Central Heat Pump Water Heating Systems for Decarbonizing Multifamily Buildings: Market Assessment, Energy Performance and Cost Impact Analysis

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ABSTRACT

Central Heat Pump Water Heating (HPWH) systems are pivotal for enhancing energy efficiency and reducing carbon emissions. Supported by various incentive programs and policies aimed at curbing carbon footprints, the HPWH market has experienced significant growth. To support the 2025 California Energy Code (Title 24, Part 6) Codes and Standards Enhancement (CASE) initiative, we conducted a comprehensive study on central HPWH technology. This involved market assessment, energy performance evaluations through simulations and laboratory testing, and analyses of first costs and utility expenses.

Through interviews, literature review, and analysis of utility programs, we assessed product availability and the feasibility of system design strategies. Collaborating with plumbing engineers, we devised concept designs for multifamily prototype buildings of different sizes, comparing their energy performance and utility costs against a baseline gas water heating system compliant with the California Energy Code. Our findings revealed HPWH performance variability based on equipment features and system configurations. Despite higher utility costs ($61 to $592 or 2.38 to 110.8 percent increase per dwelling unit per year), HPWHs demonstrated significant reductions in GHG emissions (231 to 860 kg CO2 or 31 to 57 percent per dwelling unit). Furthermore, we compared simulation-derived HPWH system performance with laboratory testing, noting mostly aligned outcomes but identifying software refinement needs. Analyzing first cost data when compared to the baseline, we found HPWH costs per dwelling unit could be 3 to 122 percent higher for some configurations, and 0.3 to 25 percent lower for some others.

Introduction

In recent years, the surge in market awareness and demand for Heat Pump Water Heaters (HPWHs) has been driven by federal, state, local, and utility incentive programs, coupled with a cultural push to reduce carbon emissions. The importance of HPWH systems in multifamily buildings, where water heating can constitute 27 to 32 percent of total energy consumption (U.S. EIA, 2015), cannot be overstated. These systems, which utilize electricity to transfer heat energy from sources like air to potable water, offer two to three times greater energy efficiency compared to traditional fossil/gas or electric-resistance water heating systems.

Central HPWH systems are crucial for decarbonizing central domestic hot water systems, which are prevalent in most multifamily buildings. To promote their adoption, stakeholders require a comprehensive understanding of technical feasibility, market availability, energy performance, and cost implications. Various state and federally sponsored initiatives aim to evaluate and promote central HPWH systems, including efforts to enhance product availability, reliability, and awareness among design communities and building owners. Under California's

Building Efficiency Standards (Title 24, Part 6), the Statewide Codes and Standards Enhancement (CASE) Team supported the development of a compliance pathway[1] tailored for central HPWH systems, promoting their use in designs.

The Statewide CASE Team conducted a market assessment and evaluated energy performance and cost-effectiveness to contribute to HPWH requirements for the 2025 Title 24 code cycle. California Investor-Owned Utilities (IOUs) funded lab-testing of central HPWH equipment focused on developing sizing methodologies and design guidance for multifamily applications, examining key variables such as heat pump capacity and storage tank configuration.

This paper presents findings supporting the Title 24 2025 code cycle development and lab-testing results of central HPWH equipment and system configurations. It evaluates technical feasibility, market availability, energy performance, cost-effectiveness, and GHG emission impacts. The research aims to enhance industry understanding, inform decision-making, and support policymaking and utility program development, facilitating widespread HPWH adoption and advancing the state and the nation’s climate change goals toward cleaner and more sustainable energy sources.

Technology Description

Equipment Features

Heat Pump Water Heater (HPWH) equipment characteristics, notably the refrigerant type and water heating approach (single-pass or multi-pass), significantly influence their energy efficiency and design considerations, including plumbing configuration, equipment placement, and ventilation. HPWHs utilize various refrigerants with distinct thermodynamic properties, impacting operation pressure, temperature requirements, and heat transfer efficiency, thus affecting system design and installation approaches. The choice of refrigerant can also determine the necessity of electric resistance backup heating based on heat transfer rates and outdoor temperature conditions. For central HPWHs, R-134a and R-410A are currently the predominant refrigerants, though there's a trend towards natural options like CO2 (R-744) and propane (R-290) due to their lower environmental impact and suitability for central HPWHs.

Another critical design aspect is the piping configuration, with single-pass systems heating water once to the desired storage temperature and multi-pass systems heating water multiple times until the target temperature is achieved. Single-pass configurations, drawing cold water from the bottom of the storage tank and delivers hot water to the top of the storage tank, result in highly stratified tanks and are usually more efficient than multi-pass configurations. Single-pass is preferred for CO2-based HPWHs due to refrigerant characteristics. In multi-pass piping configuration, the HPWH draw water from the bottom third of the tank and delivering hot water just above the draw point, resulting in less tank stratification. Equipment using refrigerants such as R513a, R134s and R410a can accommodate as either single-pass or multi-pass configurations due to their ability to handle wide range of temperature rise (Lochivar, 2023; A.O. Smith, 2023). Designers must carefully configure plumbing systems to maintain optimal HPWH operation depending on the selected model, ensuring efficiency and performance in diverse applications.

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[1] Energy codes and standards set minimum efficiency requirement for new and renovated buildings. Buildings are obligated to comply with the energy codes (meeting all the requirement). A compliance pathway is a set of requirements that ensures buildings to comply with the energy codes.

