Characterization of Central Heat Pump Water Heating Deployment in the Multifamily Market

Final Report

ET24SWE0027

Prepared by:

Lysandra Medal TRC
Ritesh Nayyar TRC
Alfredo Jahn TRC
Amin Delagah TRC
Dove Feng TRC

February 25, 2025

Acknowledgements

The project team thanks the anonymous interview participants for their time and expertise shared in this study.

Disclaimer

Executive Summary

This report presents a comprehensive analysis of Central Heat Pump Water Heating (CHPWH) systems in the multifamily market, focusing on system characterization, market trends, challenges, and adoption opportunities. Combining insights from existing literature, laboratory tests and field data, and primary stakeholder interviews, it provides valuable guidance for policymakers, program managers, and industry professionals to overcome barriers and advance CHPWH adoption for decarbonizing the multifamily sector.

Water heating accounts for 27 to 32 percent of total energy use in multifamily buildings, according to the 2015 Residential Energy Consumption Survey by U.S. Energy Information Administration (EIA). As the industry moves towards decarbonization, CHPWH systems have emerged as a crucial technology for reducing carbon emissions and improving energy efficiency in multifamily buildings. Corresponding to project objectives, the following summarizes key study findings, followed by the relevant recommendations to address identified challenges and enhance the adoption of CHPWH systems in multifamily buildings.

1. **Implementation processes for retrofitting CHPWH systems (Objective 1)**

   Retrofitting CHPWH systems in multifamily buildings faces challenges such as space constraints, electrical capacity limitations, and integration with existing infrastructure, which can negatively impact system performance. For example, limited space may restrict ventilation, reducing heat pump efficiency, while inadequate electrical upgrades can increase reliance on less efficient backup systems. New construction projects avoid these issues by allowing for optimized system design. This study identified cost-effective strategies, including pre-configured kits, modular systems, and thorough site assessments. These strategies emphasized the need for advanced control strategies, robust CHPWH-specific Quality Assurance and Quality Control (QA/QC) frameworks within incentive program, and enhanced training for contractors and designers to focus on system selection, installation techniques, and optimization strategies.

   To address these challenges, programs should also develop comprehensive retrofit guides that include best practices for site evaluations to ensure proper ventilation and address electrical upgrades. Targeted incentives for ventilation and infrastructure improvements, combined with more advanced contractor training, can help mitigate performance issues and support successful retrofits.

2. **Identification of CHPWH system types (Objective 2)**

   CHPWH system configurations largely driven by equipment types which are categorized into single-pass and multi-pass configurations. Single-pass systems with return-to-primary (lower inlet) setups demonstrated the highest efficiency with improved stored heating capacity and better legionella control. Multi-pass systems are installer friendly and suitable for gas split “boiler” water heater replacement because they can operate reliably for similar hot water return temperature as gas boiler. In addition, unlike single-pass systems where most product are split system type, many multi-pass heaters are integrated equipment which is similar to a gas water heater that installers are experienced with. The choice of configuration significantly impacts

space requirements, ventilation requirements, installed and operating cost, system performance and efficiency.

To ensure these CHPWH system operate efficiently, it is critical to refine control strategies for integrated systems to improve performance during low-demand periods and high-temperature maintenance loads, as well as optimize configurations for efficient domestic hot water (DHW) production, with or without continuous recirculation system.

3. **Key aspects of CHPWH systems (Objective 3)**

   We documented real installed systems in this report, including key system parameters such as including refrigerant types, temperature ranges, storage volumes, and output capacities. The CHPWH market is rapidly evolving, with an increasing number of manufacturers offering products suitable for multifamily applications. There's a notable shift towards low-global warming potential (GWP) refrigerants, such as 454B and 513a and ultralow GWP refrigerants, such as CO2 (R-744) nationally and propane (R-290) internationally.

   To keep pace with these system developments, we recommend continuing gathering and analyzing real-world performance data from installed systems to refine design and operational practices. This study also suggests that contractors explore innovative installation approaches, such as using modular, preconfigured kits and sub-metering, to streamline CHPWH deployment and support system startup and operation.

4. **Operational data review (Objective 4)**

   The Annual System Coefficient of Performance (SysCOP) emerged as the most relevant metric for evaluating overall system efficiency, considering factors such as technology choice, rated unit COP, sizing, piping configuration, controls, and temperature maintenance design. Advanced control strategies, such as proper temperature sensor placement, adaptive algorithms, and variable-speed pumps, can enhance SysCOP by maintaining thermal stratification and efficiently responding to real-time demand. Systems with properly configured Digital Master Mixing Valves (DMMVs) further improved temperature consistency, reduced energy losses during low-demand periods, and minimize reliance on backup systems.

   This report also revealed that high temperature maintenance loads and inadequate ventilation in retrofits negatively impacted SysCOP, which suggests the need for proper system sizing and infrastructure upgrades. Poor integration of backup systems, such as over-reliance on electric resistance heating, reduce efficiency. To address these challenges, programs should implement extended post-installation monitoring to ensure optimal performance and address any issues that arise. Programs and measure packages should adopt SysCOP as the standard performance metric to drive adoption of optimized designs and ensure that installations deliver measurable energy savings and carbon reductions.

5. **Utility incentive program review (Objective 5)**

   Utility programs in California support CHPWH adoption in multifamily buildings by promoting high-efficiency systems and low-GWP refrigerants, but stakeholders mentioned that their effectiveness is hindered by gaps such as limited cost coverage, procedural complexities, and insufficient focus on retrofit challenges. These programs disproportionately favor straightforward projects over complex retrofits, focus on equipment efficiency rather than system efficiency, lack provisions for long-term monitoring, and unable to address retrofit challenges like ventilation and electrical upgrades comprehensively. To improve outcomes, we recommend the following program improvements: 1) streamline application processes; 2) increase incentives coverage to better align with actual retrofit installation costs; 3) improve incentive structure to motivate quality installation from contractors; 4) develop targeted retrofit resources such as best practice checklist and incorporate contractor training; 5) Require performance-based metrics like SysCOP to ensure lasting energy and emissions benefits. Additionally, we also recommend expanding education efforts to inform building owners, property managers, and contractors about the benefits, installation practices, and long-term savings potential of CHPWH systems.

6. Insights from stakeholders (Objective 6)

Interviews with industry professionals revealed positive experiences with CO2 based split CHPWH systems, citing benefits such as energy efficiency and environmental friendliness. However, stakeholders also noted challenges related to proper sizing of heaters and storage volume, affordability, setpoint temperature management for effective load shifting, and integration with existing building systems. Stakeholders generally expressed optimism about wider CHPWH adoption in multifamily buildings but mentioned that training, financial incentives, and QA/QC frameworks as critical to overcoming high costs, limited expertise, and integration challenges in CHPWH adoption.

7. Consensus from laboratory, field, and stakeholder insights (Objective 7)

Laboratory tests, field data, and stakeholder interviews highlight the performance and challenges of CHPWH system configurations in multifamily applications. Single-pass systems, particularly those with return-to-primary (lower inlet) configurations, demonstrated high efficiency with COP values of up to 3.9 for SANCO2, as well as energy savings of 68% and GHG reductions up to 90%. Multi-pass systems, while less efficient under some conditions, showed stable performance with COP values up to 2.3 when tank stratification was maintained.

Laboratory and field insights emphasized the need for proper system sizing, tank stratification in system design, installation, and maintenance practices. For example, ensure tanks are configured to maintain thermal layers, which improves efficiency and hot water availability. Stakeholders emphasized the need for financial incentives, training programs, and tailored system designed to improve adoption. Programs such as TECH Clean CA and SMUD Multifamily Incentives successfully bridge cost gaps through rebates for low-GWP refrigerants and efficiency-based incentives and bring CHPWH systems close to gas cost parity in retrofit projects. Significant load shifting potential (32-63% during peak periods) also enhances grid integration and cost savings. To ensure success, stakeholders recommended prioritizing high-performing configurations like single-pass systems with refrigerants such as R-134a and CO2, while avoiding oversized tanks and inadequate swing tank setups. Future research should focus on modular system designs, advanced performance metrics (e.g., SysCOP), and contractor training to optimize system performance, reduce costs, and increase reliability.

Abbreviations and Acronyms

Acronym	Meaning
3CE / CCCE	Central Coast Community Energy
ADU	Accessory Dwelling Unit
AIA	American Institute of Architects
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAMBE	Bay Area Multifamily Building Enhancements
BayREN	Bay Area Regional Energy Network
BOMA	Building Owners and Managers Association
BTU	British thermal unit
BUILD	Building Initiative for Low-Emissions Development Program
CA	California
CASE	Codes and Standards Enhancement
CCE	cool climate efficiency
CEDA	California Energy Design Assistance
CESHP	California Energy-Smart Homes Program
CHPWH	central heat pump water heater
COP	coefficient of performance
CO2	Carbon Dioxide
CPUC	California Public Utilities Commission
DHW	domestic hot water
DMMV	digital master mixing valves
EAT	entering air temperature

Acronym	Meaning
EIA	Energy Information Administration
ESA MFES	Energy Savings Assistance Multifamily Energy Savings
EV	electric vehicle
EWT	entering water temperature
GHG	greenhouse gas
GWP	global warming potential
HP	heat pump
HPWH	heat pump water heater
HVAC	heating, ventilation, and air conditioning
IOU	investor-owned utility
kBTu	thousand British thermal units
kWh	kilowatt-hour
LADWP	Los Angeles Department of Water and Power
LIWP	Low Income Weatherization Program
LWT	leaving water temperature
MF	multifamily
NEEA	Northwest Energy Efficiency Alliance
PA	program administrator
PG&E	Pacific Gas & Electric
QA/QC	quality assurance and quality control
ROI	return on investment
SCE	Southern California Edison

Acronym	Meaning
SCOP	seasonal coefficient of performance
SMUD	Sacramento Municipal Utility District
SPOC	single point of contact
SysCOP	system coefficient of performance
TECH	Technology and Equipment for Clean Heating
TMV	thermostatic mixing valve
UEF	uniform energy factor

Table of Contents

List of Tables

List of Figures

Introduction

Central Heat Pump Water Heating (CHPWH) systems are a crucial technology for decarbonizing multifamily buildings. Water heating energy use in multifamily buildings can account for 27 to 32 percent of total energy use based on the 2015 Residential Energy Consumption Survey by U.S. EIA. Heat Pump Water Heating (HPWH) systems use electricity to produce hot water by transferring heat energy from one source, typically air, to potable water. The 2022 Title 24 Statewide All-Electric CASE research suggested central gas-fired domestic hot water (DHW) systems are common in most multifamily buildings, except for those with a small number of dwelling units. There are approximately 58,000 buildings in California with these systems, comprising 1.9 million housing units.

While a variety of residential HPWHs are available to the single-family residential market, CHPWH systems are relatively new technology, with limited field installations in multifamily buildings in California. Field research has found that many early HPWH installations in centralized applications with continuous recirculation systems before 2020 did not perform well due to low COP, poor design, and maintenance issues (Banks, et al. 2022). In typical multifamily buildings where HPs have been installed and commissioned appropriately, projects often have endured steep installation and commissioning challenges and associated installed and operating costs, and they are operating at a lower system COP than anticipated (Valmiki, et al. 2023).

This study aims to characterize the deployment of CHPWH systems in the multifamily market, focusing on system configurations, installation practices, and performance metrics. By examining these aspects, the research seeks to identify barriers to adoption and opportunities for improving the implementation of CHPWH technology in multifamily buildings.

Objectives

This project conducted a market characterization of CHPWH deployment barriers and opportunities for multifamily buildings. The main objectives of this study were:

1. To understand implementation processes for retrofitting CHPWH systems in multifamily buildings, focusing on identifying cost-effective strategies, best practices, and overcoming barriers to increase adoption and enhance system performance.
2. To identify and analyze CHPWH system types, comparing them with established configurations listed by the Northwest Energy Efficiency Alliance (NEEA) in their Advanced Water Heating Specification publication.
3. To document key aspects of CHPWH systems, including refrigerant types, water temperature parameters, storage volumes, and output capacities.
4. To examine operational data, focusing on heat pump control strategies, mixing valve configurations, and the integration of backup water heating systems.

5. To review utility incentive programs and their impact on CHPWH adoption in multifamily buildings.
6. To gather insights from stakeholders, including contractors, manufacturers, and program managers, on their experiences with CHPWH systems in multifamily applications.
7. To synthesize findings from laboratory tests, field data, and stakeholder interviews to provide comprehensive recommendations for improving CHPWH deployment in multifamily buildings.

This study aimed to provide valuable insights for designers, engineers, policymakers, and utility program managers to inform decision-making and improve the adoption and performance of CHPWH systems in multifamily applications.

Methodology & Approach

Figure 1 illustrates the project methodology, which includes five scopes: review of literature, collect system data, collect interview data, analyze data, and report findings and recommendations.

Figure 1. Project Methodology

Literature review

The project team conducted a comprehensive literature review to gather existing knowledge on Central Heat Pump Water Heating (CHPWH) systems in multifamily applications. This review encompassed equipment selection, design practices, installation methods, and operating costs. The team leveraged completed CalNEXT projects, including ET19SCE1010, ET19SCE7110, and ET22SWE0017 to build upon previous research.

Additionally, the review identified CHPWH products and system design approaches currently deployed in California, summarized data from existing incentive programs such as Technology and Equipment for Clean Heating (TECH) and Energy Smart Homes and described the impact of these programs on market adoption of CHPWH.

This comprehensive review provided a solid foundation for understanding the current state of CHPWH technology and its implementation in multifamily buildings.

Program Data

The project team conducted a comprehensive review of Central Heat Pump Water Heating (CHPWH) deployment in multifamily buildings, combining insights from literature review, laboratory testing, field data analysis, and stakeholder interviews. The study revealed that single-pass configurations, especially with return-to-primary (lower inlet) setups, generally offer higher efficiency and stable performance. However, challenges such as proper sizing, temperature management, and integration with existing building systems were noted. Key findings include the importance of advanced control strategies, proper tank stratification, and optimal temperature sensor placement for system efficiency.

The study also highlighted significant training needs across various market actors, including designers, contractors, and building operators. Utility incentive programs were found to play a crucial role in promoting CHPWH adoption, though procedural complexities and high upfront costs remain barriers. Recommendations include prioritizing single-pass systems, implementing sophisticated control systems, conducting thorough site assessments, enhancing contractor training, expanding incentive programs, and supporting long-term performance monitoring. These measures aim to overcome current barriers to CHPWH adoption and realize the technology's full potential for energy efficiency and decarbonization in multifamily buildings.

Lab Test Review

The project team analyzed a comprehensive laboratory test report from the Applied Technology Services (ATS) Advanced Technology Performance Lab in San Ramon, California (CA). This report evaluated various CHPWH system configurations for multifamily buildings under controlled conditions, testing different HPWH equipment including Sanden Gen3, Colmac CxA and CxV, and AO Smith CHP-120. The tests simulated various multifamily building sizes, hot water usage patterns, and temperature maintenance loads.

