet the design day water heating load, as has been done for residential applications using the Ecosizer software program (Ecotope 2023).

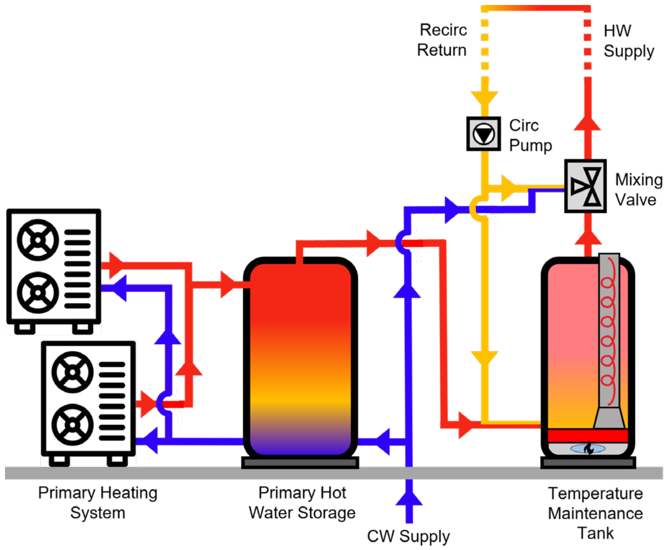
The full-service restaurant utilized for this design example, along with the next two design examples, has a dedicated dish room with a pre-rinse spray valve, a door-type dish machine and a three-compartment sink as well as various hand sinks located throughout the facility, utility sinks in the food 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.

Results indicate that two of the scenarios stand out as being cost effective while providing energy and water savings, those are the scenarios involving the condensing water heater and electric heat pump assist. While none of these scenarios provide a carbon-free solution, since they rely on a gas water heater, they showcase opportunities to limit the use of the gas water heater thereby helping to support the buildings overall carbon reductions.

Design Scenarios with a Gas-Fired Primary Water Heater for Full-Service Restaurants

This design example presents the impacts of pursuing six different upgrades while relying on a gas-fired primary water heater. Table 16 summarizes the six upgrades, reading left to right from least efficient to most efficient. Scenario 1, on the left of the table, is the base case conventional hot water system with a 100-gallon 199,000 Btu gas-fired storage water heater, operating at 70 percent TE, and set at 145°F setpoint. This system includes a continuously recirculating standard efficiency pump, pipe insulation on straight distribution pipe only, an ENERGY STAR® high-temperature door-type dish machine, and a 1.2 gpm PRSV.

Moving to the right is Scenario 2, which can be considered a low first-year cost optimization scenario. This scenario involves keeping fixed the water heater specification and adding a digital MMV, a 0.8 gpm PRSV, advanced ECM pump with constant temp operation, and adding pipe insulation where gaps are present in existing setup to ensure pipes are continuously insulated. The pipe insulation improvements and the use of a MMV to precisely control outlet temperature, alone, reduces the distribution supply temperature from 145°F to 142°F, without impacting the return temperature and improves the operating efficiency of the water heater from 70 percent to 75 percent.



The third scenario involves switching from a standard efficiency gas water to a high-efficiency condensing water heater and upgrading from an ENERGY STAR® level high temperature door type dish machine to a heat recovery model that only uses a cold-water supply, therefore is ventless and doesn't require a type II hood. These changes improve the operating efficiency of the water heater to 90 percent, reduces the mixed outlet temperature to the recirculation supply loop to 122°F, and cuts in half the water use at the dish machine from 1.4 gallon per rack to 0.71.

The next scenario starts exploring the implications of adding heat pumps to the design as a supplemental heating source. Scenario four adds two small electric heat pumps and a 119-gallon storage tank upstream to assist the smaller 80-gallon 130,000 Btu condensing gas water heater water heater as illustrated in figure above. The heaters combined meet the 136,000 Btu health department minimum requirements for the facility. To simplify the energy contribution from each water heater, it is assumed that the HPs meet the daily hot water load of 224,100 Btu at a 4.3 operating COP and the downstream gas heater meets the recirculation pipe heat loss needs of 237,500 Btu at 80 percent operating TE.

