Heat Pump Water Heating Systems

Considerations for Selecting a Configuration

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This technology brief is intended for building owners, architects, MEP engineers, green building consultants, and homeowners who are making design decisions around heat pump water heating (HPWH) systems in new construction multifamily buildings. This paper draws from the findings of the EPIC research project (EPC 15-097) optimizing domestic hot water in four multifamily affordable all-electric new construction projects in California. The research focused on the evaluation of domestic hot water heat pump systems in four multifamily affordable all-electric new construction projects in California. Final Report: Getting to All-Electric Multifamily ZNE Construction Publication Number: CEC-500-202X-XXX.

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Heat Pump Water Heating Configurations

There are many different equipment and configuration options for electric heat pump water heating (HPWH) systems. This tech brief focuses on considerations around three primary HPWH configurations.

Individual Heat Pump Water Heater
This type of system is comprised of a single residential-sized HPWH, either with a combined (integrated) heat pump and tank, or a split system with monoblock heat pump and separate hot water storage tank. Recirculation systems from water heater to end use fixtures will vary based on manufacturer recommendations and building-specific plumbing designs. Individual HPWH systems are most applicable for less dense multifamily buildings such as garden style, townhomes, or other configurations with adequate in-unit interior or unit-adjacent space for equipment installation. If a property is individually metered, hot water energy use would be included in the resident bills. Hot water metering configuration is also a factor whether it is directly metered to apartments or centrally metered at the building level.

Central Heat Pump Water Heater
This type of system is comprised of one or more heat pump water heaters, large storage tank(s), and typically have a recirculation system, serving a large number of units (more than eight), usually for an entire building, or portion of a building. Central HPWH systems are most applicable for larger, denser multifamily buildings (mid-rise and high-rise; low-rise double loaded corridor) that utilize other central mechanical systems, have limited space for individual systems at each apartment, and have adequate space for equipment installation. These systems can be integrated or packaged systems or modular split systems. Integrated systems include storage and packaged systems utilize separate storage tanks. Modular systems (monoblock) are split systems with separated compressor and storage. The heat pump units can be configured in parallel and paired with right-sized storage to create appropriate customized system for project.

Combined Central Heating, Cooling & Domestic Hot Water Heat Pump
This type of system is comprised of a single large heat pump unit that can provide both hot and chilled water simultaneously, large storage tank(s), and a recirculation system, as well as the four pipes and multiple pumps for supply and return of heating and cooling water to radiators or fan coils. Such a combined system is intended to provide heating, cooling, and domestic hot water for an entire building in a single plant. These systems often occupy a large footprint, require above-average engineering resources as well as third party service contracts, and are really best-suited for diverse load profiles and simultaneous heating/cooling use, which is not common in multifamily buildings. Because they are uncommon in multifamily, this paper does not focus on combined central heat pump systems.

Studied Hot Water Systems

Atascadero, CA
Building Type: Low-rise double-loaded interior corridor (two buildings)
DHW System Type: Individual HPWH
DHW System Details: Tank-type Rheem HPWH for each apartment with on-demand recirculation loop, installed one next to another inside a louvered metal shed on the buildings' roofs.

Calistoga, CA
Building Type: Low-rise garden-style (three buildings)

DHW System: Combined Central Heating, Cooling & Domestic Hot Water (DHW) Heat Pump
DHW System Details: Aermec system with chilled and hot water hydronic distribution and an integrated recirculation loop, installed with storage outside adjacent to one of the buildings.

Cloverdale, CA
Building: Low-rise double-loaded interior corridor (one building)
DHW System: Combined Central Heating, Cooling & DHW Heat Pump
DHW System Details: Same as Calistoga

Sunnyvale, CA
Building: Mid-rise double-loaded exterior corridor (three buildings)
DHW System: Central HPWH
DHW System Details: Modular Sanden HPWH system with a dedicated Rheem tank-type recirculation HPWH, with Sanden heat pumps in the open-air parking garage connected to storage tanks inside an adjacent mechanical room.

