# Phase Change Material Applications in Multifamily Water Heating

## Final Report

ET25SWE0050


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## Disclaimer

# Executive Summary

California's multifamily buildings face complex challenges in transitioning to low-carbon domestic hot water (DHW) systems, especially in retrofit scenarios where space, cost, and distribution inefficiencies limit electrification. This CalNEXT technology development report introduces a novel design: integrating Phase Change Material Thermal Energy Storage Systems (PCM TESS) into central DHW systems to enable more cost-effective and space-efficient central heat pump water heater (CHPWH) upgrades. This design reduces distribution losses, supports load shifting, and minimizes the need for large central storage tanks by repurposing existing recirculation infrastructure into a PCM charging loop. This report presents initial engineering designs, energy modeling results, and stakeholder feedback to inform future lab testing and field demonstrations.

## Key Findings

- **System Design Innovations**: The volume of central storage required for load shifting in typical CHPWH designs, combined with the need for swing tanks to manage recirculation loads, often creates challenges for buildings with space-constrained mechanical rooms. These components can increase first costs and reduce overall system performance. The proposed distributed PCM system design addresses these issues by repurposing distribution and recirculation piping into a PCM charging loop, eliminating the need for swing tanks and reducing central storage volume by up to 67%. Compact, high-density PCM modules function as instantaneous water heaters for individual or grouped units, making the system both space- and cost-efficient. Major changes to traditional recirculation systems to serve as recharging loops will require updates to existing design guidelines and potentially building codes to support distributed storage designs.
- **Energy and Cost Savings**: Energy modeling of the PCM design shows a 26% reduction in heat loss from central recirculation systems and an 8% reduction in overall DHW load. In a 28-unit California multifamily building, this translates to 21.8 MMBTU in energy savings and $530 in annual operating cost savings for boiler systems. For CHPWH applications, load shifting enabled by PCM TESS can yield cost savings under time-of-use (TOU) rates, despite slightly higher energy use due to reduced central plant efficiency.
- **Technology Limitations**: Current CHPWH technologies limit PCM integration due to supply temperature constraints. As more systems emerge that can efficiently produce higher supply temperatures at lower delta T, opportunities for PCM TESS will expand. Lower-melting-point PCM materials may also address limitations of the commonly used P58 material.
- **Market Barriers**: While PCM TESS is gaining traction in HVAC and commercial sectors, residential water heating applications remain nascent. High first costs, installer unfamiliarity, and lack of standardized data limit adoption.
- **Equity in Program Design**: With over 90% of central water heating units in California multifamily buildings occupied by renters, retrofit programs must be designed to ensure benefits reach renters while addressing building owner concerns.

## Recommendations for PCM Advancement in the California Market

- **Improve Compatibility Between PCM and Heat Pump Technologies**
  Develop PCM materials with lower melting points to align with HPWH operating ranges and validate integration through lab and field testing.

- **Promote PCM TESS as a Space-Saving Solution for Multifamily Retrofits**
  Compact PCM modules can reduce central storage size and overcome space constraints in older multifamily buildings, enabling electrification retrofits.

- **Conduct a Field Study to Compare DHW Recirculation Performance in DAC and Non-DAC Multifamily Buildings**
  Conduct a statewide metered field study comparing DHW recirculation system performance in DAC/HTR and non-DAC multifamily buildings to quantify energy losses, assess the impact of building layout and infrastructure, and inform equitable retrofit program design.

- **Invest in Workforce Engagement and Training to Support Innovative System Design**
  Train contractors, designers, and installers on PCM system benefits and provide hands-on guidance for installation and maintenance. Early and ongoing engagement will build technical capacity and accelerate market readiness for distributed PCM systems.

- **Integrate PCM into California Incentive Programs**
  Enable WatterSaver program eligibility by integrating load-shifting communication protocols and developing modeling tools, accelerating adoption, and reducing upfront costs.

Building on these findings, this report outlines a roadmap for further engineering development, field validation, and market adoption of PCM TESS. These systems offer a promising pathway to decarbonize multifamily water heating—particularly in space-constrained retrofit scenarios.