Scenario five presents an example with a gas HP assist. This example relies on a medium sized gas HP with 113-gallon indirect storage tank to the condensing water heater. Lastly, scenario six includes a design with a full gas HP system retrofit with three gas HPs and two indirect storage tanks.

Table 16. Full-Service Kitchen Design Scenarios Using a Gas-Fired Primary Heater

	#1 Standard Gas-Fired DHW System	#2 Standard Gas-Fired DHW System with Improvements	#3 HE Gas-Fired DHW System with HR Dish machine	#4 HE Gas-Fired DHW System with Electric HP-Assist	#5 HE Gas-Fired DHW System with Gas HP-Assist	#6 Gas HP based DHW System
Water Heater Type	80% TE 100-Gal Gas-Fired WH	80% TE 100 Gal Gas-Fired WH	97% TE 100-Gal Gas-Fired Condensing WH	(2) 5.5 COP Electric HP 119-Gal Tank 98% TE 80-Gal Condensing WH	1.43 COP Split MP HP 113-Gal Indirect Tank 96% TE 100-Gal Condensing WH	(3) 1.43 COP (2) 113-Gal Indirect Tank 54,500 Btu/h
Required Minimum Input Rate (Btu/h)	176,000	176,000	136,000	136,000	136,000	136,000
Rated Input and Output Capacity (Btu/h or kW)	1 gas SWH Input: 199,000 Output: 160,000	1 gas SWH Input: 199,000 Output: 160,000	1 gas SWH Input: 199,000 Output: 193,000	1 gas SWH In: 130,000 Out: 127,000 2 electric HPs Input: 6,660 (1.9 kW) Out: 30,000 (9 kW)	1 gas SWH Input: 100,000 Output: 96,000 1 gas HP Input: 54,000 Output: 78,000	3 gas HPs Input: 163,500 Output: 234,000
Gas or ER Water Heater Operating Efficiency	70%	75%	90%	80%	80%	
HP Water Heater Operating Efficiency				4.3	1.1	1.1
Master Mixing Valve	None	Digital	Digital	Digital	Digital	Digital
Avg. Distribution Supply Temp (°F)	145	142	122	122	122	122
Pump and Recirc Pump Controls	Standard efficiency pump	Advanced ECM pump in constant temp mode	Advanced ECM pump in constant temp mode	Advanced ECM pump in constant temp mode	Advanced ECM pump in constant temp mode	Advanced ECM pump in constant temp mode
Pipe Insulation	Partial	Continuous Insulation	Continuous Insulation	Continuous Insulation	Continuous Insulation	Continuous Insulation
High-Temp Dish machine with Electric Booster	Energy Star® with Hood	Energy Star® with Hood	Cold water fed HR dish machine	Cold water fed HR dish machine	Cold water fed HR dish machine	Cold water fed HR dish machine

Water and Energy Impacts of Various Gas-Fired Primary Water Heater Designs

Each one of these scenarios has different implications for water and energy use. As shown in Table 17, the lost-cost efficiency scenario uses less water savings, however the more efficient scenarios that either include a condensing water heater or a heat pump cuts the water use almost in half. To compare energy savings across the various scenarios, Table 17 presents the annual source energy (BTU). While all the scenarios provide energy savings, scenario four that includes the electric heat pump assist provides the greatest source energy savings across all scenarios, saving 42 percent energy, at 621,000 kBtu, compared to the base-case conventional scenario.

Table 17. Full-Service Kitchen Design Scenarios Using a Gas-Fired Primary Heater: Water and Energy Impacts