System Configurations

In contrast to the standardized approach often applicable in single-family residential settings, the design of central HPWH systems for multifamily buildings often demands tailored solutions specific to building types and sizes. Previous research (TRC, 2021) has underscored the critical role of system configuration options in determining overall energy usage, potentially outweighing the impact of the heat pump equipment efficiency itself. These configuration possibilities encompass a myriad of factors, including equipment features, the design of temperature maintenance (TM) systems, sizing of primary and secondary storage tanks, and the configuration of piping for recirculated water, among others. In this paper, we focused on four system configurations that are commonly used in multifamily buildings, aligning with the configurations outlined in Advanced Water Heating Specifications (AWHS) 8.0 (NEEA, 2022). These configurations include:

- Single-pass primary heat pump with electric resistance water heater in series for temperature maintenance system (HPWH_SPST) (Figure 1).
- Single-pass heat pump with recirculation return to primary (HPWH_SPRetP) (Figure 2)
- Single-pass primary heat pump with multi-pass in parallel for temperature maintenance system (HPWH_SPwMPTM) (Figure 3)
- Multi-pass heat pump with recirculation return to primary (HPWH_MPRetP) (Figure 4)

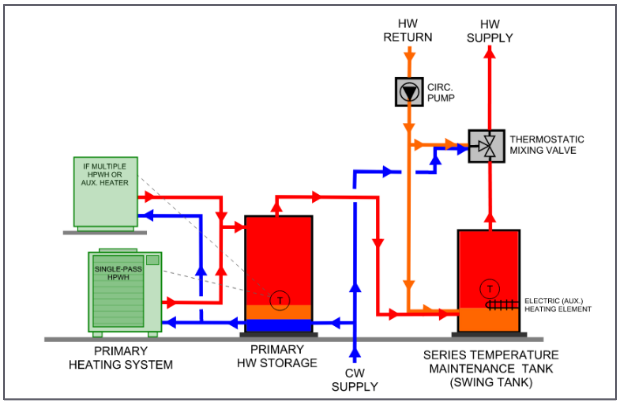

Figure 1. HPWH_SPST

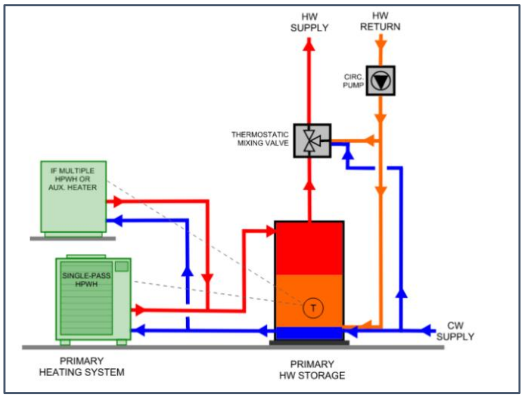

Figure 2. HPWH_SPRetP

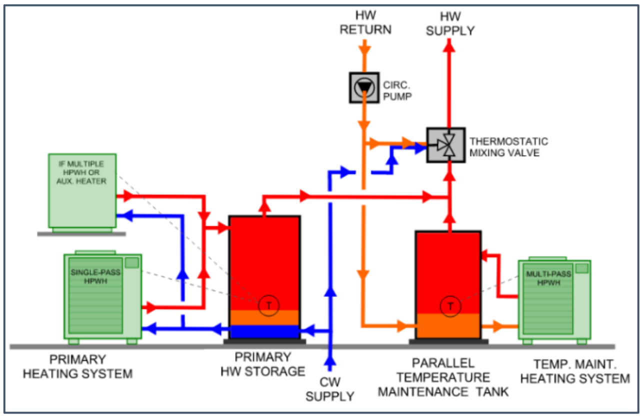

Figure 3. HPWH_SPwMPTM

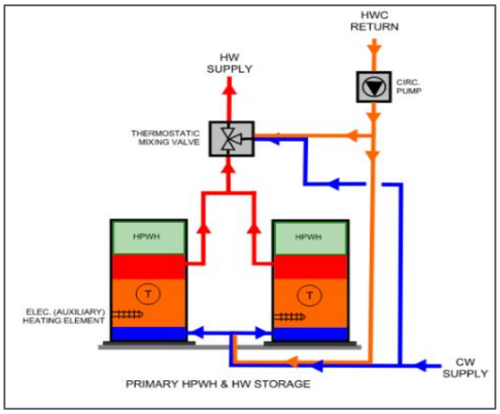

Figure 4. HPWH_MPRetP

System Performance

We assessed commercial HPWH systems based on their average annual System Coefficient of Performance (SysCOP) which represents the efficiency of the entire Domestic Hot Water (DHW) systems system. This approach is consistent with NEEA's AWHS 8.0. The NEEA AWHS specifies a qualification process for performance rating that involves evaluating each product line using annual simulations for every combination of qualified piping configurations recommended by the manufacturer, across 16 IECC climate zones (CZ) relevant to the United States. Tiers are incorporated into the specification based on the product performance and supported installation applications. The Minimum SysCOP required for Tier 1 to Tier 4 ratings are 1.5, 2.00, 2.50, and 3.00, respectively. This specification includes a Qualified Products List, which designers, contractors, and regulatory bodies can utilize for designing, regulating, incentivizing, or comparing HPWH systems based on the tier rating. This paper focuses on evaluating the performance of Central HPWH systems using SysCOP as a metric for California climate zones[2].

Methodology

The overall objective of this paper is to understand the market trends for HPWH and evaluate the energy performance, utility cost savings, environmental impact and incremental costs comparing central HPWH system with gas water heater. There are five sub-sections under this section. Market Assessment talks about the methodology we used to stay current with the HPWH market. Basis of Design summarizes the gas water heater (baseline) or HPWH designs (proposed) for multifamily prototype buildings we studied in this paper. Energy Performance explains the methodology we used to evaluate the energy savings comparing HPWH with gas water heater using energy simulation. Utility Costs and Environmental Impact shows how energy utility cost savings and greenhouse gas emissions (GHG) savings are calculated. Incremental Cost provides the methodology of how incremental costs are obtained between gas water heater and HPWH system.