## Abbreviations and Acronyms

| Acronym | Meaning |
|---|---|
| AWHI | Advanced Water Heating Initiative |
| CHPWH | Central Heat Pump Water Heater |
| DAC | Disadvantaged Communities |
| DCW | Domestic Cold Water |
| DHW | Domestic Hot Water |
| eTRM | Electronic Technical Reference Manual |
| EUI | Energy Use Intensity |
| GHG | Greenhouse Gas |
| GPM | Gallons Per Minute |
| HP | Heat Pump |
| HPWH | Heat Pump Water Heater |
| HTR | Hard-to-Reach |
| HVAC | Heating, Ventilation, and Air Conditioning |
| IECC | International Energy Conservation Code |
| IOU | Investor-Owned Utility |
| IPC | International Plumbing Code |
| kWh | Kilowatt-hour |
| LBNL | Lawrence Berkeley National Lab |
| NEEA | Northwest Energy Efficiency Alliance |
| NREL | National Renewable Energy Lab |
| NYSERDA | New York State Energy Research & Development Authority |

| Acronym | Meaning |
|---|---|
| PCM | Phase Change Material |
| PCM TESS | Phase Change Material Thermal Energy Storage System |
| PG&E | Pacific Gas & Electric |
| SCE | Southern California Edison |
| SDG&E | San Diego Gas & Electric |
| SGIP | Self-Generation Incentive Program |
| TOU | Time-of-use |
| TPM | Technology Priority Map |
| WH | Water Heating |

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# Introduction

California's residential building sector faces mounting pressure to decarbonize domestic hot water systems in response to new air quality regulations, including the Bay Area Air Quality Management District's 2027 restrictions on gas water heaters (Bay Area Air District Clean Air For All n.d.) (Bay Area Air Quality Management District n.d.) and anticipated statewide mandates by 2030 (California Air Resources Board n.d.) as well as to meet the statewide carbon emissions targets. These policies create an urgent need for alternative electric water heating technologies that are affordable, low-carbon, and compatible with the diverse constraints of multifamily buildings.

This report presents initial findings from a CalNEXT technology development research project focused on defining the market opportunity and performance potential of phase change material thermal energy storage systems (PCM TESS) for multifamily water heating. PCM TESS can deliver high-density, stable-temperature thermal storage in a compact form by taking advantage of latent heat storage.

While the study includes PCM TESS applications in standalone in-unit systems and supplemental components in central domestic hot water (DHW) systems, the primary focus of the project is to investigate the potential benefits of integrating distributed PCM storage water heaters into existing central domestic hot water (DHW) systems, including reduced distribution and recirculation losses. These losses represent a significant and often under-addressed source of energy waste in multifamily buildings.

Additionally, utilizing distributed PCM water heaters allows for shifting electric loads away from utility peak energy use during the day and reduces necessary central water storage tank sizing. Most importantly, integrating distributed PCM storage water heaters allows for the design optimization and adoption of low-carbon central heating systems incorporating heat pump, solar electric, or solar thermal solutions in multifamily applications.

This report evaluates the technical performance, market readiness, and stakeholder perspectives on PCM TESS in California multifamily buildings. These findings aim to inform utility programs, manufacturers, and policymakers working to advance equitable, efficient, and scalable water heating solutions in California's multifamily sector.

# Background

## Industry Context & Development

California's multifamily sector actively seeks scalable, low-carbon water heating solutions that address technical and equity challenges. While central heat pump water heaters (CHPWHs) are gaining traction, they face persistent barriers—especially in retrofit scenarios—including space constraints, high first costs, and distribution inefficiencies.

This project explores PCM TESS as a complementary or alternative solution to CHPWHs. PCM TESS offers compact, high-density thermal storage and the potential to reduce recirculation losses, shift electric loads, and downsize central storage—all critical needs in multifamily buildings.

The Advanced Water Heating Initiative (AWHI) and the Northwest Energy Efficiency Alliance (NEEA) identify the need for innovative water heating technologies. While PCM TESS is not yet widely represented in their initiatives, this study aligns with their goals to increase the portfolio of water heating solutions by evaluating market readiness, technical performance, and deployment pathways for PCM-based systems.

The project team will attend AWHI's Heat Pump Water Heater Day on October 23, 2025, to learn about heat pump water heater (HPWH) awareness and track national trends. In the week leading up to HPWH Day, the project team will attend preliminary events presented by affordable housing providers focused on a just, clean energy transition, HPWH load shifting experts, and a full-day training event for contractors focused on installation best practices, system design, and advanced technology integration.

In parallel, the Northwest Energy Efficiency Alliance (NEEA) launched the Hot Water Innovation Prize in 2024 to encourage the development of compact, low-cost, and easy-to-install split-system HPWHs that can replace small "low boy" 38-gallon electric water heaters in constrained spaces. While NEEA expressed interest in PCM-based solutions, the project team is unaware of any PCM TESS products submitted as alternatives to monobloc or split HPWHs with conventional storage tanks. This project aligns with the Prize's objectives by characterizing market potential, identifying barriers, and offering recommendations for advancing efficient water heating technologies.