		#1 Standard Gas-Fired DHW System	#2 Standard Gas-Fired DHW System with Improvements	#3 HE Gas-Fired DHW System with HR Dish machine	#4 HE Gas-Fired DHW System with Electric HP-Assist	#5 HE Gas-Fired DHW System with Gas HP-Assist	#6 Gas HP based DHW System
Water Use	**Dish machine water use (225 racks, includes fills and top offs)**	339	339	176	176	176	176
	PRSV Water Use (Gal/d) (1.5h)	108	72	72	72	72	72
	Dish machine Cold Water Use (Gal/d)	0	0	176	176	176	176
	Total Hot Water Use (Gal/d)	847	811	472	472	472	472
Energy Use	**Recirculation Pipe Heat Loss (Btu/d)**	589,700	412,800	237,500	237,500	237,500	237,500
	Hot Water Load from Draws (Btu/d)	564,400	520,200	224,100	224,100	224,100	224,100
	Total Hot Water Load (Btu/h)	1,154,100	933,000	461,600	461,600	461,600	461,600
	WH Gas Use (Therms/d)	16.5	12.4	5.1	3.0	5.0	4.2
	WH Electricity Use (kWh/d)	0	0	0	15.3	10.0	22.5
	Dish machine and Hood Electricity Use (kWh/d)	110	110	115	115	115	115
	Pump and MMV Energy Use (kWh/d)	3.6	0.6	0.6	0.6	0.6	0.6
	Total Electricity use (kWh/d)	113	110	115	131	125	138
	Annual Source Energy (kBtu)	1,069,000	904,000	644,000	621,000	678,000	696,000

Cost Impacts of Various Gas-Fired Primary Water Heater Designs

No comparison is complete without also examining cost implications. To examine costs, one needs to not only look at installation costs, but also long-term costs after one-year of use and ten-years of use. As shown in Table 18, the base case scenario using a conventional design is estimated to have a total installed cost (labor and materials) of $49,050. After one-year of use, the total first-year cost would be $78,950 and total cost in 10-years would be $413,000. This scenario can then be compared to the efficient scenarios to determine the most cost-effective installation. As shown in Table 18, the third scenario with the condensing water heater is the most cost effective over a 10-year span at $315,100. However, two of the heat pump scenarios are also cost effective compared to the base-case scenario.

Table 18. Full-Service Kitchen Design Scenarios Using a Gas-Fired Primary Heater: Cost Impacts

	#1 Standard Gas-Fired DHW System	#2 Standard Gas-Fired DHW System with Improvements	#3 HE Gas-Fired DHW System with HR Dish machine	#4 HE Gas-Fired DHW System with Electric HP-Assist	#5 HE Gas-Fired DHW System with Gas HP-Assist	#6 Gas HP based DHW System
First Year Operating Energy Cost	$29,900	$26,600	$21,300	$21,600	$22,400	$23,300
WH Installed Cost	$9,750	$9,750	$8,075	$16,505	$35,985	$86,490
Dish machine and Hood Installed Cost	$18,150	$18,150	$23,715	$23,715	$23,715	$23,715
Total Installed Cost1	$49,050	$54,420	$58,310	$66,740	$86,220	$136,725
Payback Period	0.0	1.6	1.1	2.1	4.5	10.4
1-Year Cost	$78,950	$81,020	$79,610	$88,340	$108,620	$160,025
10-Year Total Costs	$413,000	$378,400	**$315,100**	**$326,800**	**$355,600**	$416,500

DESIGN EXAMPLE 3: FULL-SERVICE RESTAURANT WITH AN ELECTRIC PRIMARY WATER HEATER

This example relies on an electric primary water heater rather than a gas water heater. The design scenarios continue to rely on the same overall kitchen layout to Design Example 2 and the health department's interpretation of their existing hot water sizing guidelines. The only difference between Example 2 and 3 is that this example relies on an electric primary water heater, rather than a gas primary water heater. Since this design example relies only on electric water heaters, it represents examples of how restaurants could be designed to be net zero energy, as it eliminates building use of fossil fuels. Scenario 5 is also provided for illustrative purposes; however, it is not currently allowed under current California commercial kitchen health and safety regulations.

Findings from the Design Example 3 analysis show that the most cost effective and efficient approach is either Scenario 1 or 5. Given that Scenario 5 is not currently allowed under CA sizing guidance, Scenario 1 is estimated to be the best all-electric option as of the printing of this guide, from both an efficiency and cost perspective. While Scenario 1 within this all-electric design example uses slightly more annual source energy (659,000 kBtu) than the most efficient gas-fired primary water heaters from the last example (621,000 kBtu), it represents an all-electric alternative to the gas-fired water heater. Specifications for Scenario 1 are described below.