Key findings revealed that Single-pass Return to Primary (Lower Inlet) and Multi-pass Return to Primary configurations demonstrated high reliability and efficiency. Conversely, configurations with CO2 heat pumps and integrated heat pumps as stand-alone systems faced challenges in maintaining consistent performance. Factors affecting reliability and efficiency included temperature maintenance load, tank stratification, temperature sensor location, control strategies, and return water location.

Interview Data Collection

The interview approach was designed to obtain detailed insights from various stakeholders involved in the installation and operation of CHPWH systems. The stakeholders included:

- Multifamily building owners and contractors to understand their perspective on CHPWHs, drivers and barriers to installing the equipment, and discuss recent advances to gauge their interest.
- Manufacturers to discuss product offerings, market and product development challenges and their recommended system design approach.
- Incentive program managers and other subject matter experts to get a deeper understanding of program design.

Table 1 outlines the key aspects the team aimed to explore through semi-structured stakeholder interviews. TRC targeted up to 10 interviews that represented different stakeholder groups. The questions were expanded to uncover insights into the current installation practices, training needs, key performance metrics, and the impact of utility incentives on the adoption of CHPWH. The associated hypotheses reflected the initial assumptions based on preliminary literature review and conversations with internal subject matter experts. This approach helped identify specific areas for improvement in the utility program and informed the development of recommendations.

Table 1. Interview Questions and Hypothesis

Aspect	Questions	Hypothesis	Rationale
Workforce: Market Actors & Training Needs	• Who are the key market actors that need to be engaged? • What kind of training might be needed?	Contractors lack sufficient training, leading to poor performance of CHPWH systems.	Identifying key actors and training needs can help improve installation quality and system performance.
Technical factor: Installation Practices	What are the common challenges faced during the installation of CHPWH systems? How do these challenges affect system performance?	Poor installation practices, such as insufficient ventilation, lead to increased utility bills due to unnecessary electric resistance running.	Understanding installation challenges can help design better training and certification programs.
Technical factor: Energy Performance Metrics	What key metrics should the program look at as indicators of energy performance?	Current metrics are insufficient; additional technical considerations like system COP, distribution loss, and ventilation approach are needed.	Comprehensive metrics can provide a better understanding of system performance and areas for improvement.
Economic factor: Utility Incentives Impact	How do utility incentives impact the market? Are the incentives too high?	High incentives may lead to unintended negative motivations for contractors to prioritize sales over quality installations.	Evaluating the incentive structure can help align contractor motivations with program goals.

Table 2 provides an overview of the interviewed stakeholders' roles and organizational activities. These market actors may wear multiple hats with expertise spans various aspects of CHPWH system design, installation, and program administration, with particular focus on multifamily building applications.

Table 2. Interview Participant's Role and Activities

Interview ID	Role Description / Organization's Key Activities
01	ID-01 specializes in the design, installation, and maintenance of central heat pump water heaters (CHPWHs) for multifamily buildings. The company primarily installs Sanden CO2 heat pump systems, focusing on energy-efficient solutions that meet the hot water demands of large residential structures while also providing commissioning and performance monitoring services post-installation.
02	ID-02 is a sales manager and manufacturer's representative for a company that works with heat pumps and other Heating, Ventilation, and Air Conditioning (HVAC) equipment. The company role involves selecting appropriate systems, providing technical insights, and ensuring that installations meet the client needs, particularly in complex settings like multifamily buildings and institutional facilities.
03	ID-03 specializes in electrification of apartment buildings throughout California. The company works with property owners to provide energy assessments and education about incentive offerings to develop an electrification plan for their buildings or portfolio. The company promotes onsite solar, heat pumps, and full electrification as part of their services.
04	ID-04 specializes in plumbing and HVAC installations in multifamily and commercial projects. The company primarily works in new construction, as well as some work involving renovation, system upgrades, and boiler and chiller equipment replacements.
05	ID-05 specializes in research projects aimed at improving retrofit delivery in multifamily buildings, with a particular focus on central heat pump water heating. The company implements various incentive programs for multifamily buildings, providing technical assistance, issuing incentives, and guiding projects through the scope of work, including the installation and commissioning of heat pump water heater systems.

Interview ID	Role Description / Organization's Key Activities
06	ID-06 is the founder and CEO of a company focusing on developing packaged central HPWH systems. Key activities include designing and integrating heat pump, storage tanks, and controls to deliver comprehensive water heating solutions for various applications, including multifamily and commercial buildings.

Reporting

Throughout the phase of the research project, the project team prepared preliminary, draft, and final reports summarizing findings and identifying CHPWH products for consideration in future demonstrations or incentive programs. This final report includes additional data analysis as needed and refined recommendations from the draft report. The Performance Target for this project is distribution of the final report to the target audience of plumbing and mechanical system designers, heat pump manufacturers, Investor Owned Utility (IOU) Program Administrators (PAs), and designers, builders, and owners of multifamily residential buildings through their representative organizations (the American Institute of Architects (AIA), the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and the Building Owners and Managers Association (BOMA))

Heat Pump Water Heater Technologies

Effective CHPWH system design is crucial for functionality and achieving a high Coefficient of Performance (COP). Incorrectly configuring or sizing a HPWH system, similar to a traditional gas boiler system, can result in operational issues and poor performance. The section below outlines common strategies for configuring central HPWH systems. Proper integration requires choosing a system configuration appropriate for the application, driven by variables such as the type of heat pump technology deployed, water circulation methods, and temperature maintenance during low demand periods.

Before choosing a CHPWH system, it is important to understand the two major categories of HPWH equipment sold in the US today: Single-pass systems and Multi-pass systems. The two basic configurations are shown in Figure 2 and Figure 3 based on Energy Trust of Oregon's New Buildings Design Guide for Central Heat Pump Water Heaters (Energy Trust of Oregon 2023). This terminology refers to whether the water is fully heated from incoming supply temperature in a Single-pass through the HPWH, or whether the water is heated by cycling through the HPWH equipment multiple times with a small temperature lift in each cycle. The two configurations require different storage and control parameters, interface differently with supply and circulating loops, and may deploy different refrigerants. A subcategory of Multi-pass systems includes unitary heat pump water heaters, where the compressor and storage tank are combined into a single appliance. This configuration is most common in residential-scale equipment, though some larger unitary systems are available on the market for commercial applications. Larger unitary systems are particularly appropriate for food service and grocery applications.

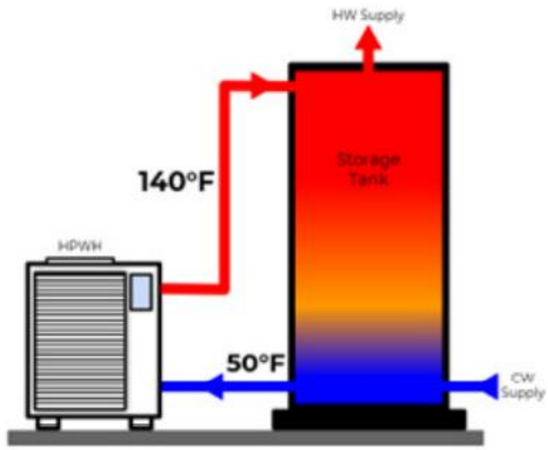


Figure 2. Single-pass: Heats water to the storage setpoint temperature in a single water pass through the refrigeration circuit, typically a 70°F to 100°F temperature lift in a single cycle[1]

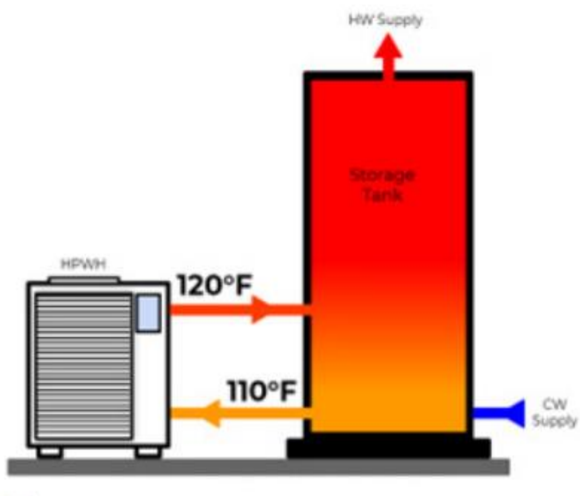


Figure 3. Multi-pass: Heats water to the storage setpoint temperature in a multiple water pass through the refrigeration circuit, typically a 10°F temperature lift for each cycle[2]

Most refrigerants currently used in HPWHs can be used in Single-pass or Multi-pass configurations. However, CO2 works best in Single-pass HPWHs. It's important to note that the heat pump water heater industry is undergoing a transition in refrigerant use. Refrigerants such as R-134a and R-

[1] Figure was taken from Energy Trust of Oregon's guide (https://www.energytrust.org/wp-content/uploads/2023/04/New-Buildings-Design-Guide-for-Central-Heat-Pump-Water-Heaters.pdf)

2 Figure was taken from Energy Trust of Oregon's guide (https://www.energytrust.org/wp-content/uploads/2023/04/New-Buildings-Design-Guide-for-Central-Heat-Pump-Water-Heaters.pdf)

410A are being phased out for various applications due to their high global warming potential (GWP). The industry is shifting towards low-GWP alternatives like R-513A and R-454B, as well as ultra-low GWP options like CO2 (R-744). This transition aligns with broader environmental regulations and industry efforts to reduce the climate impact of HVAC and water heating technologies. Most systems used today are Single-pass HPWHs, which have a number of advantages over Multi-pass systems:

- Less storage is needed in Single-pass HPWH systems because the recovery time is shorter with the same capacity.
- Higher temperatures used in Single-pass systems allow for better legionella control.
- CO2 as a refrigerant has the lowest global warming potential (GWP) of any refrigerant currently available.

CHPWH Products Overview

The 2025 Title CASE Report (CASE Initiative 2023) provides a comprehensive overview of CHPWH products currently available in the market, summarized as follows:

- **Manufacturers and Models:** The market for CHPWH in California is rapidly evolving, with products from manufacturers such as Aermec, AO Smith, Colmac, Rheem, Nyle, Sanden, Mitsubishi, Mayekawa, Lync, and Transom. The Statewide CASE Team identified 57 air-source HPWHs suitable for CHPWH applications.

- **Low-GWP Heat Pumps:** The number of low- GWP heat pumps has significantly increased, doubling from 10 products in 2019 to 20 by 2023. Examples include products from Nyle (e-series), Mitsubishi (Heat2O), Mayekawa (UNIMO AW), Lync (Aegis A series), and Transom (Hatch Air Sourced).

- **Technical Specifications:** CHPWHs typically utilize split heat pump systems, with the heat pump unit placed externally (e.g., outside, in underground parking, or on rooftops) and storage tanks located indoors in mechanical rooms. This configuration efficiently serves multiple dwelling units, with or without recirculation systems. Key specifications include primary storage volume, recovery rates, and system configurations.

  CHPWHs employ various refrigerants, predominantly R-134a and R-410A, with a trend towards natural options like CO2 (R-744) and propane (R-290) due to their lower environmental impact. The choice of refrigerant influences system design, installation approaches, and the potential need for electric resistance backup heating.

  Piping configurations are crucial, with two main types:

  - Single-pass systems: Heat water once to the desired storage temperature, resulting in highly stratified tanks and generally higher efficiency.

  - Multi-pass systems: Heat water multiple times until reaching the target temperature, resulting in less tank stratification.

Equipment using refrigerants like R513a, R134a, and R410a can accommodate either configuration. Equipment using CO2 refrigerant are preferred for Single-pass systems.

System Configurations and Design Practices

The **Northwest Energy Efficiency Alliance (NEEA)** has identified seven piping configurations for CHPWH systems, detailed in their Advanced Water Heating Guide v8.0 and summarized in Appendix A. These configurations are classified into two categories:

1. **Single-pass Systems**: Ideal for scenarios requiring large temperature lifts (e.g., 80˚-90˚F). These designs generally provide higher System Coefficient of Performance (SysCOP) with reduced heat capacity and storage tank volume needs.
2. **Multi-pass Systems**: Commonly used for temperature maintenance applications, raising water temperature incrementally, typically by 10˚F per pass.

Equipment Layout Considerations: New Construction vs. Retrofits

When installing CHPWH in multifamily buildings, the approach varies significantly between new construction and retrofits (Energy Trust of Oregon 2023).

New Construction: The layout in new buildings can be optimized for CHPWH systems, allowing integration of proper infrastructure, including space, ventilation, and electrical capacity for efficient operation from the outset.

Retrofit Projects: In existing buildings, structural constraints often require creative solutions. Retrofitting may involve electrical upgrades, space adjustments, and reusing existing tanks to limit disruption. System COP may be lower due to limited opportunities to improve distribution efficiency.

Key Considerations for Retrofits

Retrofitting an existing central gas or electric water heating system with a CHPWH system can be challenging. Conducting thorough onsite visits early in the process can save significant time and effort. Here are the key considerations:

- **Site Visits:** Conduct initial site assessments to evaluate infrastructure needs.
- **Electrical Capacity:** Ensure sufficient electrical service, especially in gas-to-electric conversions.
- **Equipment Location:** Choose locations with adequate drainage and minimal acoustic impact. Parking garages are often suitable, benefiting from buffered temperatures in winter.
- **Storage and Temperature Maintenance:** Position tanks and systems to meet spatial and seismic requirements. Existing tanks may be repurposed as swing tanks, especially electric resistance types.

Guidelines For Locating HPWH Compressors

- **Accessibility:** Allow clear access to the service panel.
- **Ventilation**: Position the unit with sufficient airflow clearance and exhaust management.

- **Acoustic and Proximity Considerations**: Avoid placing near tenant windows to reduce noise disturbances.
- **Weather Protection**: Position to prevent debris and rain accumulation, and in cold climates, elevate units above snow levels.

By following these guidelines, HPWH systems can be effectively installed to maximize efficiency and minimize operational disruptions.

Thermal Storage and Temperature Maintenance System Considerations

When locating thermal storage tanks and temperature maintenance system components, engineers should consider the following factors:

- **Dimensions and Weight:** Large storage tanks require substantial support, and seismic requirements must be met.
- **Drainage:** Include a floor sink for condensate and relief valve drainage.
- **Thermostatic Mixing Valve (TMV):** Use a digital TMV to accommodate the temperature fluctuations typical of CHPWH systems.
- **Secondary Heat Exchanger:** When required, coordinate space for the heat exchanger to maintain system COP.

Evaluating System COP for Optimal Performance

While understanding the efficiency of individual components in a system is important, the most critical metric for building managers is the performance of the entire system as a whole. An efficient piece of equipment installed in an inefficient system will result in poor overall performance.

The performance of any HPWH is influenced by three main variables: entering water temperature (EWT), leaving water temperature (LWT), and entering air temperature (EAT). For any heat pump, a Performance Map can be created by varying these variables, indicating the heat output and required energy input under different conditions. This map provides the equipment's COP at various conditions but does not consider other installation factors that affect overall system performance.

The values for EWT, LWT, and EAT depend on the climate, system design, storage sizing and arrangement, integration of temperature maintenance systems, backup capacity, and control systems. Additionally, overall energy use is driven by the amount and timing of water demand, and the size of the temperature maintenance load compared to the primary water heating load.