## Water Heating Configurations in Multifamily Buildings

Water heating represents a substantial portion of energy use intensity (EUI) in multifamily buildings, which typically rely on two primary water heating configurations: standalone in-unit and centralized or shared systems. The following sections provide an overview of the characteristics, advantages, and limitations of in-unit and central DHW systems, setting the stage for evaluating the potential role of PCM TESS in addressing these challenges. These sources provide critical context for understanding system performance, building typologies, and retrofit challenges.

The study also drew on findings from several CalNEXT research efforts, including the:

- Multifamily Split-System HPWH Market Study (ET25SWE0026),
- HVAC Thermal Energy Storage System Field Evaluation (ET23SWE0022),
- Master Mixing Valve Field Study (ET22SWE0047),
- Multifamily Domestic Hot Water Recirculation Survey (ET24SWE0061), and
- Low Income Multifamily Housing Characteristics Study (ET22SWE0033).

### In-Unit Systems

In-unit water heaters give residents control over water temperature and simplify billing. Still, they require valuable space in constrained apartments and routine maintenance, which may necessitate coordination between the building owners/managers and residents and incur labor expenses. Electrification options are expanding, including integrated and split-system HPWHs, tankless models, and emerging PCM systems. While HPWHs offer strong efficiency benefits, they often require additional space, ventilation, and electrical upgrades compared to unitary gas and electric resistance water heaters. Split-system HPWHs, though quieter and more flexible, have higher costs, complex installation, and limited availability. PCM system manufacturers aim to overcome these barriers, but adoption remains limited due to market immaturity, installer unfamiliarity, and cost.

## Central Systems

Central DHW systems are prevalent in larger multifamily buildings (see Figure 2) and typically include hot water generation, storage, distribution, and recirculation. These systems offer centralized maintenance and operational efficiencies but pose challenges when electrifying legacy infrastructure.

### HOT WATER GENERATION AND STORAGE

Hot water is often generated by direct-fired fuel water heaters, a key target for electrification. CHPWHs have emerged as viable alternatives but sizing them for peak demand can lead to oversizing, short cycling, and high first costs. To mitigate this, systems are typically sized for average loads with added storage to meet peak demand. Balancing generation and storage are essential for cost-effective and efficient operation.

Retrofitting a boiler system to a CHPWH can expose underlying distribution issues previously masked by the boiler's higher generation capacity. These may include piping crossover, pressure fluctuations, poorly functioning recirculation loops, and imbalanced flow. Because CHPWHs typically operate with lower thermal output than boilers, unresolved inefficiencies become more pronounced after retrofit (Association for Energy Affordability (AEA) n.d.).

Stakeholder interviews revealed that building owners and operators often perceive CHPWH systems as complex and unfamiliar, requiring long-term support and training. Space constraints in mechanical rooms, structural limitations, and the need for large storage tanks further complicate installation. Outdoor components must be protected from freezing temperatures and weather exposure. Supplemental equipment, such as swing tanks, is often required to manage recirculation loads. Additional CHPWH information and design factors can be found in Appendix B.

### DISTRIBUTION AND RECIRCULATION SYSTEMS

Recirculation systems maintain hot water temperature throughout the building by continuously circulating water, reducing waiting times and water waste. California plumbing codes limit the distance between fixtures and hot water sources to 50 feet, necessitating recirculation loops in many multifamily buildings. Recirculation also helps mitigate Legionella risk by maintaining minimum temperatures of 120°F.