Design Scenarios with an Electric-Fired Primary Water Heater for Full-Service Restaurants

This design example examines all-electric DHW system options. Similar to the prior design examples, the scenarios in Table 19 become more complex from left to right. Because electric resistance water heaters, as a primary water heater, is not advisable from a cost and efficiency perspective, these examples all rely on an electric heat pump as the primary water heater. The first scenario uses a light commercial hybrid HP/ER 112-gallon water heater. To meet the health department electrical input requirements, 3 units would need to be installed, in parallel, indoors. Hybrid heaters tend to operate at lower COPs, 2.5 COP is estimated in this design example to meet both the hot water draw and recirculation reheating load.

The next scenario involves adding a large split multi-pass HP outside or on the roof that heats two 112-gallon storage tanks in parallel at an input rate of 33kW. The operating COP is similar to hybrid heaters since they are asked to meet both the hot water draw and recirculation reheating load. In this scenario, the annual operating cost of multi-pass HPWHs was the same as the hybrid heat pump configuration.

The remaining three scenarios shown in the right columns of Table 15 use a small split single pass HP with some combination of storage tank(s) and ERWH to meet the primary or secondary water heating load. The most compact option (scenario three) is the ERWH with HP-assist, which involves installing two small HPs at an elevated position in the kitchen to save space and maximize efficiency from the warmer air near the ceiling for an operating COP of 4.3. These units meet the hot water draw load and a 30kW 112-gallon ERWH met the reheat load from the recirculation system at 90 percent operating TE.

The fourth scenario uses a swing tank configuration where the primary HP and storage tank is sized to meet the hot water use while using an electric resistance water heater upstream to offset recirculation loop pipe heat losses. This configuration also improves reliability, adds redundancy, and improves the operating COP of the primary HPWH. This strategy reduces the number of HPs required based on existing health department sizing guidelines, thus reducing cost and space requirements versus a recirculation return to a primary tank configuration. Specifically, this scenario uses a swing tank design with four small split single pass HPs placed in the exterior and connected to two 119-gallon storage tanks and 30kW 112-gallon ERWH. The HPs are modelled to meet all the hot water draw loads and 50 percent of the recirculation reheat load.

The last scenario, scenario five, is also a swing tank scenario, but instead of using the existing health department sizing guidelines based on input rate, it sizes the water heaters using output rate, which is currently not allowed in California, but worth reviewing. In this scenario, using plumbing engineer sizing guidelines, 6 small split systems are placed in the exterior connected to two storage tanks with a smaller 3.4 kW ERWH acting as the swing tank, where the heating element is placed in the upper portion of the tank. This type of ERWH is used in the residential market to provide backup heating for a solar water heater. This backup ER water heater design is well suited for this HP swing tank application as the unit is cost effective, and it allows the ERWH water temperature to swing above the 125°F setpoint during draws where higher temperature 150°F hot water flows through the unit from the primary storage tank. The ERWH would only be activated during the off hours where hot water draws are limited to maintain the recirculation loop and extended times over the day when the hot water draws are minimal.