Market Assessment

To stay abreast of the rapidly evolving industry, our market assessment process for evaluating the current landscape and technical viability primarily employed the following methodologies:

- Product research: We conducted comprehensive research into existing central heat pump water heater (HPWH) systems available in the market to understand their features, specifications, and performance metrics.
- Interviews: To gain valuable insights into market trends, technical challenges, and emerging design practices, we conducted interviews with key stakeholders including designers, contractors, and manufacturers within the industry.
- Review of design documentation: We analyzed design drawings and compliance forms from various sources to understand prevailing design standards and regulatory requirements. Data sources include utility programs databases, Home Energy Rating System (HERS) providers, design consultants, and research projects funded by programs

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[2] In California, most climate zones align with IECC Zone 3-4.

like the Electric Program Investment Charge (EPIC) Program. This in-depth review aimed to elucidate current HPWH design practices and application trends.

Basis of Design

To support energy performance and cost impact analysis, we collaborated with a seasoned HPWH design consultant firm to formulate the Basis of Design (BOD) for both the base case and proposed central DHW systems across four multifamily prototype buildings (as detailed in Table 1). This collaborative effort yielded system sizing criteria, equipment selection parameters, and plumbing configurations representing industry best practice.

Table 1. Prototype Buildings Used for Energy, Cost, and Environmental Impacts Analysis

Prototype Name	Description
LowRiseGarden	2-story, 8-unit apartment building. Average dwelling unit size: 960 ft^2. Total floor area 7,680 ft^2 Baseline DHW system: individual gas water heaters with thermal efficiency 0.8 and 0.2 Solar Savings Fraction (SSF) in CZ1~9, and 0.35 SSF in CZ10~16
LoadedCorridor	3-story, 36-unit apartment building. Average dwelling unit size: 960 ft^2. Total floor area 40,000 ft^2 Baseline DHW system: central gas water heater with thermal efficiency 0.8 and 0.2 SSF in CZ1~9, and 0.35 SSF in CZ10~16
MidRiseMixedUse	4-story (4-story residential, 1-story commercial), 88-unit building. Avg dwelling unit size: 870 ft^2. Total floor area 113,100 ft^2 Baseline DHW system: central gas water heater with thermal efficiency 0.8 and 0.2 SSF in CZ1~9, and 0.35 SSF in CZ10~16
HighRiseMixedUse	10-story (9-story residential, 1-story commercial), 117-unit building. Avg dwelling unit size: 850 ft^2. Total floor area 125,400 ft^2 Baseline DHW system: central gas water heater with thermal efficiency 0.8 and 0.2 SSF in CZ1~9, and 0.35 SSF in CZ10~16

The configurations we investigated for the central HPWH system energy and cost analysis can be found in Figure 1 through Figure 4. Table 2 through Table 6 provide a summary of the primary HPWH equipment and temperature maintenance HPWH selection for the four configurations across the four building types. The 2025 Title 24 Multifamily DHW CASE report provided more detailed equipment schedules such as storage tank size, temperature maintenance equipment sizing and selection (Feng, Delagah, Garcia, & Haile, 2023).

Table 2 Primary Heat Pump for Proposed HPWH_SPST Configuration

Building Type	Qty.	Manufacturer	Model	Recovery Capacity (Btu/h)
LowRiseGarden	1	SanCO2	GS4	15,000
LoadedCorridor	5	SanCO2	GS4	15,000
MidRiseMixedUse	2	Mitsubishi	Heat2O	110,000
HighRiseMixedUse	2	Mitsubishi	Heat2O	110,000

Table 3 Primary Heat Pump for HPWH_MPRetP Configuration

Building Type	Qty.	Manufacturer	Model	Recovery Capacity (Btu/h)
LowRiseGarden	2	Colmac	CxV-5	26,019
LoadedCorridor	6	Colmac	CxV-5	26,019
MidRiseMixedUse	3	Colmac	CxA-20	83,452
HighRiseMixedUse	3	Colmac	CxA-20	83,452

Table 4 Primary Heat Pump for HPWH_SPwMPTM Configuration

Building Type	Qty.	Manufacturer	Model	Recovery Capacity (Btu/h)
MidRiseMixedUse	1	Mitsubishi	Heat2O	110,000
HighRiseMixedUse	2	Mitsubishi	Heat2O	110,000

Table 5 Temperature Maintenance HPWH for HPWH_SPwMPTM Configuration

Building Type	Qty.	Manufacturer	Model	Capacity (gallons)	Electrical Power Consumption (kW)
MidRiseMixedUse	2	Colmac	CxV-5	26,019	2
HighRiseMixedUse	4	Colmac	CxV-5	26,019	4

Table 6 Primary Heat Pump for HPWH_SPRetP configuration

Building Type	Qty.	Manufacturer	Model	Recovery Capacity (Btu/h)
LowRiseGarden	1	Colmac	CxV-5	26,019
LoadedCorridor	1	Nyle	E360	105,750
MidRiseMixedUse	2	Nyle	E360	105,750
HighRiseMixedUse	3	Nyle	E360	105,750

Energy Performance

We evaluated various central HPWH system energy performance using energy simulations and laboratory testing. We also collected field performance data from monitored real-world projects provided by an experienced design firm to gain practical insights into system efficiency, reliability, and effectiveness. The lab and field data are from independent resources.

We conducted energy savings analysis utilizing the prototype building models, employing the 2025-0.4 Research Version of the CBECC software for both the base and proposed cases, in adherence to standards established by the CEC (California Energy Commission n.d.). The base case models represent a gas DHW system, serving as the benchmark against which the proposed models are evaluated. In contrast, the proposed models representing common design approaches, encompassing different configurations of central HPWH systems based on the BOD. This analysis provided insights into the comparative energy performance of the base and proposed central DHW systems.