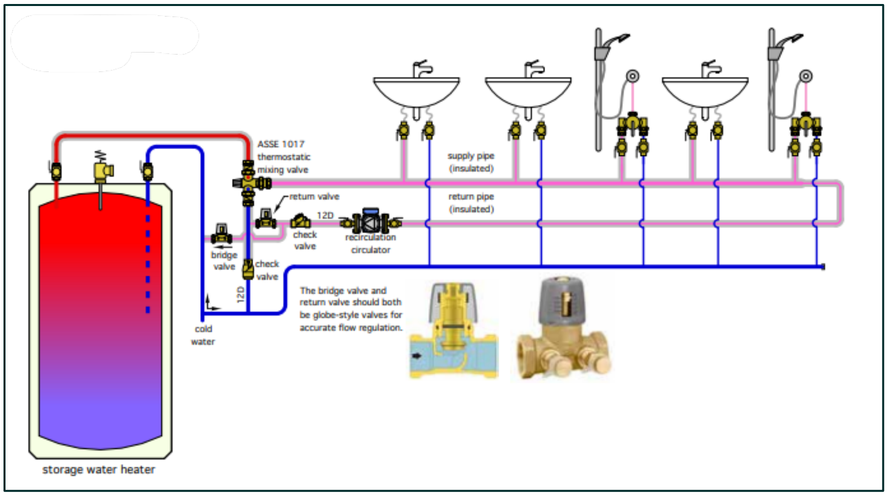


**Figure 1: Common central DHW recirculation system design Source: (Caleffi Hydronics Solutions 2017).**

However, recirculation systems can reduce the efficiency of condensing boilers and heat pump water heaters. Single-pass heat pumps operate most efficiently when heating domestic cold water (DCW) from 50-60°F up to 140°F or higher. Recirculated water often returns to the central plant at 105-110°F, reducing the temperature lift and efficiency. To address this, electric swing tanks are commonly used to reheat the recirculated water (New Buildings Institute 2025). While effective, over-reliance on electric resistance heating, especially in buildings with low hot water loads, can significantly reduce overall system efficiency. HPWHs can be 3-4 times more efficient than electric resistance heating (Daher, et al. 2024). The three most common recirculation system designs for CHPWHs are illustrated in Appendix C.

Recirculation systems also introduce significant heat loss, especially in older buildings with uninsulated piping or poor system balancing. An Efficiency Vermont study conducted with affordable housing developer Evernorth found standby losses up to 14.8 kBTU/hr in one building, accounting for 13% of the total building energy use intensity (EUI) and over $2,000 per year in energy costs in a space heating-dominated climate (Willner, Hand and Mascolino 2024). Another study reported that the median heat loss of a typical DHW loop is 93 Watts (317 kBTU/hr) per apartment, which can represent 25 to 50% of the heat required for a water heating system (Kitner and Larson 2019). A separate paper found that recirculation losses can account for approximately one-third of energy use in multifamily buildings (Zhang 2013).

In one study, researchers compared calculated and measured heat loss in two buildings and found observed values differed from calculated values by factors of 1.35 and 1.95 (Green and Heller 2022). The same report recommends best practices for reducing distribution and recirculation heat loss, including using master mixing valves, load balancing, insulating distribution piping, and eliminating areas of thermal bridging.

The 2022 California Energy Code requires hot water systems with recirculation pumps or heat trace to include controls capable of automatically turning the system off. The International Plumbing Code (IPC) requires temperature-actuated mixing valves (i.e., master mixing valves) at the hot water source, while the Uniform Plumbing Code, the model code that California's own Plumbing Code is based on, does not. One CalNEXT study found mixed results, with savings ranging from -4.9% to +11.4%, when adding digital master mixing valves to central DHW systems in a range of building types (TRC 2024), highlighting the need for further innovation.

### PCM Thermal Energy Storage Systems

PCM-integrated central systems offer a novel approach to mitigating distribution and recirculation losses. By decoupling heat generation from demand, PCM modules can be distributed throughout the DHW system to reduce recirculation runtime, improve load shifting, and alleviate space constraints. Dual heat exchanger designs enable simultaneous charging and discharging, enhancing compatibility with heat pumps and time-of-use (TOU) pricing.

PCM TESS offers a promising strategy to address the significant heat losses associated with DHW recirculation systems and several key barriers to the adoption of central heat pump water heaters (CHPWH). Successful deployment will depend on thoughtful system design, contractor education, and alignment of incentives, especially in disadvantaged and hard-to-reach communities. As heat pump technology evolves and PCM materials diversify (e.g., lower melting point options), the opportunity for PCM TESS integration will expand.

## Objectives

The primary objectives of this study were to:

- Provide primary and secondary market research to illustrate the market opportunity and technology performance with electric load shifting and heat pump designs for PCM TESS water heating products.
- Develop optimized engineering design concepts integrating PCM TESS into central water heating systems in CA multifamily buildings and evaluate the proposed designs' energy savings, cost impacts, and emissions savings.
- Provide insights into the market landscape, baseline conditions, and the potential for electrification and load-shifting through thermal energy storage.
- Produce actionable recommendations for CA utility programs, multifamily and energy efficiency advocates, and regulatory bodies.
- Provide an initial framework for applying the findings and recommendations for PCM TESS products to be included in energy efficiency and demand response programs.