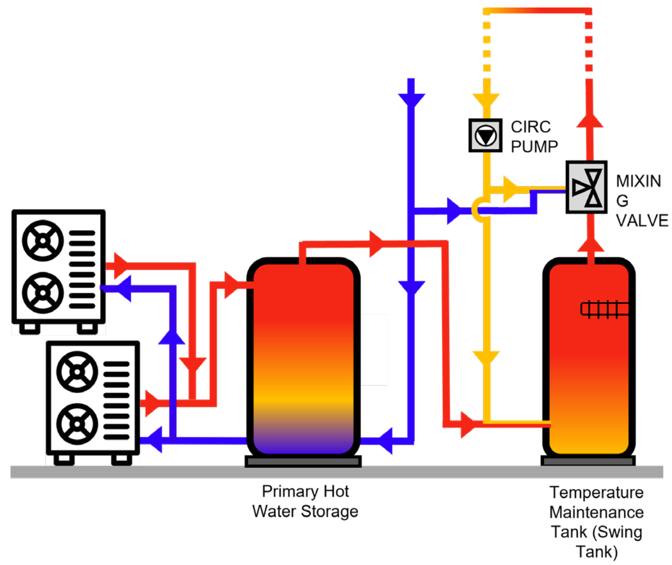


Table 19. Restaurant DHW Design Scenarios with Electric-Based Primary Heaters

	#1 Hybrid HP/ER WH	#2 Multi Pass Split HP with Electric Backup	#3 Electric Resistance WH with HP-Assist	#4 Single Pass HP with Swing Tank (CCDEH sizing)	#5 Single Pass HP with Swing Tank (Plumbing engineer sizing guidelines)
Water Heater Type	(3) 4.2 COP Hybrid HP/ER 112-Gal 11.3 kW at 208V	3.2 COP Split MP HP (2) 112-Gal Tanks with 3.4 kW at 208V	(2) 5.5 COP Electric HP 119-Gal Storage Tank 99%TE ERWH 112-Gal 30 kW at 208V	(4) 4.7 COP Electric HP (2) 119-Gal Storage Tank 99%TE ERWH 112-Gal 30 kW at 208V	(6) 4.7 COP Electric HP (2) 119-Gal Storage Tank 99%TE ERWH 112-Gal 3.4 kW at 208V
Required Minimum Input Rate (kW)	30.5	30.5	30.5	30.5	30.5
Rated Input and Output Capacity (Btu/h or kW)	3 electric HP/ ER SWH Input: 33.9 kW Output: 66 kW	1 electric HP Input: 33 kW Output: 105 kW 2 ER SWHs Input: 6.8 kW Output: 6.8 kW	1 ER SWH Input: 30 kW Output: 30 kW 2 electric HPs Input: 1.9 kW Output: 9 kW	1 ER SWH Input: 30 kW Output: 30 kW 4 electric HP Input: 3.8 kW Output: 18 kW	1 ER SWH Input: 3.4 kW Output: 3.4 kW 6 electric HP
Gas or ER Water Heater Operating Efficiency			90%	90%	90%
HP Water Heater Operating Efficiency	2.5	2.5	4.3	3.5	3.5
Master Mixing Valve	Digital	Digital	Digital	Digital	Digital
Avg. Distribution Supply Temp (°F)	122	122	122	122	122
Pump and Recirc Pump Controls	Advanced ECM pump in constant temp mode	Advanced ECM pump in constant temp mode	Advanced ECM pump in constant temp mode	Advanced ECM pump in constant temp mode	Advanced ECM pump in constant temp mode
Pipe Insulation	Continuous Insulation	Continuous Insulation	Continuous Insulation	Continuous Insulation	Continuous Insulation
High-Temp Dish machine with Electric Booster	Cold water fed HR dish machine	Cold water fed HR dish machine	Cold water fed HR dish machine	Cold water fed HR dish machine	Cold water fed HR dish machine

Water and Energy Impacts of Various Electric-Fired Primary Water Heater Designs for Full-Service Restaurants

As is evident in prior examples, each one of these scenarios has implications for water and energy use. As shown in Table 20, these scenarios all use the same amount of water. The 5th scenario provides the greatest energy savings at 655,000 kBtu. However, given that this scenario is not currently allowed under California guidelines, the most efficient allowed approach is either the first or second scenarios, which do not include the small split single pass HP. Both of these options use slightly more annual source energy (659,000 kBtu) as seen in the most efficient gas-fired primary water heaters from the last example (621,000 kBtu), however they provide an all-electric alternative to the gas-fired water heater.

Table 20. Full-Service Kitchen Design Scenarios Using an Electric-Fired Primary Heater: Water and Energy Impacts

		#1 Hybrid HP/ER WH	#2 Multipass Split HP with Electric Backup	#3 Electric Resistance WH with HP-Assist	#4 Single Pass HP with Swing Tank (CCDEH sizing)	#5 Single Pass HP with Swing Tank (Plumbing engineer sizing guidelines)
Water Use	PRSV Water Use (Gal/d) (1.5h)	72	72	72	72	72
	Dish machine Cold Water Use (Gal/d)	176	176	176	176	176
	Total Hot Water Use (Gal/d)	472	472	472	472	472
Energy Use	Recirculation Pipe Heat Loss (Btu/d)	237,500	237,500	237,500	237,500	237,500
	Hot Water Load from Draws (Btu/d)	224,100	224,100	224,100	224,100	224,100
	Total Hot Water Load (Btu/h)	461,600	461,600	461,600	461,600	461,600
	WH Gas Use (Therms/d)	0.0	0.0	0.0	0.0	0.0
	WH Electricity Use (kWh/d)	54.1	54.1	92.6	67.4	53.0
	Dish machine and Hood Electricity Use (kWh/d)	115	115	115	115	115
	Pump and MMV Energy Use (kWh/d)	0.6	0.6	0.6	0.6	0.6
	Total Electricity use (kWh/d)	170	170	208	183	168
	Annual Source Energy (kBtu)	659,000	659,000	809,000	711,000	655,000