The Pacific Gas and Electric (PG&E) Applied Technology Services (ATS) laboratory embarked on a comprehensive testing initiative aimed at refining sizing methods and design strategies for central HPWH Systems in multifamily settings. This endeavor entailed a thorough investigation into critical design variables, including heat pump capacity, storage tank dimensions, and optimal operational modes. Furthermore, the insights gleaned from these experiments have been instrumental in enhancing the CBECC central HPWH model, with ongoing utilization for software calibration. This process ensures precise modeling of HPWH system performance, thereby empowering designers and engineers to craft energy-efficient multifamily structures.

The lab conducted exhaustive testing to evaluate the performance and limitations of various central HPWH systems. Tests included different refrigerants like CO2, R-134a, and R-410a, and heating methods such as single and multi-pass heating. Key equipment assessed included Sanden Gen3, Colmac CxA 15 and CxV 5, and AO Smith CHP-120 HPWH units. Beyond specific models, configurations were analyzed, focusing on factors like tank sizing, piping arrangements, and temperature settings. Tests were conducted at the lab using two chambers with controlled ambient conditions. Over 250 tests were performed to cover diverse design parameters and operational scenarios. Chambers were constructed to accommodate various HPWH sizes and setups, with insulated walls and ceilings. Environment control systems maintained precise temperatures (40 °F to 140 °F) and humidity levels (30% to 80% RH).

Utility Costs and Environmental Impact

Most multifamily operators select small commercial gas and electricity rate plans as opposed to residential plans as they are generally lower in cost for their main gas meter and electrical panel serving non-dwelling unit end uses such as centralized DHW systems, centralized HVAC systems, hallway and exterior lighting, laundry and other shared areas and services. Utility costs were estimated based on the Pacific Gas and Electric (PG&E) commercial electric rate B-10 TOU (PG&E, 2024) and commercial gas rate G-NR1 (PG&E, 2024). The average electricity rate used in the calculations is \$0.41/kWh, and the gas rate is \$1.66/therm.

The environmental impact assessment focused on quantifying the reduction in GHG emissions, leveraging the GHG hourly factors published by California Energy Commission (CEC, 2023) to estimate the environmental benefits of transitioning to heat pump water heating systems. These hourly factors are used to convert predicted site energy use to long run marginal greenhouse gas emissions. The hourly factors vary by location, time of day and season. The average grid GHG electricity emission factor is 0.1988 lb CO2e /kWh, and the average natural gas GHG emission factor is 13.29 lb CO2e/therms. We applied these multipliers to the annualized gas and electricity use in the baseline and HPWH cases and determined the difference.

Incremental Cost

For both the baseline gas and proposed central HPWH systems, we worked with two mechanical contractors to get cost estimates for the same system designs used for energy simulation based on the BOD. The mechanical contractors provided material and labor cost estimates for the entire central DHW systems, disaggregated by the central DHW equipment itself; DHW plant piping; commissioning and startup; general conditions and overhead; design and engineering; and a contractor profit or market factor. The difference between the baseline and proposed systems costs is the incremental costs.

The cost for the central natural gas boiler system was extracted from the 2022 All-Electric Multifamily CASE Report (TRC, 2021), which we augmented by applying inflation rates from the CPI Inflation Calculator (U.S. Bureau of labor statistics) for use when estimating

2023 costs to align with the central HPWH cost in the 2025 Multifamily DHW CASE Report (Feng, Delagah, Garcia, & Haile, 2023) led by TRC.

Results

Market Assessment

Our market analysis delves into the burgeoning sector of commercial-sized Heat Pump Water Heaters (HPWH), particularly those designed for central systems serving multiple dwelling units. We've observed significant growth and transformation in this market, evidenced by comparing our product research findings from 2019 with insights gleaned from the 2022 CASE report. Back in 2019, our research identified 41 air-source HPWH units meeting the criteria for suitability in central HPWH applications, with the exception of Sanden units, which fell short of the 20 kBtu/hr threshold. Building upon this foundation, our 2023 product review unveiled a remarkable increase, with a total of 57 air-source HPWH units now either available or expected to be so in the near future, all suitable for central HPWH applications.

This expansion is notable not just in terms of quantity but also in the diversity of manufacturers offering products or soon to be available. Key players in this regard include Aermec, AO Smith, Colmac, Rheem, Nyle, Sanden units, Mitsubishi, Mayekawa, Lync, and Transom.

Another noteworthy trend is the proliferation of low-GWP (Global Warming Potential) heat pumps. According to the 2022 CASE Report, there were merely 10 low-GWP air source HPWH products in 2019. However, by 2022/2023, this number had doubled (see Figure 5), with product additions from manufacturers such as Nyle e-series, Mitsubishi Electric Trane HVAC US, Lochinvar, Mayekawa, Lync Aegis A series, and Transom Hatch.