## Methodology & Approach

This project includes a market characterization study, engineering design development, system energy and cost modeling, and stakeholder engagement. Stakeholders include those familiar with the California multifamily building market, central HPWH and PCM TESS manufacturers, packaged solution distributors, and incentive program administrators. This study employed a multi-phase approach to evaluate the feasibility, performance, and market potential of PCM TESS for water heating applications in multifamily buildings in California.

## Market Evaluation

The market evaluation focused on the current state of California's multifamily water heating market and the emerging opportunities for PCM TESS technologies. The project team conducted a comprehensive literature review to evaluate multifamily water heating systems, focusing on in-unit and recirculation-based configurations. The review included technical assessments of PCM TESS applications, limitations of existing systems, and recent findings from CalNEXT studies on split-system HPWHs and recirculation optimization. Priority was given to sources that addressed energy savings, demand response potential, installation costs, and electrification upgrade pathways.

The literature review also incorporated research on the cost and performance of conventional electric water heaters and PCM-based thermal storage solutions. Special attention was given to studies and initiatives supported by CalNEXT, TECH Clean California, the California Public Utilities Commission (CPUC), and other California energy agencies.

In addition to secondary research, the team conducted outreach interviews with PCM product manufacturers and distributors to gather specifications, cost data, and insights into market readiness. These interviews helped identify the most common baseline water heating systems (e.g., electric resistance, gas, and HPWHs), their performance characteristics, and the physical and economic constraints. Stakeholders were asked open-ended questions about the barriers and opportunities for PCM TESS adoption, particularly in the context of California's multifamily housing stock and electrification goals. Interviews also explored the needs of disadvantaged communities (DACs) and hard-to-reach (HTR) populations, including affordable housing property managers and contractors, to ensure equitable inclusion in future program design.

Key questions explored:

- Lessons learned from retrofits in HTR or DAC multifamily buildings and critical considerations for approaching this work
- Persistent challenges in affordable housing or low-to-moderate-income (LMI) buildings that PCM could help resolve, including issues related to building type, size, vintage, and metering
- Strategies to prepare the market for building owners and operators, including programmatic actions to support PCM adoption amid electrification and system complexity
- How did you identify sites for your projects, and what lessons were learned about site selection?

While responses were not always exclusive to DAC or HTR segments, they provided valuable insights applicable to most multifamily buildings.

Program administrators were also contacted for their input and feedback about PCM product integration into their programs for water heating market transformation.

The technical evaluation focuses on PCM TESS water heating performance, integration, and design considerations in multifamily applications with central DHW systems. The team conducted a detailed analysis of PCM product specifications, including thermal storage capacity, physical size, and compatibility with existing water heating infrastructure.

Both primary and secondary research were used to identify commercially available PCM TESS products and assess their technical viability. Manufacturer interviews and online research provided data on equipment costs, installation requirements, and system configurations.

The project team used the National Renewable Energy Laboratory (NREL) ResStock database to gain insight into key characteristics of multifamily buildings in CA, establish baseline assumptions for central water heating systems, and estimate the statewide energy and greenhouse gas (GHG) savings opportunity for integrating PCM TESS into multifamily DHW systems. NREL developed the ResStock database with support from the U.S. Department of Energy and offers real-time data visualization of an immense range of market factors and data. The database provides granularity on modeling diverse housing stock and distributional impacts of building technologies across different communities through multiple public and private data sources, statistical sampling, sub-hourly building simulations, and high-performance computing.

The project team used the U.S. Energy Information Administration (EIA) Residential Energy Consumption Survey (RECS) data to further characterize the CA multifamily building stock. The data in RECS is derived from several housing units statistically selected to represent all housing units occupied as a primary residence. In cases where similar data was available in both RECS and ResStock, the project team cross-referenced the data.

## Distributed PCM System Design

The team developed a preliminary design to integrate PCM TESS into a typical central DHW recirculation system. Insights into PCM TESS characteristics gained through primary and secondary research, stakeholder engagement, considerations around load shifting and time-of-use (TOU) pricing, and general DHW load and system sizing guided the development of the preliminary designs.

Energy models were developed to estimate energy savings, peak demand reductions, and the impacts of indirect emissions. Additionally, models were used to evaluate energy efficiency, demand response potential, and compatibility with heat pumps and load-shifted electric heating sources. The models compare distributed PCM TESS to conventional gas water heaters and split-system HPWHs. The analysis includes a comparative assessment of the cost, usage, and load-shifting capabilities of PCM TESS.