Standard test protocols for mechanical equipment, like those from federal and ASHRAE standards, focus on equipment performance but do not address the operational and design characteristics of systems. These protocols can help create a Performance Map for compressor equipment but do not reflect real-world performance when control, storage, and recirculation elements are included.

The most relevant metric for designers, owners, policymakers, code officials, and utility programs is the Annual System COP (SysCOP). This metric represents the annual energy demand of the entire water heating system (including primary heating and temperature maintenance) divided by the energy input required. Annual System COP enables the determination of average annual energy use and savings, providing a comprehensive measure of system efficiency.

Annual System COP includes all major components of a DHW system and their interactions, reflecting how effectively the system operates. This metric considers technology choice, sizing, piping configuration, controls, and temperature maintenance design, integrating equipment performance with building logistics.

Efforts like the Advanced Water Heating Specification and the California Energy Commission's Performance Code Compliance Approach analyze DHW system COP to evaluate energy use in delivering DHW to occupants. These approaches emphasize the importance of DHW plant configuration and equipment selection, as both significantly impact plant efficiency. A high-efficiency, Single-pass heater may have an excellent COP, but if the system has a high temperature maintenance load requiring substantial electric resistance heating, the overall efficiency drops.

Figure 4 illustrates the differences between individual component efficiency ratings and the whole system COP metric[3].

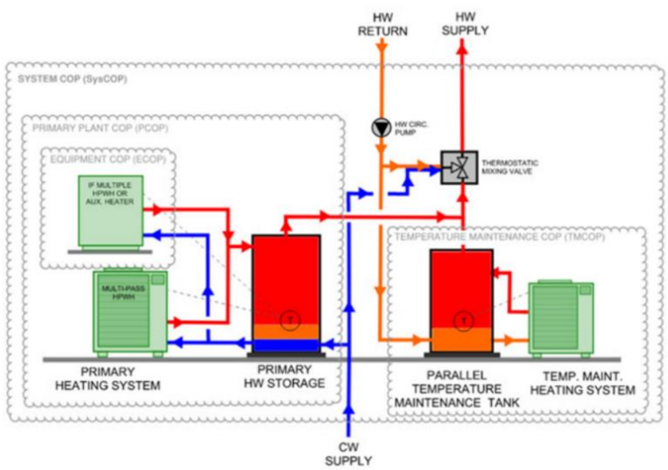


Figure 4. COP Boundaries

[3]Based on Energy Trust of Oregon, "New Buildings Design Guide."

NEEA Qualified Commercial Heat Pump Water Heaters: Key Metrics and Applications

The Commercial Heat Pump Water Heater Qualified Products List (NEEA 2024), compiled by the Northwest Energy Efficiency Alliance (NEEA), offers a comprehensive overview of various heat pump water heater models designed for commercial use. This list provides essential details to help stakeholders identify the most suitable and efficient water heating solutions for their needs. While we reference the key aspects covered by the QPL, we have enhanced the terms for clarity and context. The key aspects include:

- **Manufacturer and Model:** This section identifies the brand and specific model of each heat pump water heater, enabling users to compare products from different manufacturers.
- **Efficiency Ratings:** The list includes important metrics such as the Coefficient of Performance (COP), which indicate the energy efficiency of each model. These ratings help users understand how effectively each unit converts energy into heating output.
- **Heating Capacity:** This section lists the heating capacity of each model, typically measured in BTU/hour or kilowatts (kW), reflecting the energy output of the units and helping users determine the suitability of each model for their specific heating demands.
- **Refrigerant Type:** The type of refrigerant used in each model is specified, such as R-134a, R-410A, or CO2. This information is crucial as it affects the environmental impact and operational characteristics of the units.
- **Application Suitability:** This aspect notes the intended applications for each model, such as multifamily residential buildings, commercial facilities, or industrial settings. This helps users identify the most appropriate models for their specific use cases.

The Advanced Water Heating Specification outlines comprehensive testing conditions for heat pump water heaters, focusing on performance across various climates and usage patterns. The Cool Climate Efficiency (CCE) test, a cornerstone of the specification, evaluates units at ambient temperatures of 67°F, 50°F, and 35°F, with weightings of 35%, 40%, and 25% respectively. This test ensures optimal performance in colder regions where average temperatures fall below 60°F. Additionally, the specification includes a freeze protection test at -4°F for 24 hours, sound level testing with specific dBA limits, and a high-volume draw test to assess performance under demanding conditions. The document also details optional warm climate efficiency testing at 67.5°F and introduces increasingly stringent requirements for higher performance tiers. These include tests for minimal use of electric resistance heating, compressor shut-down notifications, and condensate management. The specification emphasizes default operating mode settings and incorporates specific draw patterns to simulate real-world usage. For split systems, a Seasonal Coefficient of Performance (SCOP) is calculated using climate data from five Pacific Northwest cities. Overall, these testing conditions are designed to provide a comprehensive evaluation of heat pump water heater efficiency and reliability across diverse environmental and operational scenarios.

Utility Program Review

This section summarizes the program data review, such as product specifications, design practices, program requirements, and potential impacts on product selection the various incentive programs in California that offer various levels of support for both new construction and alterations in market rate and affordable multifamily housing, aiming to enhance energy efficiency and promote the adoption of clean energy technologies. Appendix B provides a summary of the various incentive programs in California that offer various levels of support for both new construction and alterations in market rate and affordable multifamily housing. This information was compiled through TRC's Single Point Of Contact (SPOC) program.

Installation Data

The various programs listed in the table target both new construction and alterations in multifamily buildings, encompassing market-rate, affordable housing, and equity-focused projects. While specific numbers of installed central heat pump water heaters (CHPWH) are not provided for each program, these initiatives collectively aim to promote CHPWH adoption through substantial incentives, technical support, and design assistance. Programs such as the **California Energy-Smart Homes Program (CESHP)** and **Sacramento Municipal Utility District (SMUD) Multifamily Program** offer significant incentives for both new construction and retrofits, with additional bonuses for projects that incorporate low-GWP refrigerants or advanced design practices.

Analysis of these utility incentive programs reveals findings about incentive costs and impacts:

- A total of 398 central heat pump water heater systems were installed through the TECH program.
- The average cost per CHPWH unit from the TECH program was $38,050.08, with an average incentive of $18,322.70, covering less than half of the total cost.
- CESHP enrolled five multifamily projects that installed CHPWHs to replace gas water heaters.
- CESHP incentives covered only 30-40% of the overall electrification costs, which included converting space heating, cooking, and clothes drying to electric.

While specific installation costs for CHPWH systems were not detailed in every program, installation challenges often lead to higher costs due to the complexities involved in retrofitting existing buildings. Factors such as space constraints and necessary electrical upgrades can add to installation expenses. Programs that include installation oversight or inspection requirements may indirectly influence product selection. Contractors and building owners may lean towards products that are known to pass inspections easily or have a track record of successful installations within the program.

Products and Specifications

The products supported by these programs vary in their specifications, typically focusing on high efficiency and environmentally friendly refrigerants. Many programs require or strongly recommend that installations be performed by certified contractors. This requirement can influence product selection, as contractors may prefer systems they are trained and certified to install, potentially limiting the range of products considered. Review of utility incentive programs data indicates that common installed systems include:

- Storage capacities primarily of 119 gallons, with some units having capacities of 199, 200, or 320 gallons.
- **Heating Capacity:** Ranges typically from 3.5 kW to 12 kW depending on the product and manufacturer.
- **Coefficient of Performance (COP):** Typically ranges from 3.0 to 4.5. This high-efficiency requirements may limit product choices to those that meet or exceed specific COP ratings. Programs like California Energy-Smart Homes prioritize high-efficiency equipment, which can narrow down eligible products.
- **Refrigerants Used:** Common refrigerants include R-134a, R-410A, and CO2. Several programs, such as **TECH Clean CA** and **Sacramento Municipal Utility District (SMUD) Multifamily Program**, offer additional incentives for using low-GWP refrigerants like CO2, which can influence product selection toward more sustainable options.

Design Practices

Programs that emphasize specific design practices—such as proper ventilation or thermal storage optimization—may guide stakeholders toward products that integrate well with these practices. Some incentive programs include a design review process, where program administrators or technical experts evaluate proposed system designs. This oversight can impact product selection by steering projects towards preferred equipment that aligns with program goals and best practices.

Design practices encouraged by these programs include:

- **Proper Ventilation:** Ensuring adequate ventilation to maintain system efficiency and prevent unnecessary electric resistance heating.
- **System Integration:** Emphasis is placed on integrating CHPWH systems with existing building infrastructure, especially in retrofit scenarios. Programs like the **SMUD Multifamily Program** also incentivize electrical infrastructure upgrades to support efficient system integration.
- **Thermal Storage Optimization:** Optimizing thermal storage design and placement is key to enhancing performance and minimizing energy losses. For example, the **SMUD Multifamily Program** offers tiered incentives based on the size of heat pump storage per bedroom served.

Program Eligibility and Incentive Requirements

Each program has specific requirements for eligibility and incentive qualification:

- **BUILD Program:** Targets new construction of affordable housing with a focus on low-GWP technologies and energy efficiency criteria. Incentives can be applied to CHPWH systems through base incentive structures or low-GWP bonuses.

- **California Energy-Smart Homes Program:** Offers up to $5,000 for CHPWH design in both new construction and alterations. Additional support is available for design costs related to efficiency upgrades.
- **TECH Clean CA:** Provides incentives for both market-rate and equity projects, with $900/kWh available for equity projects and an additional $200/kWh bonus for low-GWP systems.
- **Bay Area Regional Energy Network (BayREN) Bay Area Multifamily Building Enhancements (BAMBE):** Supports alterations in multifamily buildings with a cap of $1,000 per apartment served (up to $100,000 per property). This program emphasizes energy efficiency in retrofits.
- **SMUD Multifamily Program:** Offers tiered incentives based on the size of heat pump storage per bedroom served ($1,500–$2,000/unit), with additional bonuses for electrical infrastructure upgrades.

The Role of Utility Incentives, Impact of Timing and Payment, and Contractor Motivations

Utility incentives play a critical role in driving the adoption of CHPWH systems in multifamily buildings. These incentives help reduce the financial burden of upfront costs, making CHPWH systems more attractive to building owners and developers. Some projects reported being fully funded through available incentives, which underscores the critical role these programs play in encouraging the transition to more energy-efficient systems. However, the effectiveness of these programs is influenced by several factors, including the **timing of incentive payments** and the motivations of contractors involved in the installation process.

The 2024 Water Heater Market Characterization Study provides valuable insights into the impact of utility incentives and program participation on contractor behavior and HPWH adoption. These findings can enhance the existing content in the "Characterization of CHPWH in multifamily (MF)" report:

Almost half (46%) of installers have participated in an energy efficiency program, while about a quarter (24%) have participated in an electrification/decarbonization program. This indicates significant engagement with utility programs, but also highlights substantial room for growth in participation rates.

A quarter of respondents are aware of these programs but have never participated, suggesting an opportunity to convert these aware but non-participating contractors. More concerning is that one-fifth of respondents (20%) were unaware of programs altogether, underscoring the need for improved outreach and communication about available incentives and programs.

Quality Assurance and Quality Control in CHPWH Incentive Programs

While the lab tests and stakeholder feedback provide crucial insights into CHPWH performance, it's equally important to consider how these systems are implemented and verified in practice, particularly within incentive programs. While many incentive programs exist to promote the adoption of CHPWHs, there is a noticeable lack of comprehensive QA/QC frameworks specifically tailored for these systems. The following points summarize the current state:

- **Technical Assistance and Verification:**
    - **Multifamily (MF) Programs:** Most MF programs provide some level of technical assistance to ensure that installations meet specific eligibility criteria and technical requirements. This often includes guidelines on proper installation practices and may involve verification processes to confirm that the installed systems comply with program standards.
    - **Non-Residential (NR) Programs:** In contrast, NR programs, particularly those focused on integrated systems, often do not offer the same level of technical assistance and verification. This gap in support could lead to inconsistent installation quality and performance.
- **Documentation Requirements:** Programs typically require contractors to submit documentation detailing the installation process, including equipment specifications and compliance with energy efficiency standards. However, the depth and rigor of these documentation requirements can vary significantly from one program to another.
- **Limited Specificity for CHPWH:** Although many programs mention general project verification and eligibility criteria, they often lack detailed descriptions of QA/QC processes specifically for CHPWH installations. This could include commissioning protocols, performance testing requirements, or systematic quality checks post-installation.
- **Potential for Variability:** The absence of a standardized QA/QC framework may lead to variability in how installations are executed and verified across different programs. This inconsistency can impact the overall effectiveness of the incentive programs in ensuring that CHPWHs perform as intended.
- **Focus on General Quality Control:** While some programs emphasize broader quality control measures—such as contractor training and site assessments—these do not always translate into specific QA/QC protocols for CHPWHs. The focus tends to be more on ensuring compliance with general energy efficiency measures rather than on rigorous commissioning or ongoing performance monitoring specific to heat pump water heaters.
- **Lack of Distribution System Verification:** There is often a lack of requirements to verify that distribution system issues, such as cross flow, have been checked and fixed prior to gaining approval for incentive programs. This oversight can lead to suboptimal system performance and energy efficiency.
- **Submetering for Quality Assurance:** Submetering of existing systems can be used to check for cross flow and fix it, as well as to right size the heat pump. This is a quality issue because under sizing can cause excessive use of backup or swing tank electric resistance (ER) heating, while oversizing can lead to short cycling and inefficiency.

In summary, while California's incentive programs for CHPWHs incorporate some level of quality control through technical assistance and documentation, there is a gap in detailed QA/QC frameworks that specifically address commissioning and performance verification for these systems. This gap is particularly pronounced in non-residential programs, where technical assistance and verification are often lacking. Additionally, the lack of requirements to verify distribution system issues and the potential for using submetering as a quality assurance tool highlight areas for improvement. As such, stakeholders may benefit from advocating for more robust QA/QC measures tailored to the unique characteristics of heat pump water heater technology, ensuring optimal performance and reliability of installed CHPWHs.

Utility Incentives Structure

Utility incentives are designed to offset the high initial costs associated with CHPWH installations, which can be a significant barrier to adoption. These programs often provide rebates or financial support to building owners who choose to install energy-efficient systems like CHPWH. The availability and structure of these incentives can significantly impact market adoption:

- **Direct Rebates:** Utilities may provide rebates directly to building owners or contractors based on energy savings or system efficiency. For example, some programs offer rebates per dwelling unit served by a CHPWH system, which can significantly reduce the overall project cost.
- **Midstream Incentives:** In some cases, utilities provide midstream incentives directly to contractors or distributors. This approach simplifies the process for contractors by offering immediate discounts at the point of sale, eliminating the need for post-installation rebate applications. This method also encourages contractors to promote CHPWH systems more actively.
- **Load Shifting Programs:** Some utilities offer additional incentives for systems that can shift energy use away from peak demand times, further enhancing grid stability and reducing operational costs for building owners
- **Performance-Based Incentives**: Programs often include performance-based incentives that reward systems achieving higher efficiencies (COP ratings typically ranging from 3.0 to 4.5). This not only encourages the selection of high-efficiency models but also aligns financial support with energy savings.