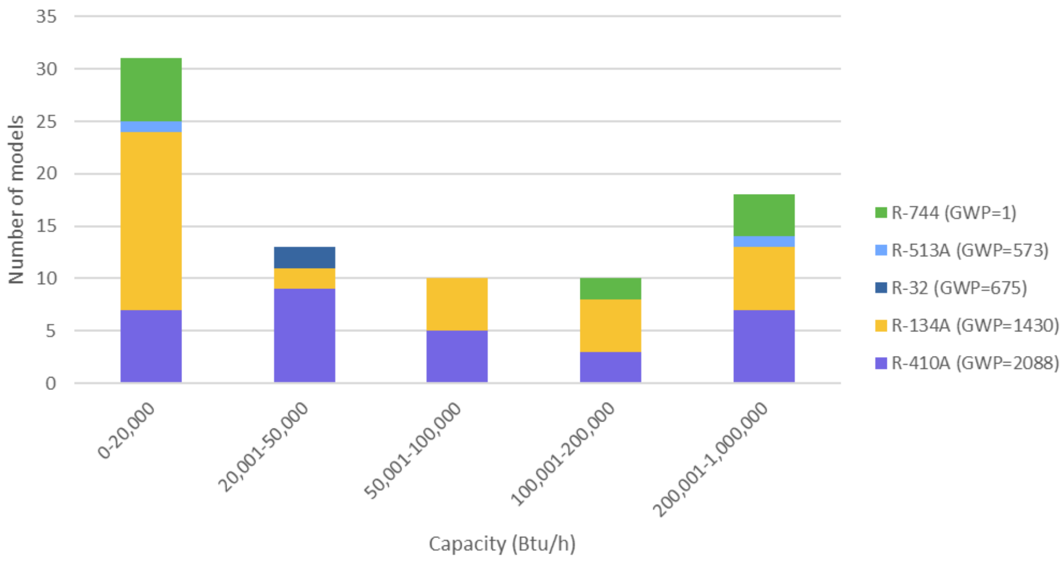

Figure 5. Air source HPWHs: refrigerant per system capacity

In line with this expansion, manufacturers are innovating with plug-and-play packages as a novel market delivery method. In our discussions with central HPWH practitioners, a consistent theme emerged: the desire for enhanced design assistance and plug-and-play configurations comprising heat pump, storage tank(s), controls, and associated components. This approach aims to simplify installation, reduce engineering complexities, and potentially lower initial system costs. Notable initiatives in this space include Mitsubishi HEAT2O, marketed as Origin by Steffes, and SanCO2 (formerly Sanden), collaborating with skid manufacturers to develop skid packages or site assembled HPWH systems.

These ongoing efforts underscore the industry's commitment to innovation and customer-centric solutions, particularly in the realm of low-GWP heat pump technology.

Energy Performance

We calculated the annual electricity savings, and natural gas savings, per dwelling unit for all prototypes and all configurations. Figure 6 shows the annual electricity savings (kWh) per dwelling unit in representative California Climate Zones (CZs) (California Energy Emission, 2022) for LoadedCorridor and MidRiseMixedUse prototypes as example results. Between the various HPWH configurations, the electricity consumptions increased between negative 451 to 1,882 kWh (1,538 to 64,21 kBtu) per dwelling unit compared to the baseline gas system due to fuel switching across all CZs and all prototypes. The annual gas savings (kBtu) per dwelling unit are the same for all central HPWH configurations but varied depending on climate zones and building prototypes. The annual gas savings ranged from 5,578 to 15,849 kBtu per dwelling units across all CZs and all prototypes.

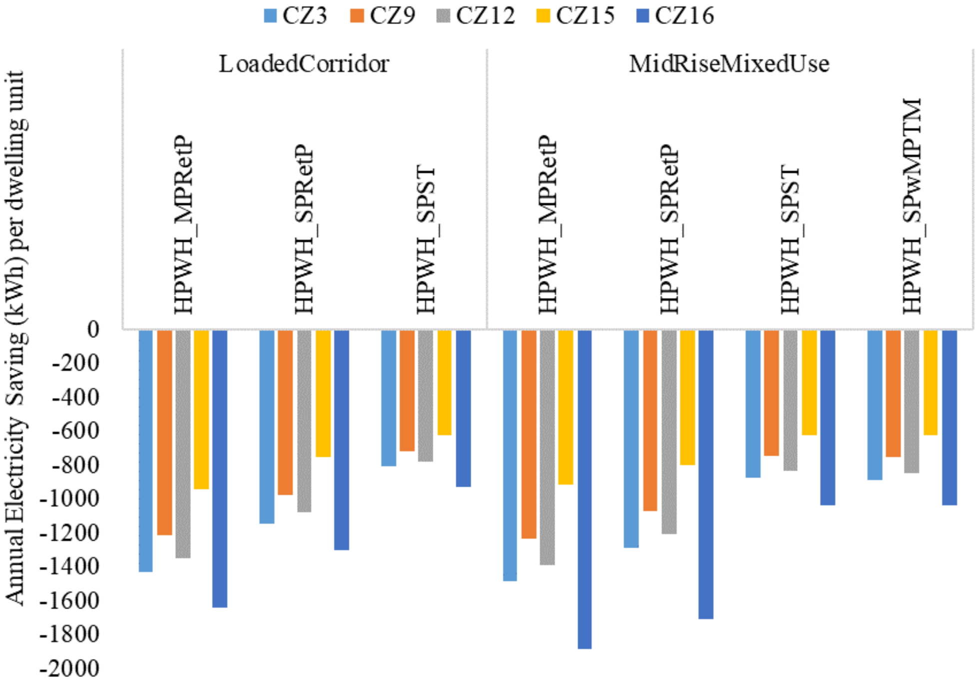

Figure 6. Annual Electricity Savings (kWh) Per Dwelling Unit For California Climate Zones

We evaluated SysCOP to compare with the NEEA AWHS v8.0 Tiers. Our analysis, based on CBECC simulations for Climate Zone 12, yielded SysCOP estimates ranging from 2.05 to 3.91 annually. Notably, all configurations surpassed the requirements of NEEA Tier 2, which specifies a minimum SysCOP of 2.0. This outcome supports the development of the 2025

California energy code prescriptive pathway for central HPWH designs. This pathway allows compliance of system configurations endorsed by manufacturers meeting the efficiency standards of NEEA Tier 2 or higher.