# Findings

## Market Evaluation

### Review of Prior Research & Stakeholder Engagement

Initial findings from the literature review highlight several technical benefits of PCM TESS for water heating applications. These systems offer cost savings through reduced utility demand charges (ESTCP 2019), enhanced resiliency by serving as backup thermal storage, and space efficiency due to their compact design compared to traditional water-based storage (NY/E Water Heating Systems

2025). While these findings underscore the potential of PCM TESS, the project team recognized that technical performance alone does not guarantee successful adoption. To ground the assessment in real-world conditions, the team complemented the literature review with extensive stakeholder engagement, interviewing experts across engineering, research, manufacturing, distribution, contracting, and nonprofit sectors. These conversations provided critical insights into market readiness, equity considerations, and practical challenges such as space constraints, system complexity, and workforce capacity. Together, the research and stakeholder perspectives informed recommendations for future deployment and product development.

### SIMULATION-BASED RESEARCH

Researchers at LBNL developed a simulation framework to evaluate the energy use, operational costs, and GHG impacts of integrating active PCM TESS into HVAC and DHW systems. One study modeled three building types: a portable building (i.e. modular building), a large commercial retail store, and a multifamily residential apartment unit, all with unique HVAC and DHW systems (Lawrence Berkeley National Laboratory, et al. 2021). Using Modelica to simulate PCM components, the study found that peak electric demand costs in the multifamily scenario were reduced by 55% compared to an all-electric baseline, and overall energy use remained essentially unchanged (Lawrence Berkeley National Laboratory, et al. 2021). Building on this modeling effort, current research is validating the performance of low-GWP air-to-water combi heat pump systems paired with PCM TESS in cold climate multifamily buildings (Walker n.d.). The research has identified a reduction in heat pump sizing by 60%, a reduction in peak demand by 40-80% compared to an all-electric baseline, and a 40-60% reduction in electricity consumption during peak periods (Walker n.d.).

### FIELD DEPLOYMENTS AND MANUFACTURER INSIGHTS

As part of the New York State Energy Research and Development Authority's (NYSERDA's) NextGen Buildings Innovation Program, a PCM manufacturer installed its units at eight trial sites with various thermal energy sources (e.g., oil/gas boilers, solar thermal, and water-to-water heat pumps). The project team interviewed the manufacturer and reviewed their published case study (Sunamp n.d.) to understand lessons learned from multifamily retrofit projects. Insights from this engagement included: central boiler gas reductions due to PCM integration, transitions from obsolete central systems to in-unit, under-sink PCM installations, and use of PCM to pull heat from central loops for direct apartment-level storage.

In one ongoing project, small PCM modules were installed above the washer and dryer in-unit, utilizing "dead space" and freeing up closet space previously occupied by water tanks. Similar space-saving benefits could apply to central mechanical rooms, potentially increasing rentable space and reducing first costs.

### EQUITY-FOCUSED RETROFIT CASE STUDY

Heather Village, a multi-owner equity townhome community listed as a Hard-to-Reach Community (Paine n.d.), provides lessons for a successful decarbonization retrofit. Although not a multifamily building, Heather Village featured centralized DHW systems. The design and consulting firm Carbon Zero Building's empathetic and transparent approach was critical in resolving in-unit water heating issues and coordinating among diverse stakeholders. Their strategy emphasized clear communication and education on practical benefits such as cost savings and reliability, creating opportunities for resident feedback to build trust, and maintaining flexibility to manage unexpected costs in older buildings. This case underscores the importance of communication and adaptability in equity-focused retrofits.

#### STAKEHOLDER PERSPECTIVES ON MARKET READINESS

Stakeholder interviews revealed several critical factors influencing the adoption of PCM TESS in multifamily applications. A plumbing design-build contractor noted that state incentives requiring advanced energy specifications have enabled retrofits in income-eligible and affordable housing projects. Similarly, a CalNEXT partner emphasized that successful projects often depend on aligning multiple funding sources to ensure comprehensive improvements. They observed that many older buildings present systemic water heating challenges—such as piping crossover and failed pumps—that cannot be resolved by simply upgrading the water heating source. Instead, a holistic approach supported by additional funding is required.