Impact of Timing and Payment

The timing of incentive payments is crucial for both building owners and contractors:

- **Upfront vs. Post-Installation Payments:** Many contractors prefer upfront incentives or instant rebates because they reduce cash flow concerns during installation. Delayed payments or requiring finalized permits before disbursing funds can be a barrier, as it increases financial risk for both contractors and building owners. Programs that streamline payment processes tend to see higher participation from contractors.
- **Project Timelines:** The timing of water heater replacements can also affect incentive effectiveness. Offering bonuses for early replacement (before equipment failure) can help

utilities avoid emergency replacements with less efficient systems. Additionally, longer project timelines may allow contractors to integrate CHPWH installations into broader building upgrades (e.g., solar panels or electric vehicle (EV) charging infrastructure), spreading costs across multiple projects and making them more attractive to property owners.

Contractor Motivations

Contractors play a pivotal role in the successful deployment of CHPWH systems. Their motivations are influenced by several factors:

- **Training and Expertise:** Contractors who have received comprehensive training on CHPWH systems are more likely to recommend them to clients. However, many contractors lack sufficient knowledge about these relatively new technologies, which can lead to hesitation in promoting them. Expanding training opportunities can help bridge this gap, increasing contractor confidence in recommending CHPWH solutions.
- **Profit Margins:** Contractors are driven by profitability and often prioritize projects that offer higher returns with less complexity. If CHPWH installations involve challenges such as space limitations, the need for electrical upgrades, or complex system integration, contractors may be less inclined to push for these systems unless there is an opportunity for higher fees or incentives that compensate for the added complexity.
- **Incentive Alignment:** Contractors are more likely to advocate for CHPWH installations when utility incentives align with their financial interests. Incentive programs that offer bonuses or additional compensation for certified installations can serve as a strong motivator for contractors to promote CHPWH systems over traditional options.
- **Risk Mitigation:** Contractors may be cautious about recommending newer technologies like CHPWH systems if they perceive a high risk of underperformance or customer dissatisfaction. Utility programs that offer performance guarantees or provide ongoing support for system maintenance can help mitigate these concerns, making contractors more comfortable with recommending and installing these systems.

Lab Test Review

The project team conducted a comprehensive review of the Applied Technology Services (ATS) laboratory test report (Green, et al. 2024), which provides valuable insights into the performance and commissioning of Central Heat Pump Water Heating (CHPWH) systems. This report, produced from data from the ATS Advanced Technology Performance Lab in San Ramon, CA, evaluates various CHPWH system configurations for multifamily buildings under controlled laboratory conditions.

The study tested different HPWH equipment, including split systems with the Sanden Gen3 SANCO_2, Colmac CxA and CxV, and unitary hybrid HP/Electric Resistance heater with the AO Smith CHP-120. It simulated various multifamily building sizes, hot water usage patterns, temperature maintenance loads, heating plant size and configuration, and heater and master mixing valve setpoints to understand how different system configurations perform in real-world scenarios.

By analyzing this report, the project team gained crucial data on the reliability and efficiency of different CHPWH system configurations. The results highlight which configurations perform well and which face challenges in delivering consistent hot water and maintaining efficiency. This information is essential for identifying reliable system designs, potential pitfalls in installation and operation, and areas where further training or technical improvements may be needed.

In this Lab Test Review section, we present a comprehensive summary of system COP for various CHPWH configurations and heat pumps tested under different heat loss rates.

Table 3 summarizes the results of laboratory tests conducted on SANCO$_2$, CxA-15, and CHP-120. These tests evaluated different system configurations, including return-to-primary, swing tank and return-to-parallel tank setups, under varying heat loss rates. The data presented includes the configuration type, heat pump model, heat loss rate, and the resulting system COP.

This information is crucial for understanding how different CHPWH configurations perform under various conditions. It allows us to compare the efficiency of HP systems operating in single-pass and multi-pass, different temperature maintenance strategies and impact of temperature setpoint. By presenting this summary, we aim to provide designers, engineers, and policymakers with valuable insights to inform decision-making when selecting and implementing CHPWH systems in multifamily buildings.

The table highlights several key points:

1. The impact of heat loss rates on system performance
2. Differences in COP between Single-pass and Multi-pass systems
3. The effect of different configurations and temperature setpoints on system efficiency

Table 3. System COP Summary for Various Configurations with Continuous Recirculation from ATS Report

Configuration	Heat Pump	Heat Loss Rate per Apartment	System COP at Heat Pump (HP) Setpoint
Return-to-Primary (Single Pass)	Sanden SANCO$_2$	100 W	3.9 at 140°F
		200 W	3.6 at 140°F
Return-to-Primary (Single Pass)	Colmac CxA-15	50 W	2.5 at 140°F
		100 W	2.5 at 140°F, 2.1 at 160°F
		150 W	2.5 at 140°F

Configuration	Heat Pump	Heat Loss Rate per Apartment	System COP at Heat Pump (HP) Setpoint
Return-to-Primary (Multi Pass)	Colmac CxA-15	50 W 100 W 150 W	2.1 at 140°F 2.3 at 140°F 2.2 at 140°F
Swing Tank **(Single Pass Primary HP)**	SANDEN $SANCO_2$	50 W 100W 150 W	3.8 at 140°F 3.3 (extrapolated) 2.8 at 140°F
Swing Tank (Single Pass Primary HP)	Colmac CxA-15	50 W 100W 150 W	2.1 at 140°F 2.0 at 140°F, 1.9 at 160°F 1.8 at 140°F
Primary HP (Single Pass) - Secondary HP (Multi Pass)	Colmac CxA -15 (Primary) + CxV-5 (Secondary)	50 W 100 W 150 W	2.2 at 140°F 2.3 at 140°F 2.3 at 140°F
Unitary HPWH Return-to-Primary	AO Smith CHP-120	100 W	2.4 at 120°F, 2.1 at 140°F
Unitary HPWH No Recirculation	AO Smith CHP-120	0 W	2.7 at 120°F, 2.4 at 140°F

Reliability and System COP of Different CHPWH Configurations

The reliability of Central Heat Pump Water Heater (CHPWH) systems in multifamily applications hinges significantly on the configuration chosen and recirculation flow rate, as each setup interacts differently with the building's hot water demand and temperature maintenance requirements. The system COP of an air-source centralized HP is dependent many factors including ambient conditions, configuration type, refrigerant type, single pass or multi pass operation, operating mode, temperature setpoints, split or unitary HP, hot water draw volume, and temperature maintenance load. The reliability and system COP for each notable configuration and HP tested in the lab is summarized.

Single-pass Return to Primary (Lower Inlet) Configuration. This configuration was the highest efficiency configuration tested for the $SANCO_2$ and CxA-15 at 3.9 and 2.5 respectively at 100 watts per apartment of heat loss. The CXA-15 with 134a refrigerant maintained stable performance across different load profiles and helped preserve tank stratification. This system kept relatively low average entering water temperatures to the heat pump (around 90°F in baseline testing), allowing for high efficiency. Temperature maintenance heat loss rate had minimal impact on the CxA-15, while increasing HP temperature setpoint to 160°F had significant impact in reducing system COP to 2.1.

The $SANCO_2$ system with CO2 refrigerant demonstrated good reliability in the majority of tests in return to primary configuration, but was not 100% reliable since stress testing with two straight 24-hour tests with the low use draw profile resulted in inadequate hot water availability in a few instances over the 48-h draw test at only high recirculation flow rates. Otherwise, this configuration demonstrated the highest system COP with overall fair reliability, but requires further research or design guidance to ensure 100% reliability either by designers avoiding the design scenario with high recirculation pump flow rates or by designers incorporating a distribution system optimization such as a balancing valve on the return line to the tank or pump controls to avoid the chance of the storage tank loosing significant hot water capacity prior to HP activation during low draw periods. This issue was more related to control settings than the configuration itself, suggesting that optimized controls could improve performance.

Multi-pass Return to Primary Configuration. This CxA-15 setup demonstrates stable performance under varying temperature maintenance loads with a COP of 2.3 at 100 watts per apartment of heat loss. The Colmac CxA model showed reliable operation and only a small reduction in COP with partial tank stratification, which was better than expected for a Multi-pass system.

Single-pass Primary with Series Secondary Electric Resistance Heater (Swing Tank) Configuration. This configuration provides adequate hot water delivery and maintains excellent thermal stratification in the primary tanks compared to return-to-primary configurations since the warm recirculated water only returns to the swing tank. Unfortunately, this doesn't translate to a high system COP. The COP decreased significantly with increased temperature maintenance loads for both the $SANCO_2$ and CxA-15 units. At 100 watts per apartment, the $SANCO_2$ system COP was 3.3 (extrapolated) and for CxA-15, it was 2.0 at 140°F and 1.9 at 160°F. With the CxA-15, the lower unit COP at elevated setpoint temperature of 160°F was mostly offset by minimizing electric resistance use in the swing tank from the higher incoming water temperature from the HP. Thus, while this configuration is the lowest system COP of all split systems tested, building additional tank storage capacity for load shifting comes at a minimal reduction to overall efficiency. The efficiency of this configuration depends heavily on the control strategy and sensor placement in the swing tank and actual temperature maintenance loads.

Single-pass Primary with Parallel Secondary Loop Tank. This setup while expensive and taking up the highest mechanical room footprint shows good performance with a system COP of 2.3 at 100 watts per apartment and COP is very stable under different temperature maintenance load conditions, making it a reliable choice for multifamily buildings.

Unitary Heat Pump Return to Primary Configuration. The CHP-120 system COP at 100 watts per apartment was low at 2.1 at 140°F and 2.4 at 120°F setpoint temperature. The system COP was lower than anticipated at 2.7 at 140°F and 2.4 at 120°F setpoint without a temperature maintenance load (no recirculation). These systems faced challenges with supply temperatures dropping significantly during low domestic hot water (DHW) usage periods when used with a temperature-maintenance loop leading to inadequate hot water delivery. Control setpoints were inadequate for this application, leading to inefficiencies. These light commercial hybrid heater results corroborated with preliminary findings from lab testing of 80 gal. residential hybrid heaters that showed system COPs at 1.4 with continuous recirculation at 150 Watts per apartment at 125°F setpoint and inadequate hot water delivery (Delagah 2020). Interestingly, the same residential unit tested with demand based controls for the recirculation pump improved system COP to 2.5 and offered good hot water delivery.

Key Factors Affecting Reliability and Efficiency

1. **Temperature Maintenance Load**: Systems with low temperature maintenance loads below 50-70 watts per apartment) performed better with swing tank configurations, this is applicable to new construction buildings where building codes require continuous insulation and 3rd party pipe insulation verification and rarely is possible when retrofitting existing building where median heat loss of recirculation loops is 93 watts per apartment (Green, Evan; Heller, Jonathan 2022) and can reach 200 watts per apartment (Ecotope 2017).
2. **Tank Stratification**: Maintaining proper stratification in storage tanks serving heat pumps is crucial for system efficiency and reliable hot water delivery (Green, et al. 2024).
3. **Temperature Sensor Location**: Proper placement of temperature sensors within tanks in thermowells is critical for effective system operation and to minimize HP short cycling.
4. **Control Strategies**: Unitary and split HP systems require careful control strategies to maintain consistent hot water delivery, especially during low-usage periods. Demand pump controls have shown to be an effective strategy to ensure reliability and high COP of unitary and CO2 based split HP systems in return to primary storage or unitary heater configuration (Delagah 2020).
5. **Return Water Location**: The location where return water enters the tank significantly impacts stratification and system efficiency (Green, et al. 2024).

Field Data Review

This section summarizes findings from field studies of Central Heat Pump Water Heating (CHPWH) systems in multifamily buildings and hotels, drawing on data from the ET22SWE0047 (Garcia, et al. 2024) and ET22SWE0017 (Valmiki, et al. 2023) CalNEXT reports and ACEEE Summer Study report (Brooks, Neal and Young 2024).

Field Study of Master Mixing Valve Energy Efficiency Potential Report Findings

- Energy Savings: A 21-unit multifamily building demonstrated 6.8% energy savings after digital master mixing valve (DMMV) installation.

- Heat Pump Performance: A 51-unit hotel with two AO Smith CHP-120 heat pump water heaters showed mixed results:
    - Initial 40% energy reduction after setpoint adjustments increased system COP from 0.6 to 1.0
    - Unexpected 4.9% increase in energy use post DMMV retrofit
    - Challenges with temperature maintenance and control strategies

Commercial and Multifamily CO2 Heat Pump Water Heater Market Study and Field Demonstration Report Findings

- Energy Performance: CHPWH systems reduced energy consumption by 68-69% compared to code-compliant natural gas systems with average system COP of 2.6 and 2.7 in two sites.
- Utility Costs: Despite energy savings, utility costs increased significantly (176-223%) due to higher electricity rates and demand charges.
- Load Shifting: Systems demonstrated 32-63% load reduction during peak periods.
- Installation Challenges: Oversized storage tanks and complex plumbing configurations reduced efficiency and increased costs ($4,082-$6,311 per residence).

Large-Capacity CO2 Heat Pump Study Findings

- Lassen Building Mitsubishi Heat2O CO2 HP with Swing Tank Configuration System COP of 2.3 and Return to Primary Configuration (to Cold Tank) System COP of 2.7
- Demonstrated that return to primary configuration with large CO2 HPWH is reliable when supply and return temperatures are on the low end and with adequate controls.
- Discussion on the impact of hot water draw and temperature maintenance load on system COP

These studies highlight both the potential and challenges of CHPWH systems in multifamily applications as follows:

- Proper system configuration and control strategies are crucial for optimal performance.
- While CHPWH systems offer significant energy and emissions savings, economic challenges persist due to electricity costs.
- Extended monitoring and commissioning periods may be necessary to optimize real-world performance.
- Simplified system designs and load shifting strategies could improve cost-effectiveness and efficiency.

Stakeholder Interview

Most interviewees reported positive experiences with central heat pump water heater (CHPWH) systems, citing benefits like energy efficiency, lower operating costs, and environmental friendliness. The following section notes some challenges, particularly around proper sizing, temperature management, and integration with existing building systems.

Common System Configurations

- **Single-pass Configurations**: Predominantly used, with some Multi-pass systems also in use.
- **Return-to-Primary and Dedicated Temperature Maintenance**: Both configurations were represented among the interviewees.

Perceived Benefits

- **Energy Savings**: Significant energy savings were reported compared to conventional systems.
- **Environmental Impact**: Reduced carbon emissions were a key motivator for adopting CHPWH technology.
- **Operational Benefits**: Improved reliability and quieter operation were noted as advantages.

Challenges and Limitations

- **Sizing and Capacity**: Proper sizing for larger buildings was emphasized as critical.
- **Temperature Fluctuations**: Managing temperature fluctuations was a common challenge.
- **Integration**: Integrating CHPWH systems with existing building infrastructure posed challenges.
- **Upfront Costs**: Higher initial costs compared to conventional systems were frequently mentioned.
- **Contractor Familiarity**: Limited contractor expertise with CHPWH technology was a barrier.