Considerations for Applications

Many factors can be considered when determining what HPWH system to install, including access to airflow for venting, electric metering configuration and billing preference, electric service capacity, load diversity and simultaneity, location of available space, system complexity, and load shifting capabilities. However, this document will focus on the three most fundamental factors: location of available space, building configuration, and system cost.

Location of Available Space

Physical space for equipment is a major consideration for HPWH system selection and design, particularly compared to gas systems that may not need to include storage. Many types of DHW equipment, particularly residential style equipment, are not outdoor-rated and therefore require indoor space. Outdoor-rated DHW equipment, more commonly central or commercial style equipment, is less constrained, but still requires outdoor space for installation, and also tends to be quite large (again, compared to gas equivalents). Interior space, particularly within apartments, is usually very limited, and identifying the optimal space for a DHW installation can help determine the most appropriate system type.

Individual HPWH systems typically require a modest area, but this space is inside or adjacent to the dwelling units, which can sometimes reduce rentable apartment space. The required space may be larger than is required for a gas storage to account for taller and/or wider tank and adequate ventilation. For buildings that can dedicate apartment square footage, whether it be interior to the unit or by an exterior closet, individual HPWH systems may be feasible. Apartments in low-income multifamily housing are typically very space constrained and are right at the owner's renting value limit, so dedicating rentable space to equipment is not always practical. Lack of in-unit space does not necessarily rule out an individual HPWH configuration as an option, though. Some buildings house individual DHW system equipment in common area space, as was done at the Atascadero site. However, this installation situation comes with other considerations like length of water distribution and chases for electrical and plumbing.

Central HPWH systems, on the other hand, demand a relatively large contiguous area to serve the whole building, but this is concentrated in a single location, and generally does not impact unit square footage. Central systems are most often located on a roof, in or adjacent to a garage, or other common area space with access to outdoor air, and where the sound from the heat pump units will not be an issue. Another option for central HPWH system placement is exterior to the building; however, this also requires usable square footage that is protected in some way (encapsulated by a wall, on a level pad, etc.). For buildings that have limited common area space and do not have dedicated mechanical room(s), central HPWH systems are less appropriate.

Available space should be considered in tandem with other decision drivers as described below; however, it is a consideration that can make the other drivers moot under certain conditions.

Building Configuration

Multifamily buildings have been characterized here based on size and geometry. For size, they are divided into three categories: low-rise (1-3 stories), mid-rise (3-10 stories), and high-rise (10+ stories). Multifamily buildings come in many different geometric configurations that do not fall as clearly into discreet categories, but the most common configurations are listed below. Along with size, building geometry is a direct driver of building density and therefore, has implications for space availability, too. Though all building configurations can theoretically accommodate both central and individual HPWH system designs, certain building configurations lend themselves to favoring one HPWH system type over others.

Though not exhaustive, the following list details the **most common** DHW system types per building configuration:

<u>Low-rise Garden-Style & Townhouse:</u> Individual DHW system in exterior closet, no recirculation because of compact distribution.

<u>Low-rise Double-Loaded Corridor:</u> Individual DHW system in interior closet, no recirculation; or central DHW system per building typically with recirculation.

<u>Mid-rise Interior Double-Loaded Corridor:</u> Central DHW system in interior or exterior common area space serving whole building or per building, with recirculation.

<u>High-rise Interior Double-Loaded Corridor:</u> Central DHW system in interior or exterior common area space serving whole building (sometimes multiple plants), with recirculation.

Shorter and non-corridor style buildings are typically less dense and more spread out, thereby increasing distribution piping length for a central HPWH system and associated piping materials, piping cost, and distribution piping heat loss. Conversely, taller and corridor-style are typically denser and compact with more limited space inside the apartment and exterior apartment space, making central systems more appropriate.

System Cost

System cost is most typically the ultimate end-stop consideration when contemplating a central versus an individual HPWH system. A system's cost refers to both the upfront cost of the equipment, its installation, and the operational and maintenance costs over the system's life. The upfront cost often takes center stage as the main driver when selecting the system type. Operational cost is also considered, both in who is responsible for paying the operational costs and how much those costs might be over the life of the system. Despite the major implications on overall system cost, operational cost is typically a second-tier consideration behind upfront cost where sticker shock effect does not have the same impact when spread over a longer timescale. Additionally, development costs are separated from asset and management costs, which means the two categories of financial impact are not considered together or necessarily compared.