Cost Impacts of Various Electric-Fired Primary Water Heater Designs for Full-Service Restaurants

As with the prior examples, this example compares scenarios across estimated installation costs and long-term costs after one-year of use and ten-years of use. Findings suggest that the installed costs are relatively similar, with the exception of Scenario 2, which is nearly 74 percent more than Scenario 3, which is the least expensive. However, when examining ten-year costs, the differences between scenarios diminish. In the long-term, Scenarios one and five are similarly the least expensive options. The electric-fired primary heater scenarios are slightly more expensive than the gas-fired primary heater scenarios, but they fall within a similar range of costs.

Table 21. Full-Service Kitchen Design Scenarios Using a Electric-Fired Primary Heater: Cost Impacts

	Hybrid HP/ ER WH	Multipass Split HP with Electric Backup	Electric Resistance WH with HP-Assist	Single Pass HP with Swing Tank (CCDEH sizing)	Single Pass HP with Swing Tank (Plumbing engineer sizing guidelines)
First Year Operating Energy Cost	$24,200	$24,200	$28,700	$25,800	$24,100
WH Installed Cost	23,340	66,730	16,915	25,480	26,560
Dish machine and Hood Installed Cost	$23,715	$23,715	$23,715	$23,715	$23,715
Total Installed Cost	$73,575	$116,965	$67,150	$75,715	$76,795
Payback Period	4.0	9.3	8.6	5.5	4.3
1-Year Cost	$97,775	$141,165	$95,850	$101,515	$100,895
10-Year Total Costs	$364,400	$405,800	$408,200	$382,500	$364,100

DESIGN EXAMPLE 4: FULL-SERVICE RESTAURANT WITH DISTRIBUTED GENERATION

Design Example 4 introduces a different type of hot water distribution system than that found in Examples 2 and 3. This example highlights efficiency and cost impacts that can be experienced when adding POU heaters to remote fixtures. Doing so can reduce the length of the main recirculation system and thereby generate savings. This design example first explains the updated design. It then highlights the water and energy impacts on both a gas and electric primary water heater system and then concludes by presenting the cost impacts on both the gas and electric primary water heater systems.

As shown through this example, distributed generation systems show potential as they offer low upfront costs and deliver operating savings with very quick payback periods of under two years. The challenge is to have building owners, designers and the health department embrace this design strategy. Some health departments do not allow POU heaters. This is likely due to early generation low-cost residential models that had higher activation flow rates and had poor reliability that did not give this technology a good early reputation. Modern high performance POU heaters have been tested and performed reliably in a full-service restaurant case study in California (Frontier Energy 2018). They were found to decrease hot water wait times in lavatories and increased sanitation levels. Before installation, they also passed plan check at the local health department without issue.

Full-Service Kitchen Design Scenarios Using Distributed Generation

Both scenarios presented in this design rely on POU heaters combined with a larger water heater located closer to the kitchen and dish room. The primary recirculation loop feeds heavy use fixtures such as the pre-rinse station, three- compartment sink and mop sink. Utilizing an advanced energy recovery dish machine allows the machine to be removed from the distribution system. The dish machine 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 dish room's hot water load. The elimination of the dish machine, bar sinks and hand sinks from the distribution system allows for a smaller water heater than that assumed in a conventional water distribution system.