Design and Implementation Considerations

- **Sizing and Capacity Planning**
  - **Load Calculations**: Thorough load calculations are essential for system success.
  - **Future Needs**: Consideration of future building needs when sizing systems.
- **Integration with Existing Building Systems**
  - **Space Requirements**: Challenges in retrofitting due to space constraints.
  - **Piping Systems**: Integration with older piping systems was noted as problematic.
- **Controls and Monitoring Strategies**

- **Advanced Controls**: Essential for optimizing performance.
- **Remote Monitoring**: Recommended for ongoing system management.

- Maintenance and Operational Requirements
  - **Regular Maintenance**: Crucial for long-term performance.
  - **Training**: Training for building staff on system operation and maintenance was recommended.

Performance and Efficiency Factors

- Impact of System Configuration on Efficiency
  - Single-pass Systems: Generally reported as more efficient.
  - Multi-pass Systems: Worked well in certain applications.
- Temperature Management and Stratification
  - Tank Stratification: Maintaining proper tank stratification was identified as key for system efficiency.
- Influence of Climate and Usage Patterns
  - Climate Impact: Climate significantly affects system performance.
  - Usage Patterns: Variable occupancy patterns affect efficiency.
- Comparison to Conventional Water Heating Systems
  - Energy Savings: Most interviewees reported significant energy savings compared to conventional systems.

Best Practices and Recommendations

- System Selection and Design Guidelines
  - Site Assessment: Thorough site assessment and load calculations are recommended.
  - Future Building Needs: Consider future building needs when sizing systems.
- Installation and Commissioning Procedures
  - Proper Commissioning: Critical for system success.
  - Extended Monitoring: Extended monitoring post-installation to ensure optimal performance.
- Optimization Strategies for Different Building Types
  - Tailored Design: Tailor system design to specific building types and usage patterns.

- **Training and Education Needs**
    - Contractor Training: Better education and training for contractors and building operators.

Future Outlook and Research Needs

- **Emerging Technologies and Innovations**
    - Promising Developments: Noted in heat pump technology and controls.
- **Areas Requiring Further Study**
    - Long-Term Performance: Long-term performance data and optimization strategies.
- **Potential for Wider Adoption in Multifamily Buildings**
    - Optimism: Most interviewees were optimistic about wider CHPWH adoption.
- **Policy and Incentive Considerations**
    - Incentives: Importance of incentives and supportive policies in driving adoption.

Financial Considerations and Incentive Programs

High upfront costs remain a key barrier for many building owners, despite the potential for long-term energy savings. Both interviews and literature findings underscore the need for improved incentive structures. ID4 highlighted the critical role of rebates and utility incentives, which can offset initial costs and encourage adoption. However, multiple interviewees noted that procedural complexities, such as navigating permitting processes and securing timely approvals, may further complicate adoption efforts.

Training and Market Development Needs

The adoption of Central Heat Pump Water Heaters (CHPWHs) in multifamily buildings faces several challenges, with a lack of training and expertise among contractors and contractors being a significant barrier. Interviewees frequently cited inadequate training as a root cause of poor installation quality, leading to issues such as improper system sizing, insufficient ventilation, and imbalanced recirculation loops. ID2 emphasized the critical role of proper training to avoid inefficiencies like increased utility costs due to electric resistance running unnecessarily. The literature reinforces this by highlighting the need for rigorous quality verification and post-installation assessment to ensure systems perform optimally (NBI 2023). The 2024 Water Heater Market Characterization Study provides valuable insights into the current landscape of water heater contractors:

1. Industry Diversification: Most water heater contractors (65% of respondents) reported that their company performs both HVAC and plumbing work, indicating a trend towards diversification in the industry.
2. HPWH Installation Trends: Contractors engaged in both plumbing and HVAC work are more likely to install heat pump water heaters (HPWHs) compared to those focused solely on plumbing (55% vs. 48%).
3. Marketing Efforts: Companies offering both plumbing and HVAC services are significantly more active in marketing HPWHs, promoting them through company websites (84% vs. 53%), social media (75% vs. 38%), and direct advertisements (67% vs. 11%) compared to plumbing-only contractors.

These findings underscore the importance of considering the varied backgrounds and business models of water heater contractors when developing training programs and market transformation strategies for HPWHs in multifamily buildings. The study also highlighted key barriers to HPWH adoption:

1. The prevalence of emergency replacement scenarios (46% of water heater installations on average)
2. Higher upfront costs of HPWH equipment
3. Low consumer awareness of HPWHs

To address these challenges and facilitate the effective implementation of CHPWHs, various market actors require specific training and support: Table 4 **Error! Reference source not found.**summarizes relevant market actor in the adoption of CHPWH in multifamily buildings and suggested training and support needs required to facilitate the effective implementation of these systems.

Table 4. Relevant Market Actor and Training Needs

Market Actor	Training Needs
Contractors and installers	Contractors need specialized training on the installation, commissioning, and maintenance of CHPWH systems. This includes understanding the specific requirements for different types of heat pumps (e.g., Single-pass vs. Multi-pass systems) and the integration of these systems within multifamily buildings.
Building Owners and Property Managers	They require training on the benefits of CHPWH systems, including energy savings, cost-effectiveness, and sustainability. Additionally, they need to understand the operational aspects and potential return on investment (ROI) to make informed decisions.

Market Actor	Training Needs
Engineers and Designers	Engineers and designers need advanced training on system design, including proper sizing, integration with existing systems, and strategies for optimizing performance under various conditions. They should also be familiar with the latest technologies and best practices in system configuration.
Utility Companies and Energy Efficiency Programs	These stakeholders need to be educated on the benefits of CHPWH systems and how to effectively promote their adoption through incentives and regulatory frameworks. Understanding the technical and economic aspects of these systems will help them design better support programs.

In light of these findings, training programs should be tailored to address the diverse skill sets of contractors who work across multiple trades. Additionally, strategies need to be developed to address emergency replacements and improve consumer education to drive HPWH adoption in multifamily buildings.

Summary of Findings

This section provides a comprehensive overview of the key insights gathered from the study on Central Heat Pump Water Heating (CHPWH) systems in multifamily applications. This section synthesizes information from various sources, including stakeholder interviews, field data, and laboratory tests, to present a holistic view of CHPWH deployment. It covers four main areas: common installation practices and system types, factors influencing decision-making, challenges encountered during installation, and aspects of system performance and commissioning.

The purpose of this section is to offer readers a concise yet thorough understanding of the current state of CHPWH implementation in multifamily buildings, highlighting both successes and areas for improvement. By presenting these findings, the section aims to inform industry professionals, policymakers, and building owners about the practical realities of CHPWH adoption, ultimately guiding future strategies for wider implementation and optimization of these systems

Installation Practices and Common Installed Systems in Multifamily Applications

Interviewees reported working with a range of HPWH systems. ID1 primarily installs Sanden CO2 systems, known for their efficiency and use of low-GWP refrigerants. ID4 uses Single-pass systems like Sanco and Rheem in both new construction and retrofit projects. ID6 noted working with modular systems capable of scaling to meet hot water demand, with capacities ranging from 30 kBTU to 550 kBTU per hour, suitable for buildings requiring large storage tanks.

Lab test results corroborate and expand on these findings. Single-pass configurations, particularly those with return-to-primary (lower inlet), consistently demonstrate high efficiency and stable performance across various load profiles. The Colmac CxA with R-134a refrigerant showed exceptional performance, maintaining high efficiency even with increased domestic hot water (DHW) usage. Multi-pass systems, while generally less efficient than Single-pass, still demonstrated stable performance and consistent Coefficient of Performance (COP) under varying loads

Market actors suggested that not all systems are equally well-suited for multifamily buildings. ID2 highlighted that air-source heat pumps can struggle in enclosed spaces like basements due to ventilation challenges. High-pressure CO2 systems were flagged as requiring specialized handling, which could deter adoption. This aligns with lab test results showing that CO2 heat pumps in Single-pass return-to-primary configurations struggled with temperature maintenance losses, particularly in low-draw scenarios.

Several interviewees mentioned the importance of modular and turnkey systems, as these are easier to install and scale. Water-source systems (ID2) and packaged modular solutions (ID6) were noted as effective in meeting the hot water demands of multifamily buildings. These systems offer flexibility and ensure reliable performance even under varying demand profiles.

Program data from TECH Clean CA and the California Energy-Smart Homes Program (CESHP) support these findings, showing a preference for efficient and low-GWP options. The TECH program's $200/kWh bonus for low-GWP refrigerants aligns with interviewees' emphasis on CO2 systems like Sanden.

Factors impacting decisions

This section discusses how stakeholders engage with customers to ensure CHPWHs meet hot water needs in multifamily buildings and explores the primary motivations for system adoption. Overall, these interviews reveal that effective customer engagement involves clear communication, detailed planning, and leveraging financial and technical support to facilitate the adoption of efficient and sustainable water heating solutions.

Market actors emphasized the importance of tailoring system designs to meet specific project needs. ID1 spoke highly of the Sanden CO2 systems, citing their ability to meet hot water demand efficiently by producing water temperatures up to 175 degrees F, particularly beneficial for multifamily applications. ID2 and ID3 focused on the importance of offering turnkey solutions, providing technical support, and ensuring proper system sizing. They often rely on external experts or manufacturers, such as Sanco, for accurate system recommendations, especially in cases where customers lack technical knowledge.

In terms of customer motivations and factors impacting their decisions about system selection, ID1 and ID6 noted that energy efficiency, cost savings, and compliance with regulations are significant incentives. Additionally, environmental considerations such as reducing carbon footprints play a crucial role. Rebates and financial incentives were frequently mentioned as pivotal in offsetting upfront costs, with ID4 highlighting that some projects could be fully funded through available incentives.

The literature review and program data corroborate these findings, emphasizing the importance of proper system configuration for optimal CHPWH performance. Single-pass configurations, particularly return-to-primary (lower inlet), have demonstrated high efficiency and stable performance across various load profiles. The choice of refrigerant, such as CO_2 for Single-pass systems, significantly influences system design and efficiency.

Incentive programs in California, such as TECH Clean CA and Energy-Smart Homes, offer substantial support for CHPWH adoption in multifamily buildings. These programs emphasize high-efficiency systems, with additional incentives for low-GWP refrigerants like CO_2. The SMUD Multifamily Program's tiered incentive structure based on heat pump storage size per bedroom served encourages right-sizing of systems. These program requirements significantly influence product selection, pushing the market towards more efficient and environmentally friendly options while also emphasizing proper system design and installation practices.

Lab test results further underscore the importance of system configuration and control strategies. Single-pass return-to-primary (lower inlet) setups consistently demonstrate high efficiency, especially for models like the Colmac CxA with R-134a refrigerant. Multi-pass systems show stable performance and consistent COP under varying loads. However, CO_2 heat pumps in Single-pass return-to-primary configurations struggled with temperature maintenance losses, particularly in low-draw scenarios, highlighting the need for optimized control strategies.

Field studies have demonstrated significant energy savings, with CHPWH systems reducing energy consumption by 68-69% compared to code-compliant natural gas systems. These systems also achieved substantial greenhouse gas (GHG) reductions of approximately 90%, saving 30.5 and 33.6 tons CO_2e over monitoring periods. However, despite energy savings, utility costs increased significantly due to higher electricity rates and demand charges, with increases of 223% and 176% at two studied sites. Load shifting capabilities have been demonstrated, with tests showing an average load shed of 32-63% during peak periods, successfully shifting loads to off-peak and partial-peak periods

These findings from literature review, program data, and lab tests complement stakeholder insights, emphasizing the importance of proper system configuration, refrigerant choice, and control strategies for optimal CHPWH efficiency and reliability in multifamily buildings.

Field studies demonstrate CHPWH systems' significant potential for energy savings (68-69% reduction) and GHG reductions (90% decrease) compared to code-compliant natural gas systems. However, increased utility costs due to higher electricity rates and demand charges highlight the need for careful economic consideration and load shifting strategies in system design.

The demonstrated load shifting capabilities (32-63% average load shed during peak periods) offer opportunities for optimizing energy costs and grid integration. Decision-makers must weigh energy efficiency, environmental impact, economic factors, and load management potential when evaluating CHPWH systems for multifamily buildings, emphasizing the importance of advanced control strategies and system configurations.

Installation Challenges

The complexity of integrating CHPWH systems into existing infrastructure presents unique installation challenges. Interviewees pointed out that **space constraints** in retrofits, especially in dense urban environments, often limit the feasibility of installations. ID3 mentioned projects requiring significant structural modifications to make space for these systems. Literature further supports the importance of system optimization during the design phase, recommending thorough pre-installation assessments to mitigate such challenges (NBI 2023).

Studies emphasize the importance of thorough site assessments and strategic planning for successful CHPWH retrofits. Key considerations include electrical capacity, especially in gas-to-electric conversions, equipment location with adequate drainage and minimal acoustic impact, and positioning of storage tanks to meet spatial and seismic requirements. The Northwest Energy Efficiency Alliance (NEEA) has identified seven piping configurations for CHPWH systems, highlighting the need for tailored approaches based on building characteristics.

Incentive programs in California, such as TECH Clean California and Energy-Smart Homes, recognize the challenges of retrofitting and offer substantial support for both new construction and alterations in multifamily buildings. These programs emphasize proper system design and installation practices, acknowledging the complexities involved in retrofitting existing buildings. The SMUD Multifamily Program's tiered incentive structure based on heat pump storage size per bedroom served encourages right-sizing of systems, addressing space constraint issues.

Laboratory studies have revealed that proper installation and configuration significantly impact CHPWH performance. Single-pass return-to-primary (lower inlet) configurations consistently demonstrate high efficiency, especially for models like the Colmac CxA with R-134a refrigerant. However, CO2 heat pumps in Single-pass return-to-primary configurations struggled with temperature maintenance losses, particularly in low-draw scenarios, highlighting the need for optimized control strategies and careful consideration of system layout. These findings underscore the importance of proper system design and installation to overcome space constraints and achieve optimal performance in retrofit scenarios.

Field studies have revealed that oversized storage tanks and complex plumbing configurations can reduce system efficiency and increase installation costs, ranging from $4,082 to $6,311 per residence. Integration with existing building infrastructure has been identified as a common challenge by stakeholders. The importance of thorough site assessments and load calculations was emphasized for successful system design and implementation

System Performance and Commissioning

This section describes key energy performance metrics that need to be considered for successful installation, common challenges during installation, and how they affect performance. The key metrics are summarized in Table 5 (CEC 2023, NBI 2023).

Lab test results and field data have revealed that proper equipment selection, design and installation significantly impact CHPWH performance. Single-pass return-to-primary (lower inlet) configurations consistently demonstrate higher efficiency in lab and field results with both 134a and CO2 refrigerant based HPs and good reliability with 134a HPs and fair reliability with CO2 HPs. Small CO2 based HPs in swing tank and return to primary configuration have significantly higher system COP (COP increase of 1 to 1.5) versus 134a based unitary and split HPWHs in return to primary or swing tank configuration. The lab testing showed that Multi-pass return-to-primary configuration operated at competitive COPs with good reliability which was a new finding. It also showed that Single-pass HPs in Swing Tank configuration consistently has the lowest system COP of all viable and established configurations tested. The lab and field results showed that unitary HPWHs with continuous recirculation had low system COP and poor reliability but demand pump controls looks promising to solve the reliability issue and substantially increase system COP.