In addition to simulations, we complemented our assessment with lab testing results and field performance data to gauge the energy consumption of various central HPWH equipment and design approaches. Note that the intention here is not a direct comparison between lab tests, field performance, and simulation results because the three data sources were from independent research initiatives and factors like hot water draw profiles and equipment sizing can significantly impact SysCOP. The comparison sheds lights on performance pattern of HPWH product feature and system configurations. We endeavored to align simulation inputs as closely as possible with lab test conditions. To this end, Figure 7 illustrates the comparison of daily SysCOP instead of annual SysCOP since lab results reflect daily performance. Additionally, we restricted the simulation results to days with an average outdoor air temperature close to 65°F to mimic lab conditions.

When comparing various plumbing configurations for central HPWH systems, distinct efficiency characteristics emerge:

- Single-Pass heat pump in series with TM, also commonly known as the swing tank configuration: The simulation results show that the configuration is efficient by employing a high-efficiency single-pass primary HPWH to handle a portion of the temperature maintenance load. Electric resistance is utilized for maintaining hot water in the recirculation loop. This setup improves energy efficiency by strategically distributing the load between the HPWH and electric resistance components. However, when compared to lab testing results, notably, the lab results shows that the swing tank designs are less efficient, due to higher heat loss rates and reduced system efficiency regardless of the primary heat pump type.
- Single-Pass in parallel for TM: Similarly efficient to the previous configuration, this setup utilizes heat pumps for both the primary and temperature maintenance load loops. Multi-pass heat pumps in the recirculation loop effectively fulfill the entire temperature maintenance load. However, these configurations are typically best suited for multifamily buildings with four or more habitable stories due to their complexity and associated costs.
- Single-pass return to primary: This system appears to be efficient because single-pass equipment is generally more efficient than multi-pass, and there is less heat loss with simplified plumbing. However, some equipment may not operate reliably with this configuration.
- Multi-Pass Systems: Comparatively less efficient than single-pass return to primary systems, multi-pass HPWHs exhibit lower temperature lift. While still viable, these systems may not offer the same level of efficiency as their single-pass counterparts.

When compared to lab testing results, the simulation data largely correlates with lab results. However, notably, we noticed the discrepancy for the single-pass in series for TM configuration, which is commonly known as the swing tank configuration. The lab results shows that the swing tank designs demonstrate inefficiencies, resulting in higher heat loss rates and reduced system efficiency regardless of the primary heat pump type. For example, as shown in Figure 7, the swing tank configuration with CO2 in simulation shows a daily COP of 4.05. However, the lab test gives a lower daily COP of 2.8. This implies further investigation of the swing tank performance is needed and the software could be improved with additional data made available through lab testing. There are on-going and upcoming efforts to collect more field data to enhance our knowledge about the various plumbing configurations, in particularly around the applicability of swing tank design and return-to-primary configuration when paired with different heat pump water heater products,

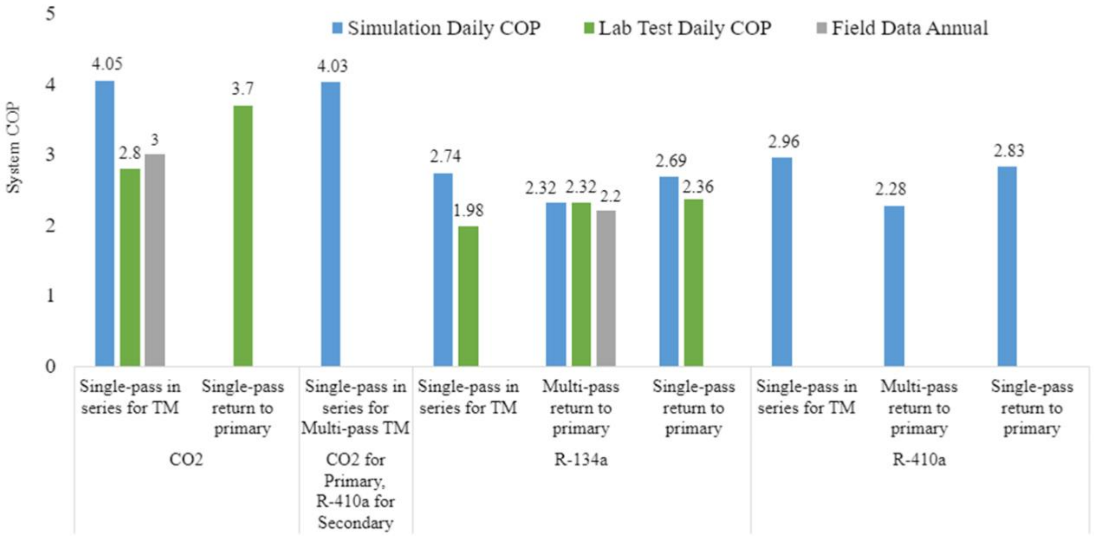

Figure 7 System COPs for various HPWH configurations from simulation, lab test and real-world projects

Utility Costs and Environmental Impacts

The annual utility cost savings were calculated and Figure 8 represents the cost savings for all configurations of the LoadedCorridor and MidRiseMixedUse prototypes in several example CZs. The findings indicate that, based on the analyzed rate structure, operating the heat pump incurs higher costs compared to the baseline gas system. Specifically, there is an increase in energy costs ranging from \$61 to \$592, translating to 2.38 to 110.8 percent per dwelling unit for all scenarios.

To put this in perspective, both gas and electricity rates and rate plans used in this analysis have experienced significant price increases. The average annual increase over a 15-year period has been 5.0% for gas and 7.2% for electricity, but in the past 5-year period the average annual increase has been much higher at 9.6% for gas and 13.8% for electricity. Per unit of energy in 2010, heating water using electricity was 5.3 times more expensive than gas. In 2024, that ratio has increased to 7.3 times more expensive, thus exceeding the cost savings potential of electric heat pumps over natural gas water heaters even though they are 4 to 5 times more efficient from a efficiency rating perspective. If electricity prices continue to increase at a higher rate than gas prices, this will significantly impact California's electrification goals and reduce the pace of market transformation to electric heat pump water heaters especially in existing buildings.