This demand recirculation system operates for an average of 1.8 hours per day (instead of 24/7). The resulting hot water distribution system would use a skinnier pipe and have a shorter recirculation loop since many fixtures are no longer connected. This results in significantly less pipe heat loss from the distribution system estimated at 75,700 Btu per day of pipe heat loss versus 237,500 Btu for the optimized distribution system where only the dish machine was removed from the centralized hot water system. With that, to provide hot water at the bar and handsinks, 10 POU electric tankless WH are installed to meet the distributed generation hot water draw load of 39,900 Btu per day. This same design is applied to both a gas-fired hot water system and an electric HPWH system. The points of use on this system are the same as in Design Example 3, and the water usage is therefore the same.

Table 22. Restaurant DHW Design Examples with Distributed Generation.

	HE Gas-Fired DHW System with HR Dish machine with Demand Circulation in Kitchen	Fully Distributed Generation w/ Electric HPWH demand circ to kitchen
Water Heater Type	95% TE Gas-Fired Condensing WH (further reduced btu/h heating capacity) + 120V POU heaters at lavatories and bar	(2) 5.5 COP Electric HP 119-Gal Storage Tank 99% TE ERWH 115-Gal 18kW at 480V (10) POU tankless at lav and bar
Required Minimum Input Rate (Btu/h or kW)	87,000	19.5
Rated Input and Output Capacity (Btu/h or kW)	1 gas WH Input: 100,000 Btu/h Output: 96,000 Btu/h 9 ER Tankless 4.1kW for Handsinks 1 ER Tankless 24 kW for Bar 3 Comp	HP Input: 1.9 kW Output: 9.0 kW 1 ERWH 18 kW for backup heating 9 ER Tankless 4.1kW for Handsinks 1 ER Tankless 24 kW for Bar 3 Comp
Gas or ER Water Heater Operating Efficiency	90%	90%
HP Water Heater Operating Efficiency	0	4.3
Master Mixing Valve	None	None
Avg. Distribution Supply Temp (°F)	120	120
Pump and Recirc Pump Controls	Demand Circulation	Demand Circulation
Pipe Insulation	Continuous Insulation	Continuous Insulation
High-Temp Dish machine with Electric Booster	Cold water fed HR dish machine with electric booster	Cold water fed HR dish machine with electric booster

Water and Energy Impacts of a Distributed Water Heater Design for Full-Service Restaurants

Both gas and electric systems see water and energy efficiencies when adding a distributed water heater system to the hot water design. Using these specifications, both the centralized gas and electric system use 388 gallons of water per day as shown in Table 23. This is considerably less than the conventional gas system shown in Design Example 2, which required 847 gallons of water per day. This diminished centralized hot water use directly translates into energy savings. Also shown in Table 23 is that the gas system would require 624,000 kBtu of annual source energy and the electric system would require 583,000 kBtu of annual source energy. This equates to a reduction in energy use compared to the gas baseline system by 42 percent and 45 percent, respectively.

Table 23. Full-Service Kitchen Design Scenarios Using a Distributed System: Water and Energy Impacts

		HE Gas-Fired DHW System with HR Dish machine with Demand Circulation in Kitchen	Fully Distributed Generation w/Electric HPWH demand circ to kitchen
Water Use	PRSV Water Use (Gal/d) (1.5h)	72	72
	Dish machine Cold Water Use (Gal/d)	176	176
	Centralized Water Heater Total Hot Water Use (Gal/d)	388	388
Energy Use	Recirculation Pipe Heat Loss (Btu/d)	75,700	75,700
	Central Hot Water Load from Draws (Btu/d)	184,200	184,200
	POU Hot Water Load from Draws (Btu/d)	39,900	39,900
	Total Hot Water Load (Btu/h)	299,800	259,900
	WH Gas Use (Therms/d)	2.9	0.0
	WH Electricity Use (kWh/d)	16.7	34.4
	Dish machine and Hood Electricity Use (kWh/d)	115	115
	Pump and MMV Energy Use (kWh/d)	0.6	0.6
	Total Electricity use (kWh/d)	132	150
	Annual Source Energy (kBtu)	624,000	583,000

Cost Impacts of a Distributed Water Heater Design for Full-Service Restaurants

As shown in Table 24, costs differences for the distributed systems are relatively similar between the gas and electric scenarios, with the electric scenario having slightly higher costs. Notably the payback period for the electric distributed system is much better than any of the electric systems without the distributed system (1.3 versus a minimum of 4.0 respectively). Both the gas and electric distributed system provide cost advantages to the gas conventional system. The gas distributed system provides 10-year savings of $83,000 compared to the gas conventional system, while the electric distributed system provides 10-year savings of $75,270 compared to the gas conventional system.