Temperature maintenance load emerged as a critical factor. Systems with low temperature maintenance loads (50 watts per apartment) performed better with swing tank configurations and were more competitive with return to primary configuration performance. This is particularly applicable to new construction buildings where building codes require continuous insulation. Swing tank configuration should be avoided in existing buildings with high temperature maintenance loads where possible due to low system COPs from lab and field study results.

Maintaining proper tank stratification is crucial for system efficiency and reliable hot water delivery. Heat pump systems required careful setpoint management to balance efficiency and hot water delivery performance. The location of temperature sensors within tanks and control strategies, especially for integrated systems, are critical for effective system operation.

Table 5. System Performance Metrics and Considerations

Metric	Importance	Considerations
System COP	System COP is a comprehensive measure that reflects the overall efficiency of the entire water heating system including the temperature maintenance tank and recirculation loop, not just the HP COP. It accounts for all energy inputs and outputs.	System COP needs to be evaluated in the context of equipment features, system configuration, and operational conditions. This includes the heat pump's performance, storage capacity, and how effectively the system maintains stratification and reduces temperature maintenance loads.
Distribution Losses	Heat loss during the distribution of hot water through pipes can significantly impact system COP.	Monitor and minimize distribution losses by ensuring proper insulation by meeting the requirements in section 160.4 of 2025 T24 where accessible, minimizing pipe lengths, and using efficient circulation strategies. Regular assessments of the distribution system can identify areas for improvement.

Metric	Importance	Considerations
Heat Pump and Storage Capacity	Properly sizing the heat pump and storage capacity is critical to meeting the hot water demands without excessive energy use.	Use detailed demand assessments to determine the appropriate capacity for both heat pumps and storage tanks. Over- or under-sizing can lead to inefficiencies and increased operational costs. Select a refrigerant and configuration to eliminate or minimize the need for backup ER or gas heating system to reduce electrical capacity requirements and demand charges. There are opportunities to place HPs in an exterior location freeing up space in the mechanical room to increase storage capacity.
Minimum Space Requirement and Ventilation Considerations	Follow HP room minimum space requirements specified by the manufacturer. If adequate space (room volume) requirements are not able to be met, provide adequate ventilation is crucial for maintaining the efficiency of heat pumps, especially in existing enclosed or semi-enclosed spaces like mechanical rooms with architectural louvers.	Ensure proper design and implementation of ventilation systems when the HP is placed indoors and is not able to meet manufacturer's minimum space requirements to support optimal heat pump performance. Inadequate space and poor ventilation can lead to excessive cooling of rooms, increased reliance on electric resistance heating, reduced heating capacity, not being able to maintain thermostat setpoint and consistently deliver hot water, and higher utility bills.
Operational and Maintenance Practices	Regular maintenance and proper operational practices can significantly influence system performance and longevity.	Develop and adhere to a rigorous maintenance schedule, including periodic checks and cleaning evaporator filter. Train building operators and maintenance personnel on best practices for CHPWH systems.

Conclusion and Recommendations

Based on the analysis of program data review, lab tests, field data, and stakeholder insights, we offer the following conclusions and recommendations to improve CHPWH deployment in multifamily buildings.

System Design and Configuration (Engineers, Designers, Contractors)

- **Prioritize single-pass systems**: Single-pass configurations, especially with return-to-primary setups, should be preferred for their higher efficiency and stable performance when using heat pumps with conventional refrigerants such as R-134a and increasingly so with CO2 systems with appropriate distribution system design with more research forthcoming. This configuration is particularly effective for systems like the Colmac CxA tested in every test setup, and Mitsubishi and SanCo2 CO2 systems at lower recirculation return temperatures, heater recirculation flow rates or with pump controls to maintain stable performance across different load profiles.
- **Consider swing tank configurations especially with CO2 HPs**: For buildings with low temperature maintenance loads (below 50-70 watts per apartment), swing tank configurations may offer equivalent performance and good reliability in an emerging market where there are variable levels of experience with the design, install, operations and maintenance community and more research and guardrails need to be developed with return to primary systems.
- **Don't pair unitary hybrid heat pump heaters with continuous recirculation systems**: This has proven in the lab and field to deliver poor performance and reliability. More research is needed to optimize these heaters for centralized applications with recirculation and to ensure existing indoor installations have proper ventilation.

Performance Optimization (Manufacturers, Engineers, Contractors, Building Operators)

- **Implement advanced control strategies**: Sophisticated control systems are essential for managing temperature fluctuations and maintaining efficiency, particularly during low-demand periods. For practitioners, this means selecting and installing controllers capable of managing multiple temperature sensors, variable speed pumps, and adaptive learning algorithms. For program implementers, consider offering additional incentives for projects incorporating advanced control systems, requiring commissioning and performance testing of these systems, and providing training resources on proper implementation and tuning of control strategies.
- **Ensure proper tank stratification**: To maintain effective thermal layering in storage tanks and optimize system efficiency, practitioners should implement strategies such as designing systems with appropriate inlet and outlet locations, using baffles or diffusers to minimize mixing, and optimizing flow rates during low-demand periods. Additionally, advanced control strategies and proper placement of temperature sensors within tanks should be employed to monitor and maintain stratification effectively.
- **Optimize temperature sensor placement**: Proper placement of temperature sensors within tanks and associated controls is critical for effective system operation.

Installation and Commissioning (Contractors, Engineers, Building Owners, Utility Companies)

- **Conduct thorough site assessments**: Comprehensive evaluations of existing infrastructure, space constraints, and future building needs are crucial for successful CHPWH installations.

Practitioners should assess the availability of electrical capacity for heat pump operation, evaluate mechanical room space for storage tanks and compressors, and identify potential ventilation pathway and drainage requirements. Additionally, site assessments should account for building-specific factors such as hot water demand profiles, thermal losses in distribution systems, and opportunities to reuse existing infrastructure. For program implementers, providing standardized site assessment checklists and technical support can help ensure consistent and effective evaluations across projects.

- **Address retrofit challenges**: Develop innovative solutions for integrating CHPWH systems into existing buildings, considering space limitations and infrastructure constraints. For example, utilize modular or pre-configured CHPWH systems that minimize on-site installation complexity, repurpose existing tanks as swing tanks where feasible, explore compact and stackable storage tank configurations to optimize space usage, and implement digital monitoring systems to enable remote system diagnostics and performance optimization. These approaches, identified through field data and stakeholder interviews, can streamline retrofits and enhance system performance even in constrained environments.

Training and Education (Manufacturers, Utility Companies, Policymakers, Contractors)

- **Enhance contractor training**: Develop targeted education programs to improve contractor expertise in CHPWH technology, installation, and maintenance
- **Educate building operators**: Provide comprehensive training for building staff on system operation and maintenance to ensure long-term performance
- **Develop design guidelines**: Create and disseminate best practices for system selection, sizing, and configuration tailored to different building types and climates

Policy and Incentives (Utility Companies, Policymakers, Manufacturers)

- **Expand incentive programs**: Broaden utility incentives to cover a wider range of CHPWH configurations and features, including low-GWP refrigerants and advanced control systems
- **Support retrofit projects**: Develop specific incentives and technical assistance programs for CHPWH retrofits in existing multifamily buildings
- **Promote low-GWP refrigerants**: Offer additional incentives for systems using environmentally friendly refrigerants like CO2
- **Optimize incentive structures:** Design tiered and performance-based incentive programs that:
  - Reward projects based on achieved energy savings and performance metrics, such as Annual System COP.
  - Provide upfront rebates to reduce financial barriers for contractors and property owners.
  - Include additional bonuses for timely adoption, such as early replacements before system failure.
  - Align incentives with contractor training and QA/QC adherence, offering rewards for high-quality installations and commissioning practices.

Performance Monitoring and Data Collection (Building Owners, Utility Companies, Contractors, Researchers)

- **Implement long-term monitoring**: Establish protocols for extended performance monitoring to gather data on real-world system efficiency and reliability
- **Create centralized data repository**: Develop a platform for collecting and sharing anonymized performance data to inform future system improvements and policy decisions

Future Research Needs (Researchers, Engineers, Manufacturers, Utility Companies)

- **Long-term performance studies**: Conduct extended field studies to gather data on long-term CHPWH performance and reliability in multifamily applications
- **Optimization strategies**: Develop and test innovative approaches for integrating CHPWH systems with existing building infrastructure, particularly in retrofit scenarios. Examples include:
    - **Ensure proper HP is specified for climate zone and installation location:** If installed indoors, ensure sufficient room volume, direct ducting is available, or room ventilation rate with controls are added. If it is an outdoor installation or outdoor air is used, ensure HP is correctly specified and sized to meet design day parameters.
    - **Electrical capacity upgrades**: Identifying cost-effective strategies for upgrading electrical systems in older buildings to support the additional load from CHPWH systems.
    - **Reuse of existing infrastructure**: Repurposing existing storage tanks or using legacy recirculation loops to minimize system disruption and reduce costs.
    - **Compact and modular installations**: Designing space-efficient systems that can be easily installed in constrained mechanical rooms or retrofitted into existing garages or basements.
    - **Integrated temperature maintenance solutions:** Incorporating advanced controls and thermostatic mixing valves that optimize system efficiency and ensure hot water delivery without the need for extensive piping rework.
    - **Load-shifting capabilities**: Implementing demand-response compatible systems to better integrate CHPWHs with utility peak-load management programs, particularly in retrofitted buildings with variable demand patterns.
    - **Temperature maintenance system solutions**: Research the best combination of strategies for the facility type and size to complement the HP retrofit project including but not limited to adding ECM pump with integrated or demand controls, master mixing valve, continuous pipe insulation, check valve, automatic balancing valve, optimizing temperature setpoints, and checking and resolving cross flow issues to ensure hot water delivery and minimize water temperature destratification in return to primary HP configuration.
- **Climate-specific performance analysis**: Investigate CHPWH performance across various climate zones to inform region-specific design guidelines and policy recommendations

By implementing these recommendations, stakeholders can overcome current barriers to CHPWH adoption and realize the technology's full potential for energy efficiency and decarbonization in multifamily buildings. Continued collaboration between manufacturers, contractors, utilities, and policymakers will be essential to drive innovation and widespread adoption of CHPWH systems in the multifamily sector.

References

Banks, Adria, Colin Grist, Jonathan Heller, and Hyunwoo Lim. 2022. "Field Measurement of Central CO2 Heat Pump Water Heater for Multifamily Retrofit." *Sustainability.* https://ecotope-publications-database.ecotope.com/2022_008_sustainability-14-08048.pdf.

Brooks, Andy, John Neal, and Nick Young. 2024. "Eliminating the Swing Tank and Other Design Considerations in Large-Capacity CO2 Heat Pump Water Heating." *ACEEE Summer Study.* Accessed 01 21, 2025. https://www.aceee.org/sites/default/files/proceedings/ssb24/pdfs/Eliminating%20the%20Swing%20Tank%20and%20Other%20Design%20Considerations%20in%20Large-Capacity%20CO2%20Heat%20Pump%20Water%20Heating.pdf.

CASE Initiative. 2023. *Multifamily Domestic Hot Water.* California Energy Codes and Standards.

CEC. 2023. "Getting to All-Electric Multifamily Zero Net Energy Construction."

Delagah, Amin. 2020. "PG&E Test Lab Updates." *BPA.* 06 02. Accessed 01 02, 2025. https://www.bpa.gov/-/media/Aep/energy-efficiency/emerging-technologies/ET-Documents/June-2-Code-Update-Prescriptive-Path-Final.pdf.

Ecotope. 2017. "Hot Water Temperature Maintenance Pilot Study." *ACEEE Hot Water Forum.* 02 22. Accessed 1 21, 2025. https://www.aceee.org/sites/default/files/pdf/conferences/hwf/2017/Oram_Session4A_HWF17_2.28.17.pdf.

Energy Trust of Oregon. 2023. "New Buildings Design Guide for Central Heat Pump Water Heaters." https://www.energytrust.org/wp-content/uploads/2023/04/New-Buildings_Design-Guide-for-Central-Heat-Pump-Water-Heaters.pdf.

Garcia, Jose, Amin Delagah, Matt Stevens, and Daniel Hacking. 2024. "Field Study of Master Mixing Valve Energy Efficiency Potential." *CalNEXT.* 09 15. Accessed 01 21, 2025. https://calnext.com/wp-content/uploads/2024/11/ET22SWE0047_Field-Study-of-Master-Mixing-Valve-Energy-Efficiency-Potential_Final-Report.pdf.

Green, Evan, Ben Larson, Mehdi Zeyghami, and Helen Davis. 2024. "PG&E and SCE HPWH Laboratory Testing and Software Updates for Multifamily Applications." https://etcc-ca.com/reports/pge-and-sce-hpwh-laboratory-testing-and-software-updates-multifamil.

Green, Evan; Heller, Jonathan. 2022. "Domestic Hot Water Distribution Heat Loss." *Bonneville Power Administration ET.* 03. Accessed 01 21, 2025. https://www.bpa.gov/-/media/Aep/energy-efficiency/emerging-technologies/20220506-DHW-Distribution-Heat-Loss---Task-7.pdf.

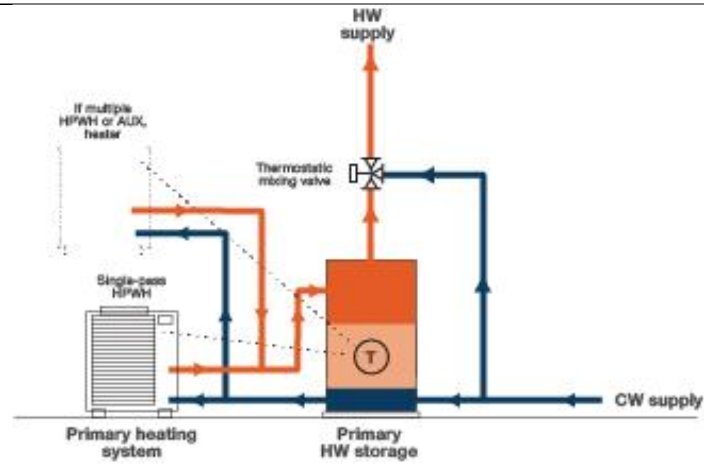
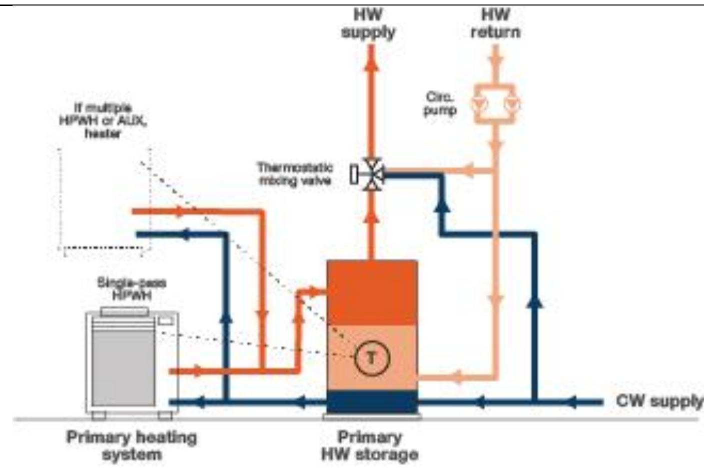
NBI. 2023. *Central Heat Pump Water Heaters for Multifamily Supply Side Assessment and Workshop - NEEA Product Council.* March 28. Accessed November 2024. https://neea.org/product-council-documents/nbi-central-heat-pump-water-heaters-for-multifamily-supply-side-assessment-and-workshop-neea-product-council.