Figure 9 illustrates the estimated annual avoided GHG emissions for each configuration of two selected prototypes by using the hourly GHG emissions factors that the CEC developed. While there was an increase in utility costs, the greenhouse gas emissions savings ranged from 231 to 860 kg CO2, translating to 31 to 57 percent per dwelling unit for the heat pump system relative to the natural gas heating systems used in most baseline systems showing significant progress toward decarbonization.

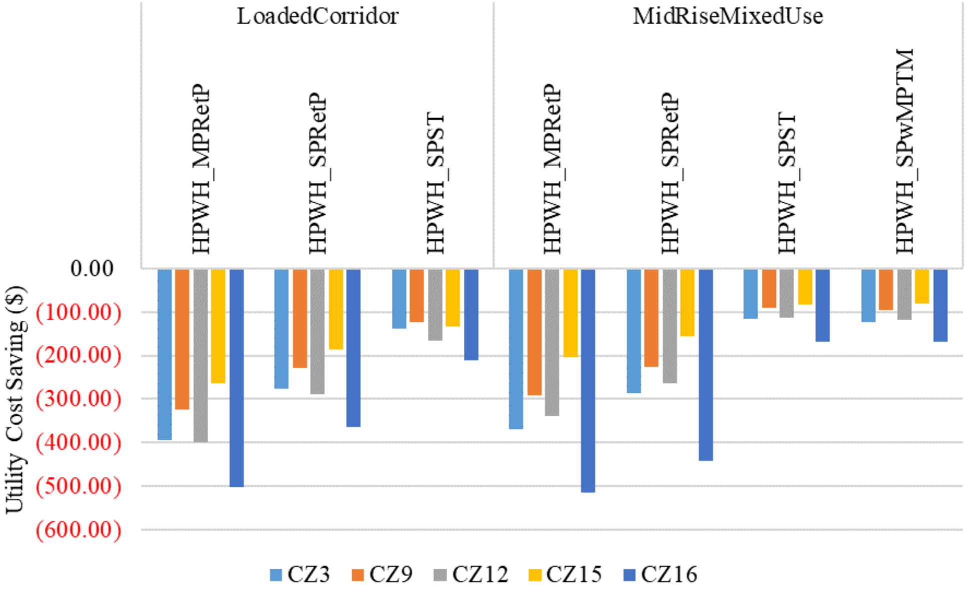

Figure 8 Annual Utility Cost Savings

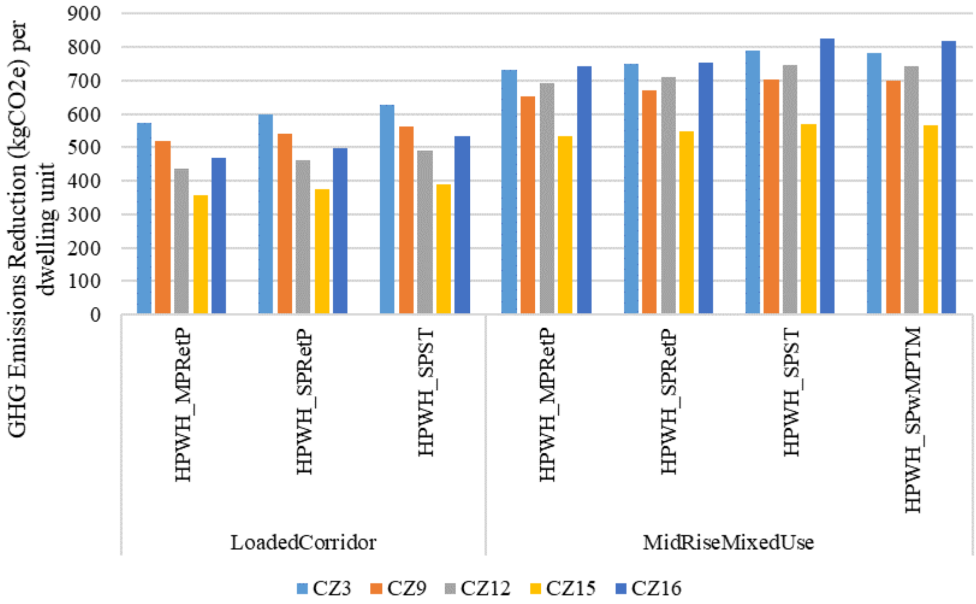

Figure 9 Annual GHG Emissions Reduction (kgCO2e) per dwelling unit

Incremental Cost

We calculated the total and per dwelling unit incremental cost in the form of additional equipment, labor cost for central HPWH system versus a conventional natural gas boiler system.

The incremental costs for the base case and proposed cases are presented in Table 7 through Table 9. Compared to the gas systems, we found a wide range of cost impacts depending on HPWH type and piping configurations. While some HPWH configurations costs could be 3 to 122 percent higher, some others could be 0.3 to 25 percent lower. Notably, the multi-pass HPWH analyzed here are more expensive than single-pass product and result in increased costs.

As a reality check, we also reviewed the cost for the central HPWH system from the recent demonstration project with central CO_2 HPWH installations in two high rise multifamily buildings (Valmiki, Sweek, Johnson, & Spielman, 2023). The project shows a higher installed cost ($4,082 ~ $6,311 per dwelling units) compared the costs we collected, likely reflecting project specific complexity that are common in real-world projects.