These distributed generation systems are generally a bit less expensive to install than conventional water heating plant systems because of the labor cost associated with installing a large recirculation loop as well as the material cost of laying pipe. The heat pump water heater still carries a significant equipment and material cost, but with a 5.5 COP it has about the same annual operating cost as the gas-fed system. One benefit of the HPWH system is that it is all electric. Part of the reason these systems have a similar annual source energy is that most of the hot water load has been placed on the dish machine and the point of use heaters. The main water heating plant has such a smaller demand that the differences in energy usage between the two heaters don't drive annual source energy as much as a total recirculating distribution system would. Put another way, the total electricity use only differs by 20 kWh/day for each system, and the gas use of the natural gas system isn't high enough to outpace the HPWH.

Distributed generation also allows for redundancy: if the water heater that feeds the bar breaks down, the restaurant can still function. Even if the main water heater breaks down, the dish machine can still operate and the restaurant can still serve customers. Conversely, if the dish machine breaks down, the restaurant can rely on its compartment sinks to provide sanitation.

Table 24. Full-Service Kitchen Design Scenarios Using a Distributed System: Cost Impacts

	HE Gas-Fired DHW System with HR Dish machine with Demand Circulation in Kitchen	Fully Distributed Generation w/ Electric HPWH demand circ to kitchen
First Year Operating Energy Cost	$21,700	$21,900
WH Installed Cost	$17,265	$22,575
Dish machine and Hood Installed Cost	$23,715	$23,715
Total Installed Cost	$56,460	$62,270
Payback Period	1.0	1.3
1-Year Cost	$78,160	$84,170
10-Year Total Costs	$329,400	$337,700

These systems likely represent the future of commercial foodservice hot water systems because of their flexibility. For new construction, distributed generation and high COP HPWHs represent a cost-effective way to design an all-electric CFS hot water system, which is becoming increasingly important in California given the number of municipalities that are banning natural gas in new buildings. For retrofit scenarios, distributed generation provides a path to electrify a hot water system without installing a bank of HPWHs because it can dodge the high recirculation losses and the large load from the dish machine which reduces the need for larger sized water heating plants. The caveat for retrofits is that many restaurants have limited available electric capacity, so installing major electric loads like heat recovery dish machines and heat pump water heaters may require the installation of a subpanel or a utility service upgrade. Installing point of use heaters may not be possible for all retrofit scenarios because it would require running new wire from the nearest subpanel, although the point of use heaters typically run at smaller amperages (i.e., <10kW) so the electric space availability is less of a concern.

Disclaimer: All 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 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 from end-use equipment and sinks, then distribution systems, and lastly at the water heater.
- Specify high-performance pre-rinse spray valves rated below 0.8 gpm.
- Specify ENERGY STAR®-certified or better dish machines with heat recovery systems and only cold water supply connections.
- 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.
- Improve hot water deliver performance through:
  - » 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.
  - » Reduce the hot water system load to the extent possible by designing for an efficient distribution system through:
  - » Continuously insulating all hot water pipes to insulation thickness requirements in code and follow insulation installation best practices
  - » Installing an ECM pump with constant temperature control for continuous recirculation systems
  - » Develop a distributed generation system using demand recirculation controls, point-of-use heaters at remote fixtures, and heat recovery dish machines.
- Position the water heater as close to the dish room and other sanitation sinks as possible.
- If specifying gas-fired water heater, specify a high-efficiency condensing water heater with or without HP assist.
- If specifying an electric water heater, specify a hybrid HP/ER storage water heater or single-pass split HP/storage tank primary heater with an upper element only ER backup or swing tank heater.

Glossary

Appurtenances – Plumbing elements in series with the recirculation loop such as pipe supports, check valves, mixing valves, balancing valves, strainers, flanges, air separators, water pumps, and monitoring sensors and inline meters.

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 Dish machines — 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 Dish machine – Dish machine 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 Dish machines — 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 dish machine 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 Dish machines — 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 Dish machines — Similar in footprint to residential dish machines, 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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