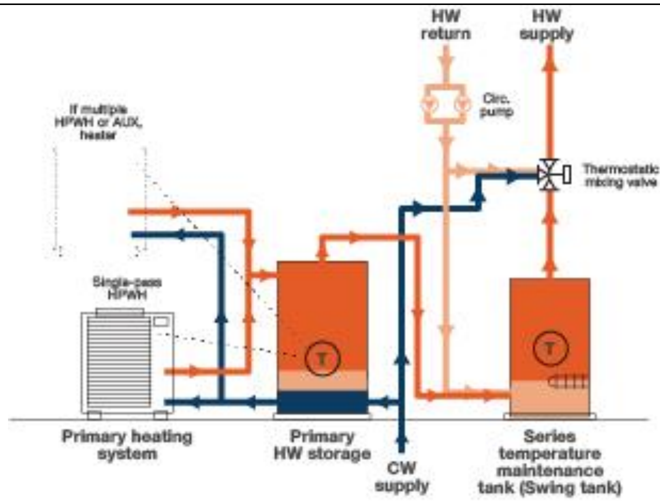
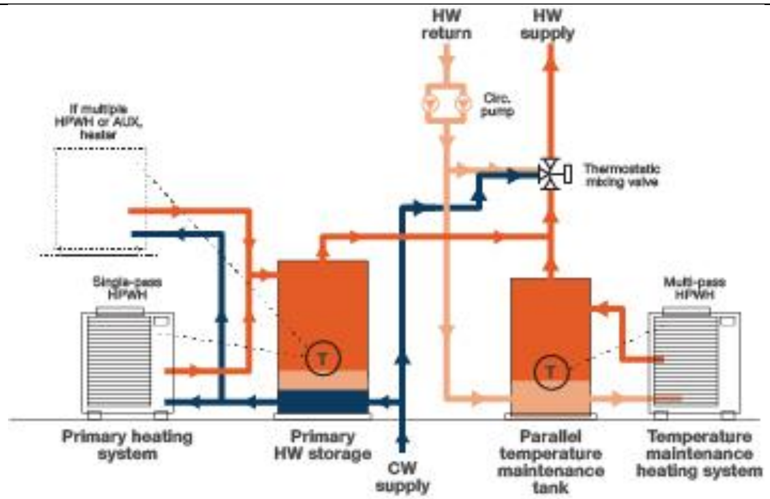
NEEA. 2024. *Commercial/Multifamily HPWH Systems Qualified Products List.* NEEA.

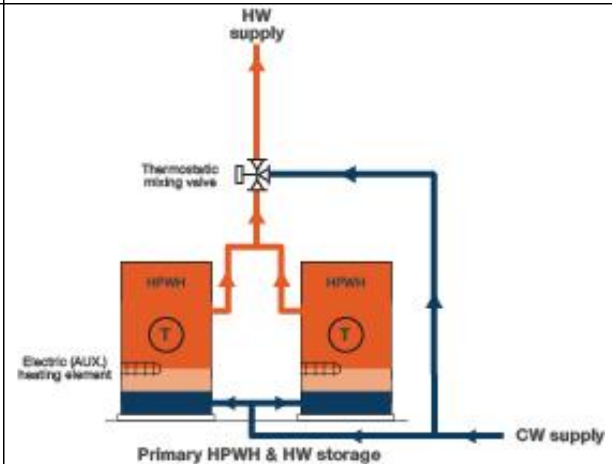
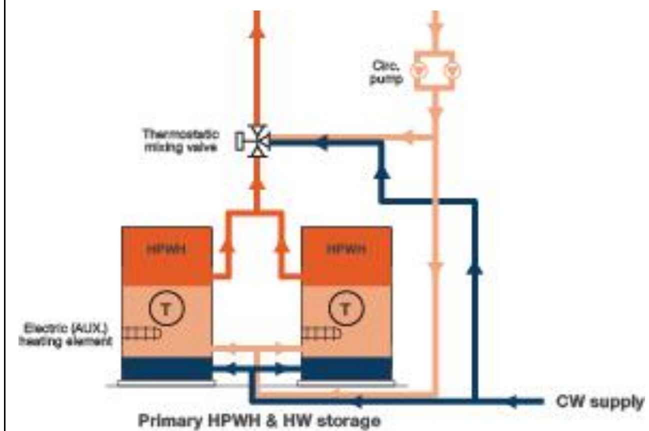
TECH Clean. 2024. *New Multifamily Central Heat Pump Water Heater Incentives Now Available in PG&E, SCE, SCG, and SDG&E Service Areas.* March 12. Accessed 2024. https://techcleanca.com/about/news/new-multifamily-central-heat-pump-water-heater-incentives-now-available-in-pge-sce-or-scg-service-areas/.

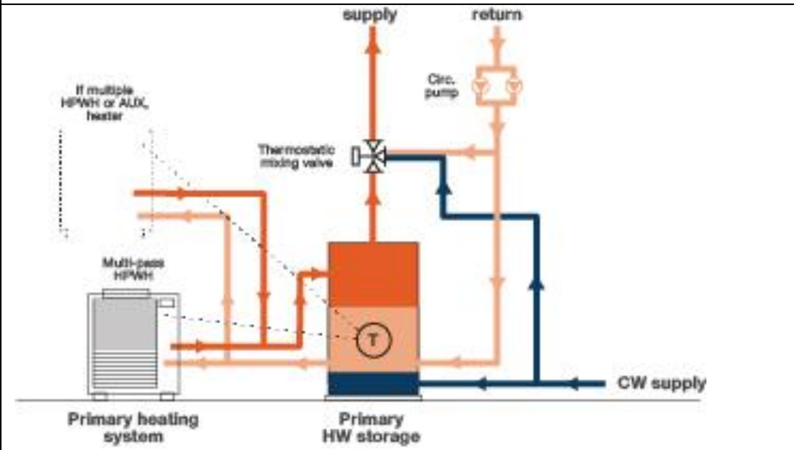
Valmiki, M, Sweek T, M Johnson, and S Spielman. 2023. *Commercial and Multifamily CO2 Heat Pump Water Heater Market Study and Field Demonstration.* CalNext. https://calnext.com/wp-content/uploads/2023/12/ET22SWE0017_Commercial-and-Multifamily-CO2-Heat-Pu.

Appendix A. System Configurations

<table>
<tr><th>System Configuration</th><th>Description</th><th>Diagram</th></tr>
<tr><td>1. Single-pass primary HPWH system without HW circulation</td><td>In this design the HPWH, or multiple in parallel, draws their cold-water supply from the bottom of the storage tank and returns the hot water to the top. This water is then pulled through a mixing valve to be distributed to the tenants a desired temperature.</td><td>
</td></tr>
<tr><td>2. Single-pass primary HPWH system with HW circulation returned to primary storage</td><td>The next step up in this design is to incorporate hot water recirculation to the storage tank. Comparing to the previous diagram, the only difference is in the warm return water in the storage tank. By adding in the recirculation loop the end point use always has hot water. Within the first design, you might have to wait for the hot water to get to the end point.
Re-introducing the recirculation loop above the cold-water inlet helps to maintain water temperature stratification and the high delta T that a single pass unit thrives off of.</td><td>
</td></tr>
</table>

System Configuration	Description	Diagram
3. Single-pass primary HPWH system with series temperature maintenance tank (Swing tank)	A temperature maintenance tank or swing tank can be added as well. Here the second tank is used to combine the hot water return and supply separating it from the cold water supply. These maintenance tanks will typically utilize an electric resistance heating element to maintain the desired temperature. The main design benefit is that the swing tank handles the temperature maintenance load, such as the recirculation loop loss, effectively. This eliminates the need to run the heat pump water heater for these loads, which would typically occur at a low Delta Temperature, resulting in poor efficiency and increased wear and tear on the unit due to frequent on/off cycling. The temperature maintenance load can accumulate significantly over the full day, varying from 10% to 80% of the total hot water load, making the role of the swing tank crucial for optimal system performance.	
4. Single-pass primary HPWH system with parallel temperature maintenance tank & Multi-pass HPWH	The final Single-pass primary system is very similar to the previous but now utilizes a Multi-pass HPWH in parallel for the maintenance tank. The benefit of introducing a Multi-pass system is to swap out the electric resistance heater for the swing tank with a HPWH. From the previous system, the swing tank heater is handling the recirculation load which is relatively small and low DT. The Multi-pass system likes low delta temperatures, which aligns well in this scenario. Of course introducing another HPWH is going to be more expensive than an electric resistance.	

System Configuration	Description	Diagram
5. Multi-pass integrated HPWH system without HW circulation	This design is for simple installations and features two integrated units. These units are Multi-pass and have integrated storage tanks. Integrated units may be a good fit for space constrained projects.	
6. Multi-pass integrated HPWH system with HW circulation returned to primary storage	Similar to, a single-pass primary HPWH system with HW circulation returned to primary storage, a recirculation loop may be added. Providing the benefits of on demand hot water greater system efficiency.	

System Configuration	Description	Diagram
7. Multi-pass primary HPWH system with HW circulation returned to primary storage	Multi-pass systems do not need to use integrated units. This design demonstrates how to layout a design with a separate hot water storage tank	

Appendix B. Incentive Programs in California for Central Heat Pump Water Heaters

Program Name	Website	Program Type	CHPWH Incentive	Implementer
California Energy-Smart Homes	https://caenergysmarthomes.com/	New Construction, Alterations	$5,000 for CHPWH design, $500 per dwelling unit served	TRC
CalEHP	https://caelectrichomes.com/	New Construction	Can be generally supported by base incentive	TRC
Clean Energy Homes		New Construction (Only Affordable Housing)	Can be generally supported by base incentive	TRC
Building Initiative for Low Emissions Development (BUILD)	https://www.energy.ca.gov/programs-and-topics/programs/building-initiative-low-emissions-development-program-build	New Construction (Only Affordable Housing)	Can be generally supported by base incentive or low-GWP kicker incentive but no specific incentive rate for CHPWH incentives.	TRC
3CE (CCCE) New Construction Electrification Program	https://3cenergy.org/rebates/new-construction-electrification-program-2/	New Construction	Can be generally supported by base incentive	Central Coast Community Energy (3CE)
3CE (CCCE) Electrify your Home	https://3cenergy.org/rebates/electrify-your-home/	Alterations	$1,000/unit served by central HPWH (same incentive rate as unitary systems, only available for income-qualified units)	Central Coast Community Energy (3CE)
TECH Clean CA	https://techcleanca.com/	Alterations	$900/kWh ($1,000/kWh for equity projects) and $200/kWh kicker for low-GWP systems (max incentive of $300k).	Energy Solutions

Program Name	Website	Program Type	CHPWH Incentive	Implementer
BayREN Bay Area Multifamily Building Enhancements (BAMBE)	https://www.bayren.org/multifamily	Alterations	$1,000/apt served (Property cap of $100,000. Program cap of $500,000)	StopWaste, AEA
Electric Homes San José	https://www.sanjoseca.gov/your-government/departments-offices/environmental-services/climate-smart-san-jos/building-electrification/electric-homes-san-jos	Alterations	$1,000/unit (or $2,000/unit for Equity Community projects), same rate for unitary and central HPWH. Total building incentives capped at $50k.	City of San Jose, Blocpower
Energy Savings Assistance Multifamily Energy Savings (ESA MFES)	https://esamultifamily.com/	Alterations (Only Affordable Housing)	Central electrification measures being finalized late 2024/early 2025.	TRC, RHA
Low Income Weatherization Program (LIWP)	https://camultifamilyenergyefficiency.org/	Alterations (Only Affordable Housing)	Can be generally supported by base incentive	AEA
SMUD Multifamily Program	https://www.smud.org/en/Business-Solutions-and-Rebates/Business-Rebates/Multi-Family-go-electric-incentives	Alterations	Central HPWH, 100% electric, <15-gal HP storage per bedroom served = $1,500/unit served. Central HPWH, 100% electric, ≥15-gal HP storage per bedroom served = $2,000/unit served	Frontier Energy, AEA
SMUD Smart Homes	https://www.smud.org/Going-Green/Smart-Homes/Builder-incentives	New Construction	Can be generally supported by base incentive	TRC
3C-REN Multifamily Home Energy Savings	https://www.3c-ren.org/multifamily	Alterations	CHPWH are eligible for unspecified bonus rebate, in addition to base $1,000/unit rebate	AEA

Program Name	Website	Program Type	CHPWH Incentive	Implementer
California Energy Design Assistance (CEDA)	http://ceda.willdan.com/	New Construction	Can be generally supported by base incentive	Willdan
SoCalREN Multifamily Program	https://socalren.com/multifamily/property-owners	Alterations	Can be generally supported by base incentive	SoCalREN
Los Angeles Department of Water and Power (LADWP) Comprehensive Affordable Multifamily Retrofits (CAMR)	https://ladwpcamr.com/	Alterations	Can be generally supported by base incentive	AEA
LADWP Zero By Design	http://www.ladwp.com/ladwpzbd	New Construction	Can be generally supported by base incentive	LADWP

Source: TRC Single Point of Contact (SPOC) Program

Additional Findings from TECH and CESHP Review

The project team reviewed several utility incentive programs that aim to promote the adoption of CHPWH systems in multifamily buildings. These programs play a crucial role in addressing the barriers identified in contractor motivations and market adoption. By offering financial incentives and technical support, utilities are working to accelerate the deployment of this technology across various building types and ownership structures.

The TECH Clean California program offers incentives to encourage the installation of central heat pump water heaters (HPWH) in multifamily buildings. This initiative aims to reduce carbon emissions and improve energy efficiency across the state, with a particular focus on multifamily properties, where 50% of Californians reside. The program provides financial incentives to contractors installing these systems, helping to offset the high upfront costs associated with adopting new, energy-efficient technologies like heat pumps. The TRC team reviewed the dataset from the program's website.

Key Findings from the Dataset:

1. Number of Installations: A total of 398 central heat pump water heaters were installed.
2. Energy Efficiency: The Uniform Energy Factor (UEF) for most units was consistently 3.4, with only 3 units having a UEF of 3.75.
3. CHPWH Distribution: The installations were spread across various climate zones, with the majority (205 CHPWHs) occurring in Climate Zone 10.

4. Storage Capacity: Most units had a storage capacity of 119 gallons (332 units), with smaller numbers having capacities of 199, 200, or 320 gallons.
5. Energy Savings: While the installations led to significant gas/propane savings (81,162 therms), there was a net increase in electricity consumption (-151,138.2 kWh).
6. CO2 Savings: The total CO2 savings amounted to 401.11 metric tons of CO2e.
7. Costs and Incentives:
    - The average cost per CHPWH system was $38,050.08.
    - The average incentive per CHPWH system was $18,322.70.