HPWH equipment is still more expensive than gas or electric resistance equipment but is becoming price competitive with other equipment options and more price competitive when evaluated at a whole-system level. The equipment material costs continue to drop as more products are available on the market, and labor costs also trend downward as more contractors gain more experience working with this equipment. When comparing central versus individual HPWH equipment, central systems have the advantage of fewer overall components; they leverage one or a few recirculation pumps rather than a pump per apartment if recirculation is present, as an example. Central systems can have significant upfront cost savings from consolidated equipment in this vein, and the upfront equipment cost advantage for central over individual systems grows as the number of units grows. However, a major added cost of central systems is that they require hot water distribution piping from the central plant to every unit, whereas buildings with individual systems have only cold-water distribution to the units. Design and engineering costs and labor installation are other variables that will inform overall total construction costs.

From an operational cost perspective, it is less cut and dry. Because central HPWH systems are typically more complex than individual systems, they take more effort to maintain and sometimes require a third-party service contract, which adds cost. Also, maintaining the system or addressing component failures is typically more costly than an individual system and may impact the majority of residents. Replacing an individual system at the end of its useful life is also a much smaller investment and endeavor. In terms of operational costs associated with energy consumption, it is less clear. Both system types can benefit from renewable energy offset from a utility bill standpoint. Operational cost should be considered when determining who is paying for domestic water heating; unless the somewhat uncommon setup of hot water sub-metering is pursued, the energy used by central HPWH systems is typically paid for by the building owner, whereas residents most typically pay for the energy used by individual HPWH systems if the system is tied to that resident’s meter.

Costs are an important calculation in the selection process. Table 1 below describes cost considerations for central systems versus individual systems to inform decision-making. As the number of units increase, overall costs for central systems can decrease while the inverse is the case for individual systems. Table 2 summarizes material costs from one developer comparing central gas to central HPWH to individual HPWH. This developer has built more than 100 complexes and since 2014, of which 80 were mixed-fuel complexes and 20 all-electric complexes. Based on their estimates, the material costs of central gas boilers and chillers is 18% greater than electric central HPWH systems. The central mechanical, electrical, and plumbing (MEP) equipment is overall more expensive than individual MEP for each apartment: central gas is 38% more expensive and central heat pump is 17% more expensive. However, lacking labor costs, we cannot conclude that individual systems are less expensive than central systems. Assuming labor is similar for central systems, gas central system 18% more expensive than central heat pump system.

Table 1. Categories of Cost Considerations for Central and Individual Systems

CATEGORY	COST CONSIDERATIONS	CENTRAL HPWH	INDIVIDUAL HPWH
SPACE	**Available Space for Install**	Large space requirement, non-rentable square footage	Small space requirement, rentable square footage
MATERIALS	**Material Cost of Heat Pump**	High cost, scales down with number of units	Low cost, scales up with number of units
DISTRIBUTION	**Materials for Distribution**	Shared supply and return with branches	Individual supply and return, redundancy
	Balancing Distribution	Balancing, per branch	N/A
	Supplemental Recirculation Heater	Additional recirculation heater or tank	N/A
	Advanced Engineering for Recirculation	Requires advanced engineering	N/A
	Recirculation Pumps	Larger pumps, fewer per unit	Less common, but when used, smaller pumps, more per unit (need 1 per unit)
DESIGN	**System Engineering**	Increased engineering and design support	Standard design team
INSTALLATION	**Install Labor**	Takes more time and expertise	No additional considerations
OPERATION	**Commissioning**	Benefits from extensive commissioning and in some cases retro-commissioning to optimize. No requirement.	Basic (mode and setpoints)
	Maintenance and Service	Requires additional expertise to maintain, may require service contract	Minimal expertise required. More and dispersed equipment to maintain.
	Operating Cost	*Variable (rate, PV)*	*Variable (rate, PV)*

Table 2. Material Costs for Central Gas, Central Electric and Individual Electric Water Heating Systems