Workforce readiness emerged as another major barrier. Stakeholders stressed the need for increased contractor training on electrification technologies and hypothesized that very few contractors currently feel comfortable working with PCM TESS. One partner with experience in multifamily DAC retrofits noted that many challenges may be logistical in nature, including tenant relocation during construction and ensuring long-term system performance. Questions raised included: How will the average contractor install, repair, and maintain these systems? Stakeholders agreed that cost savings alone cannot overcome these barriers without robust training and long-term support.

### Analysis of California Multifamily DHW Systems

California leads the nation in multifamily housing units, with over 3.1 million apartment units, more than any other U.S. state (New Buildings Institute 2025). Multifamily buildings of all sizes account for approximately 32% of California's total residential building stock. Among multifamily buildings, those with five or fewer units represent about 27% of the total stock. If the definition of "small multifamily" is expanded to include buildings with ten or fewer units, the majority of California's multifamily housing falls into this category. Multifamily construction in California increased steadily until peaking in the 1970s, after which it declined significantly.

Figure 2 shows the distribution of in-unit vs. central water heating systems based on the number of units per building. In-unit systems dominate in buildings with five or fewer units, while central systems are more common in buildings with 5 to 25 units. For buildings with 25 or more units, the distribution is more balanced, though central systems remain slightly more prevalent.

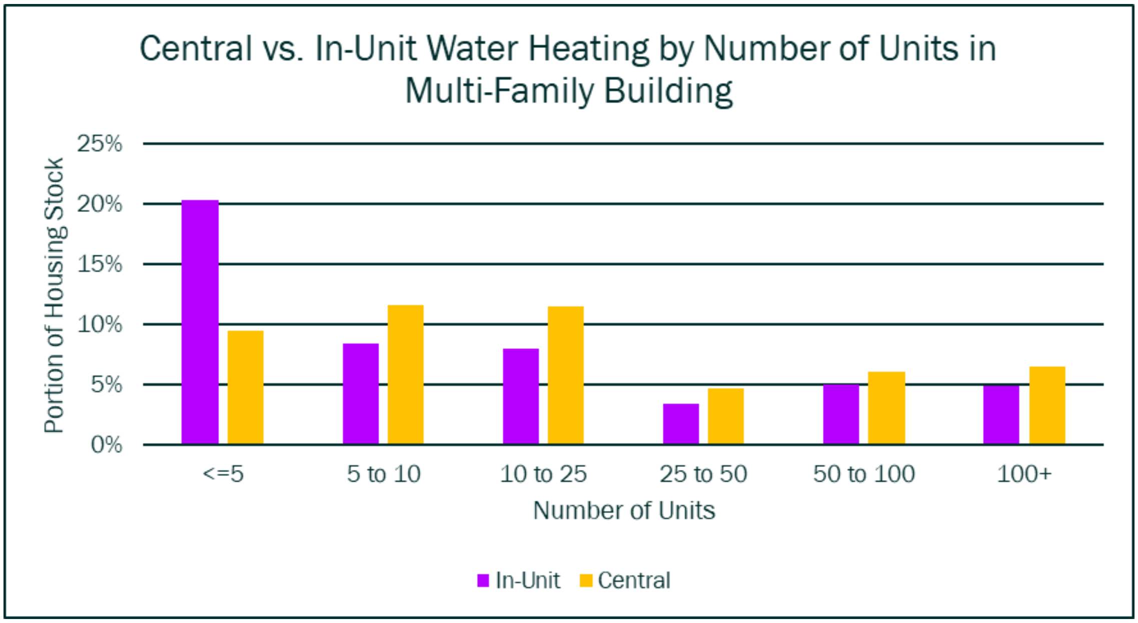


**Figure 2: Water heating type by the number of units. Source: NREL ResStock.**

Figure 3 illustrates the type of water heating system by construction year. Central systems dominated through the 1970s, while in-unit systems became more common starting in the 1980s, with a slight reversal in the 2010s. The high prevalence of in-unit systems in buildings built before 1940 can be viewed as an outlier, as this age bracket encompasses all multifamily buildings built pre-1940 rather than looking at a single decade. These older buildings tend to be smaller, making them more suitable for in-unit systems.