Table 7 Installed Cost for Baseline and HPWH cases for LowRiseGarden and LoadedCorridor

	LowRiseGarden				LoadedCorridor			
Cost	Central Gas Boiler	HPWH_SPST	HPWH_SPRetP	HPWH_MPRetP	Central Gas Boiler	HPWH_SPST	HPWH_SPRetP	HPWH_MPRetP
Equipment Total	$75,220	$46,501	$74,299	$127,863	$120,891	$107,868	$136,608	$353,118
Labor Total	$35,598	$36,358	$36,228	$45,779	$70,446	$65,571	$35,252	$72,211
Total	$110,818	$82,859	$110,526	$173,642	$191,338	$173,439	$171,861	$425,329
Total Per Dwelling Unit Cost	$13,852	$10,357	$13,816	$21,705	$5,315	$4,818	$4,774	$11,815
Incremental Cost per Dwelling Unit	NA	($3,495)	($36)	$7,853	NA	($497)	($541)	$6,500

Table 8 Installed Cost for Baseline and HPWH cases for MidRiseMixedUse

	MidRiseMixedUse				
Cost	Central Gas Boiler	HPWH_SPST	HPWH_SPRetP	HPWH_MPRetP	HPWH_SPwMPTM
Equipment Total	$181,956	$182,624	$266,070	$407,630	$238,324
Labor Total	$123,644	$83,629	$62,792	$76,372	$77,617
Total	$305,601	$266,253	$328,862	$484,002	$315,941
Total Per Dwelling Unit Cost	$3,473	$3,026	$3,737	$5,500	$3,590
Incremental Cost per Dwelling Unit	NA	($447)	$264	$2,027	$118

Table 9 Installed Cost for Baseline and HPWH cases for HighRiseMixedUse

	HighRiseMixedUse				
Cost	Central Gas Boiler	HPWH_SPST	HPWH_SPRetP	HPWH_MPRetP	HPWH_SPwMPTM
Equipment Total	$200,775	$209,364	$386,492	$422,395	$395,124
Labor Total	$148,318	$74,189	$62,325	$74,181	$89,264
Total	$349,093	$283,553	$448,816	$496,576	$484,388
Total Per Dwelling Unit Cost	$2,984	$2,424	$3,836	$4,244	$4,140
Incremental Cost per Dwelling Unit	NA	($560)	$852	$1,261	$1,156

Conclusions and Discussions

This paper presents the findings to support the California Title 24 2025 code cycle development, as well as the lab-testing results of central HPWH equipment and system configurations. Although the funded projects aimed to support building energy code changes in California, the research findings aim to enhance industry understanding of the technology, inform decision-making by designers and building owners, and support policymaking and utility program development. This, in turn, facilitates the adoption of HPWH systems and supports the state and national efforts to transition to cleaner and more sustainable energy sources.

First, we examined the technical feasibility and market availability of central HPWH systems based on product research, interviews of various market actors and review of design documentation from utility programs, design consultants, and research projects. The market analysis suggests a dynamic and evolving landscape within the commercial-sized HPWH sector, characterized by rapid product availability growth, diverse manufacturer participation, proliferation of low-GWP heat pumps and innovations in market delivery method.

Collaborating with plumbing engineers, we devised concept designs of 3-4 common central HPWH system configurations for four multifamily prototype buildings of different sizes. We evaluate the energy performance of these systems compared to central gas systems. Between the various HPWH configurations, the electricity savings were between negative 1,882 to 451 kWh per dwelling unit compared to the baseline gas system due to fuel switching across all CZs and all prototypes. The annual gas savings ranged from 5,578 to 15,849 kBtu per dwelling units across all CZs and all prototypes.

We evaluated SysCOP leveraging the approach from NEEA AWHS v8.0 for HPWH Tier ratings. Our analysis, based on CBECC simulations for California Climate Zones, yielded SysCOP estimates ranging from 2.05 to 3.91 annually. This supports the development of the 2025 California energy code prescriptive pathway for central HPWH designs which allows compliance of system configurations endorsed by manufacturers meeting the efficiency standards of NEEA Tier 2 or higher[3].

When compared to lab testing results, the simulation data largely correlates with lab results. However, notably there is discrepancy for the single-pass in series for TM configuration, which is commonly known as the swing tank configuration. While the simulation results showed that the swing tank configurations were highly efficient, the lab results shows that the swing tank designs demonstrate inefficiencies. This highlighted a continuous need for more data collection effort of various HPWH configurations and simulation software refinement.

Depending on the climate zone, HPWH equipment and piping selection, with the rate structure analyzed, buildings installed central HPWH systems will likely see an increase of energy utility costs ($61 to $592 per dwelling unit per year or 2.38 to 110.8 percent). HPWHs demonstrated significant reductions in GHG emissions (231 to 860 kg CO_2 or 31 to 57 percent per dwelling unit), showing significant progress toward decarbonization. The ability to maintain or gain momentum to transform the market from gas heaters to HPWH is a growing concern especially in existing buildings due to rapid increases in electricity costs versus gas costs.

Analyzing first cost data when compared to the baseline gas system, we found HPWH costs could be 3 to 122 percent higher for some configurations, and 0.3 to 25 percent lower for some others.

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[3] In California, most climate zones align with IECC Zone 3-4.

Overall, our research shows that there isn't a one-size-fits-all configuration for central HPWH systems. The most suitable setup depends on various factors, including climate conditions, building size, equipment availability, and cost considerations. The synthesized findings provide valuable insights applicable to central HPWH systems.

In terms of takeaways for policy development opportunities, to maximize the impact of energy codes and keep pace with rapidly evolving technology, it's essential for energy codes to leverage existing and ongoing efforts initiated by various stakeholders in the market. This includes manufacturers, utilities, government agencies, research entities, private efforts from manufacturers, designers, energy consultants, and advocacy groups.

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