System Type	Component Description	Price
Central Gas Heating, Cooling, and Hot Water System *Based on one property owner's 100 properties with ~6,000 apartments of affordable housing, all built by the same general contractor that built the Atascadero, Calistoga, and Cloverdale properties.*		
Gas Infrastructure Engineering	Gas Lateral Engineering fees (per apartment equivalent)	$ 470
Gas Infrastructure	Gas Lateral Materials **and Labor** (per apartment equivalent)	$ 938
Central Gas Domestic Hot Water	Central DHW gas boiler, recirculation pump and piping materials (per apartment equivalent)	$ 1,719
Central Gas HVAC	Central Gas Hydronic Heating Boiler and Chiller materials (per apartment equivalent)	$ 6,205
Individual Gas HVAC	Hydronic fan coil and ductwork materials (per apartment)	$ 5,725
Central Gas HVAC and DHW Total Cost Per Apartment		**$ 15,057**
Combined Central Heat Pump Heating, Cooling & Domestic Hot Water Systems *Based on one property owner's 2 properties with a total of 80 apartments of affordable housing built by same general contractor.*		
Electric Infrastructure and Engineering	Transformer--No Sizing Difference Reported	$ -
Electric Heat Pump Central HVAC + DHW	Aermec Central DHW + HVAC air source heat pump materials (per apartment equivalent)	$ 7,070
	Hydronic fan coil and ducts for air-source central Aermec System materials (per apartment)	$ 5,725
Combined Central Heat Pump Heating, Cooling & Domestic Hot Water Total Cost Per Apartment		**$ 12,795**
Individual HVAC and DHW Heat Pumps Systems *Based on one property owner's 18 properties with ~1,000 apartments of affordable housing all built by the same general contractor.*		
Electric Infrastructure and Engineering	Transformer--No Sizing Difference Reported	$ -
Individual Heat Pump HVAC	High performance heat pumps and ductwork materials (per apartment)	$ 9,195
Individual Heat Pump Domestic Hot Water	Individual 80-gallon DHW materials (per apartment)	$ 1,704
Individual Heat Pump HVAC and DHW Total Cost Per Apartment		**$ 10,899**

Central vs Individual Systems

There are many decision points or drivers when pursuing a central versus individual HPWH system. The considerations above encapsulate those major decision points. Even still, other factors contribute to what system is actually designed and eventually installed. The learnings from the HPWH research conducted through EPC 15-097 helped define what criteria drive the pursuit of a central or individual HPWH system. Each system has pros and cons, and the below table details what those are for each system.

Table 3. Considerations for Central Integrated/Packaged, Central Modular and Individual Systems

	CHPWH INTEGRATED/ PACKAGED	CHPWH MODULAR	INDIVIDUAL
OUTPUT CAPACITY	Limited to Equipment	Customizable with units	Limited to Equipment
STORAGE	Integrated: Defined Packaged: Customizable with separate storage tanks All: More storage than gas	Customizable with separate storage tanks More storage than gas	Integrated: Defined Spit: Flexible All: More storage than gas
DESIGN COMPLEXITY	Moderate with engineering More standard	Complex with engineering More Customized Increased design and sizing support	Simple
LOAD SHIFTING	Potential with packaged systems with increased storage	High potential with flexible storage Additional flexibility of heat pump operation	High potential with mixing valve installed and upsized storage
INSTALLATION SPACE	Large common or outdoor space	Flexibility- separate spaces allowable for units and storage	Integrated: Defined by overall unit size (storage and HP) and ventilation needs Split: limited by storage size but requires locating outdoor unit
O&M COSTS	Potential 3rd party service contract- operations are complicated and harder to troubleshoot	Potential 3rd party service contract- operations more complicated and harder to trouble shoot	Easy to maintain and troubleshoot. Replacement part accessible or unit swap out is manageable
LOCATION	Common spaces	Common spaces	Space in or adjacent to unit
HOT WATER DEMAND	Support variable demand profiles	Supports variable demand profiles	Susceptible to run out with sequential large draws
CONTROLS	Typically integrated	Integrated or third-party separate	Integrated and user friendly, not aggregated
TENANT FEEDBACK	Very Challenging	Very Challenging	Possible through usage and/or bills

Learn More

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