The dataset reveals that while the TECH Clean California program provides substantial incentives for central heat pump water heater installations, these incentives still fall short of covering the full cost of installation. On average, each unit costs around $38,050 to install, but the incentive only covers about $18,322 per unit—less than half of the total cost. This disparity can be attributed to several factors:

- High Installation Costs: Central heat pump systems often require significant infrastructure upgrades, such as electrical system enhancements or plumbing modifications, which drive up costs.
- Limited Incentives: TECH Clean California offers substantial incentives (up to $300,000 per system (TECH Clean 2024)), which are designed to offset a portion of the installation costs. However, for larger or more complex installations, the capped incentives may still leave a significant portion of the expenses to be covered by the building owner or developer.
- Energy Trade-Offs: While gas savings are substantial, the increase in electricity consumption could also contribute to higher ongoing operational costs for building owners.

The California Energy-Smart Homes Program (CESHP), implemented by TRC, aims to accelerate the shift to all-electric residential construction and advanced energy measures. The program provides financial incentives for various project types, including single-family homes, duplexes, multifamily low-rise buildings, and accessory dwelling units (ADUs). Its primary objective is to promote electrification by supporting the installation of efficient technologies, such as heat pumps, which are key to reducing carbon emissions and enhancing energy efficiency.

At the time this market characterization study was conducted, CESHP had enrolled five multifamily projects that installed central heat pump water heaters (CHPWHs) to replace gas water heaters. The TRC team reviewed these projects, and the findings are summarized below.

CHPWH Multifamily Projects by CESHP

Project No.	Number of Dwelling Units	CHPWH Manufacturer	CHPWH Configuration	UEF Rating	Cost Per Dwelling Unit ($)
1	100	Sanden	Multi-pass with Swing Tank	3.4	$2,180
2	44	Sanden	Single-pass with Swing Tank	3.4	$2,700
3	25	Sanden	Single-pass with Swing Tank	3.4	$3,600
4	20	Sanden	Single-pass with Swing Tank	3.4	$4,000
5	8	Sanden	Single-pass primary with hot water circulation returned to primary storage tank	3.4	$5,200

As CESHP is a whole-building electrification program, incentives are provided on a per-dwelling-unit basis rather than by individual end use. Analysis of invoices for the five projects above indicated that the total incentive covered only 30-40% of the overall electrification costs, which included converting space heating, cooking, and clothes drying to electric.

Appendix C. Interview Guide

Section A: Introduction

A0. Hello, my name is <INTERVIEWER NAME> and I am calling from TRC Companies. Thank you for agreeing to participate in this interview. As a reminder, I'm performing this work as part of a Statewide program to understand deployment barriers and opportunities of central heat pump water heaters for multifamily buildings.
Before we start, do you have any questions for me?

Great! As a reminder, we have about 45 minutes to chat today. Your responses will be kept confidential and will not be used for sales or marketing purposes. Additionally, we'd like to record today's interview solely to ensure accurate note-taking. This recording will not be shared outside of the research team and will only be used to make sure we capture your answers accurately. Are you okay with me starting the recording now?

Section B: Understand Roles and Experience

Let's start by getting a little information about you and your organization.

B1. To start, could you please briefly introduce yourself and describe your role at your company? [**Interviewer notes:** Note the individual's experience relevant to this research. Note their experience level in the industry. Confirm their business roles/titles.]

B2. How long have you been in your current role?

B3. How long have you worked with heat pump water heaters?

Section C: System Installation and Customer Motivations

C0. Now, I'm going to ask you a few questions related to heat pump water heater systems you have installed.

C1. First, could you please describe the types of heat pump hot water systems you work with?
PROBES:
- What range of storage gallon capacities have you installed?
- Do you install Single-pass or Multi-pass water heating systems?
- Have you installed systems with hot water recirculation? Demand controlled recirculation?

C2. Which kinds of systems do you install most often in multifamily buildings?
PROBE: What size buildings are these installed in?

C3. Are there particular systems that are not well suited to multifamily applications?

C4. In your experience, what types of systems perform particularly well in multifamily applications and are able to meet hot water demands?

C5. How do you work with customers to ensure their system meets their hot water needs?
PROBE: How do you assist customers in the information gathering and decision making process?

C6. In your experience, what motivates multifamily building owners to install central heat pump water heaters in their buildings?
PROBE: How does the contractor work with customers? Who offer the HP, contractors?

Section D: Program Participation

D0. Now I have a few questions about your participation with utility programs for heat pump hot water heaters.

D1. In your own words, could you please tell me about your experience participating in heat pump hot water heater incentive programs?

[Interviewer note: open ended question to get a sense of their perspectives on current programs]

D2. Do the programs adequately cover all of the kinds of systems and features you would want to install?

D2a. What systems are programs overlooking that would benefit from being incentivized?

D2b. Are the systems you would currently like to install but currently cannot because they are not incentivized?

D3. Are you involved with commissioning or monitoring system performance after installations?

PROBE: If not, who is involved in commissioning systems? Manufacturers? Building owners?

D3a. How common is it to monitor system performance to ensure the system is operating efficiently?

D3b. How could utility programs help support commissioning?

D4. Is there anything else related to heat pump water heater installations that programs could better assist with?

Section E: Barriers

E1. What, if anything, makes it difficult to promote central heat pump hot water heaters to customers?

Probe: Barriers may include

- High cost of system
- Difficult installation process
- Uncertainty about technology
- Bad past experiences.

E2. What, if anything, about the installation process is difficult when compared to conventional hot water systems?

PROBE: lack of training with CHPWH systems, poor ventilation, electrical capacity, space requirements

E3. What could help make promoting and installing heat pump hot water heaters easier?

PROBE: Informational materials, training, increased incentives for customers? Support from utilities, manufacturers, state programs?

Section F: Perspectives on Recent Advances

F0. Now I am going to ask a few questions related to technological advances. I am going to read a few different technologies and systems, and for each please tell me your familiarity and any positive or negative perceptions you have.

F1. Low global warming potential refrigerants, such as CO_2.

F2. Single pass vs. Multi-pass systems

F3. Hot water recirculation

F4. Integrated heat pump water heater systems

Section G: Closing

CLOSE1. Those are all of the questions I have for you. Is there anything you want to add or think it would be good for us to know about?

CLOSE 2. Great, thank you so much for your input. As a thank for your time, we would like to offer you a $100 gift card.

Appendix D. Interview Results

Section A. System Installation and Practices

Contractors work with a range of heat pump hot water systems, from large central systems to unitary systems, catering to various building types and project requirements. For new construction in single-family homes, 50–60 gallon heat pump water heaters are common. In renovation projects, there's a trend towards converting centralized gas boilers to split heat pump systems. System selection often varies based on project-specific requirements, building type, and application needs, indicating a flexible approach to system design and implementation.

Several heat pump systems stood out among interviewees for multifamily applications. Sanden CO2 heat pump systems were mentioned as the most common choice for multifamily applications. The Sanden SANCO2 Gen3 is specifically highlighted as a popular model. These systems use CO2 as a refrigerant, which is noted for its low global warming potential. Mitsubishi HP systems were also mentioned, though less frequently than Sanden systems. They typically use R410A as a refrigerant. Rheem HPWHs were mentioned by some contractors, often used with attached storage tanks. There was some uncertainty among contractors interviewed whether these are single-pass or multi-pass systems.

Interviewees did not identify any systems as universally unsuitable for multifamily applications. Challenges lie more in the implementation, space requirements, and building-specific factors rather than in the technology itself. Proper sizing, design, and consideration of the building's constraints are crucial for successful implementation in multifamily settings. Overall, responses suggest that well-designed and correctly sized heat pump water heating systems are capable of effectively meeting water demands in multifamily applications.

Contractors have several considerations when installing a HPWH system to ensure the system is able to meet hot water demand. Much of the work to ensure adequate hot water supply is done during the initial planning stages. This includes factoring in multiple data points to determine the right combination of products for sizing and system planning. Accurate system sizing is of primary importance. Some companies use portable flow meters for large projects to ensure proper system capacity. For example, one company left flow meters at a Great Wolf Lodge for a week to cover a busy weekend and inform sizing decisions. When flow metering is not an option due to timeline or budgetary constraints, contractors often reach out to manufacturers or engineers for sizing assistance. Contractors also consider hot water storage sizing. Running out of hot water is one of the most common concerns customers have about using HPWH systems over traditional boilers, so sufficient hot water storage to meet variable demands of multifamily buildings is important. Interviewees did not report that they are able to use industry standard sizing guidelines, but consult engineers or manufacturers and use their own installation experience to estimate proper storage sizing. While most of the system sizing work is done upfront, professionals remain available for emergencies, such as the building running out of hot water. Interviewees reported that they typically will not actively monitor system performance after installation and will assume the system is working well if they are not contacted in an emergency.

Contractors interviewed for this study reported several motivating factors that encouraged customers to pursue HPWH solutions for water heating needs. One primary driver is Electrification is being encouraged or mandated in some areas, with gas connections becoming less available for new projects. Even when projects are able to get gas connections, utilities often encourage them to build all-electric. Electrification can be an attractive option for builders because eliminating gas piping reduces installation complexity and the need for specialized labor. Rebates and incentives were a significant driver, with some owners able to get new systems for little to no cost. Contractors reported that customers were also motivated by energy efficiency and cost savings. CHPWHs offer operational cost savings (OPEX) compared to traditional systems and can have lower maintenance burdens. In addition to cost savings and electrification compliance, many building owners want to reduce their carbon footprint and decarbonize their portfolio, especially nonprofit affordable housing developers. HPWHs can help achieve these goals. Interviewees reported that building owners typically wait to switch from traditional gas boiler systems to HPWHs if their traditional system breaks and would require significant repair and replacing, or during major renovations or building rehabilitations. Another benefit of HPWH systems is increased resiliency. Electric systems can provide better redundancy compared to single-point-of-failure gas boilers.

Section B. Program Participation

Interviewees mentioned working with various incentive programs, including those offered by the California Public Utilities Commission (CPUC), local utilities, California Energy Smart Homes (CESH), and TECH. These programs are generally viewed as helpful in promoting the adoption of CHPWHs, especially in multifamily buildings. Interviewees highlighted the importance of rebates and incentives as a significant driver of HPWH adoption. Some contractors mentioned also being able to utilize midstream rebates to help keep system costs down.

Contractors did express some challenges associated with program participation. Several noted that reimbursement of incentives for installed equipment can take a long time, which can financially strain contractors who have to pay for the entire system upfront. Contractors also noted that participating in programs typically requires buildings to be all-electric. This can be challenging for building owners because some gas systems can be difficult to replace with electric alternatives, such as gas fireplaces. Having any gas using systems would make all systems, even electric systems such as HPWHs, ineligible for incentives. Contractors expressed a desire for greater program flexibility with regards to which mix of systems can be eligible for incentives. Additionally, some contractors had experienced confusion around which systems were eligible for program incentives. When questions do arise about system eligibility, program teams are usually able to provide quick answers, which helps mitigate concerns.

Contractors often have minimal direct experience working with utility providers on these programs. Building owners tend to have more insight into available incentives. Some contractors reported that they rely on suppliers and vendors to alert them about available programs rather than actively seeking them out. There may be opportunities to increase program awareness among contractors. Contractors reported that case studies would be helpful as educational material. These would help contractors to understand what systems are covered and how they perform in real-world applications.

Most interviewees indicate that the programs cover the main systems they want to install, including central heat pump water heaters for multifamily applications.

Section C. Barriers

Several factors make it difficult to promote central heat pump water heaters to customers multifamily buildings. Interviewees noted that many customers were not familiar with HPWH systems, and lacked an awareness of their potential benefits and understanding of how they perform in multifamily applications. Customers expressed concerns around cost of the system, both up front system and installation costs and costs associated with all electric water heating as opposed to traditional gas boilers. Customers also expressed concerns about reliability and maintenance burdens. Many customers are more familiar with older, potentially less reliable electric water heating solutions or tankless electric water heaters, which they have a bad impression of. This results in resistance from builders to adopting HPWH technology, which they see as new and risky. This concern about adopting what is seen as emerging technology is rooted in concerns about comfort. Building owners want to ensure that their tenants will not run out of hot water. Contractors also noted implementation challenges beyond customer perceptions. CHPWH systems can be complex, and can require specialized knowledge and familiarity to install, service, maintain.

Several aspects of the installation process for are more challenging compared to conventional hot water systems. One primary challenge is the space requirements of CHPWHs. To meet hot water demand of larger multifamily buildings, the entire system of water heating and storage is significantly larger than traditional gas boiler systems. Large buildings may require several HPWHs and multiple storage tanks in parallel to ensure tenants do not run out of hot water. Rooftop storage can require structural reinforcement as many roofs are not designed to bear the weight of a CHPWH system. Locating the system in a basement or indoor at ground level can present challenges as well. Integrated systems may not get adequate ventilation. Storage tanks on split systems can also be challenging to install in renovated boiler rooms because there may not be adequate space for the required amount of water storage. A typical solution is locating CHPWH systems outside the building, often by taking several parking spaces from the building's parking lot. Additional challenges contractors cited include difficulties integrating HPWHs into the existing building hot water system, electrical upgrades required to power the HP system, and time and paperwork associated with the installation process.

Several factors could help make promoting and installing heat pump water heaters, particularly CHPWHs for multifamily buildings, easier. Many contractors reported a desire for a more streamlined permitting process and greater access to information about system qualifications. Contractors and builders often feel unsure about which systems qualify for rebates, and need to know earlier in the design process so they do not spend money on designs that will not qualify for rebates. Clear guidelines and timely distribution of incentives help ease customer uncertainty as these factors directly influence decision making about which systems to install. Contractors also want clearer guidance from manufacturers about system sizing. One contractor estimated that systems are typically 15–20% oversized due to the guesswork that is involved in system sizing. This drives up costs and may discourage some customers from adopting HPWH technology. Contractors also expressed a desire for a simpler installation process. This may involve greater manufacturer standardization or promoting plug-and-play systems as an alternative to more engineering-intensive systems currently available.

Section D. Perspectives

The research team asked contractors and manufacturers their perspectives on several system configurations and emerging technologies associated with HPWHs.

- **Low GWP Refrigerants**
  CO2 is seen as a great option for heat pump water heaters. There is interest in seeing low GWP refrigerant options besides CO2. Propane mentioned as a potential alternative.
- **Single Pass vs Multipass Systems**
  Contractors often work with both types of systems. One contractor said that he prefers and tends to use single-pass systems, allowing for continuous operation at very low flow rates.
- **Recirculation**
  Hot water recirculation is considered essential for large multifamily projects. For multifamily apartments and smaller applications where hot water is generated for each individual unit using an integrated system, there is less need for recirculation. The main concern with recirculation is velocity. Best practice involves using variable speed recirculation pumps with thermostatic balancing valves to allow for continuous operation at low flow rates.
- **Integrated system**
  While this study does not go into detail on integrated systems and is focused on central HPWH systems, one respondent emphasized the importance of proper system design and integration in multifamily applications. Another respondent was familiar with integrated systems and generally positive about them. There was a desire for more split systems to be available on the market.