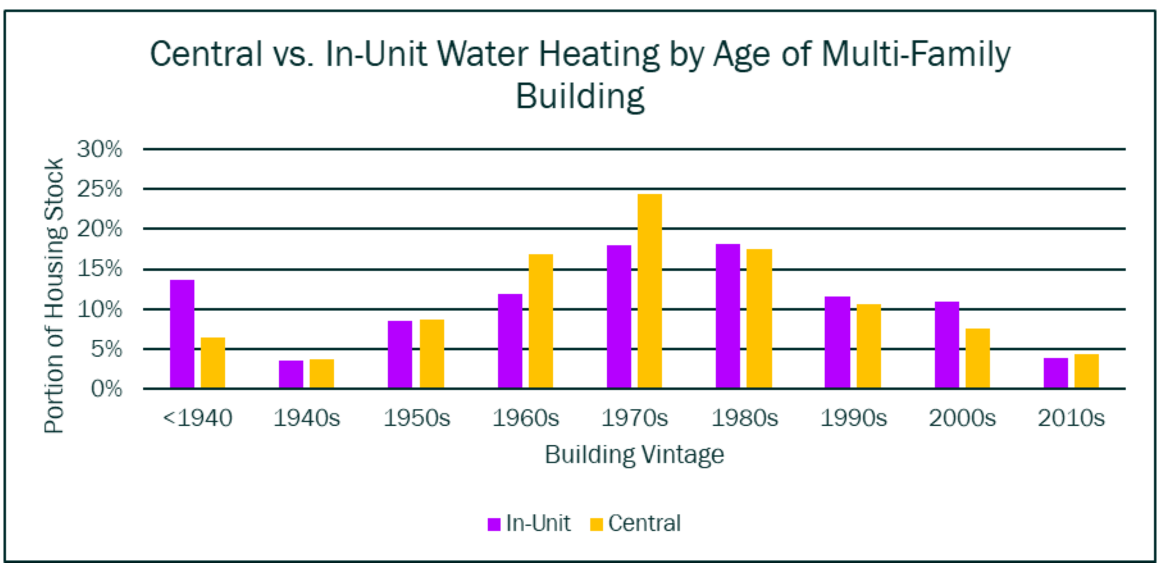


**Figure 3: Percentage of central and in-unit water heating based on the construction year of California multi-**

**family buildings[1]. Source: NREL ResStock.**

Figure 4 shows water heating system types by income level. Central systems are slightly more common in buildings serving households below 100% of the federal poverty level. In-unit systems become more prevalent at higher income levels, especially above 400% or more of the federal poverty level.

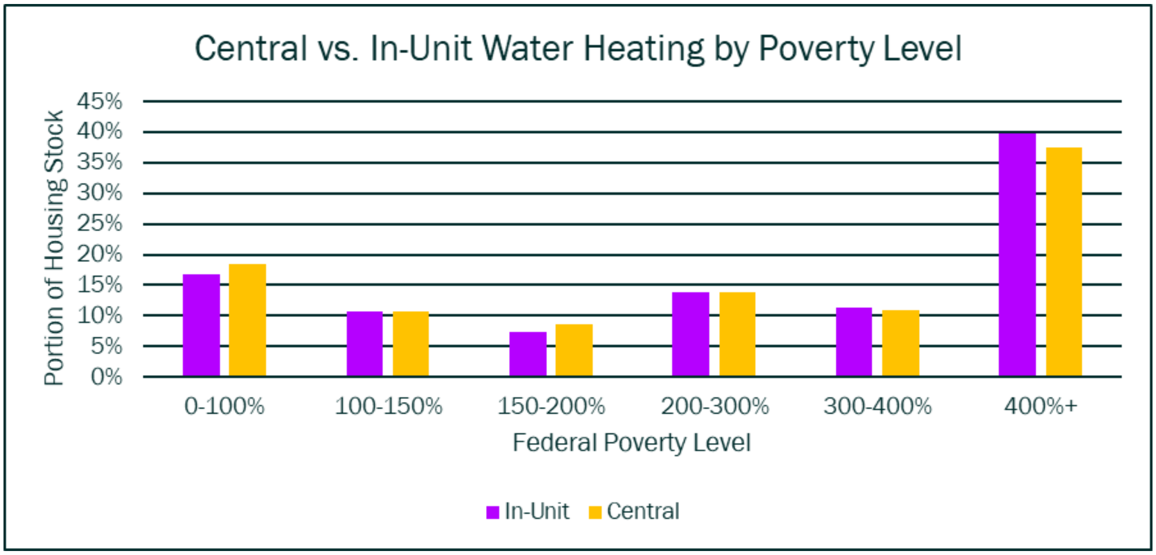


**Figure 4: Percentage of central and in-unit water heating based on federal poverty level. Source: NREL ResStock.**

In California multifamily buildings, over 90% of units with central water heating are renter-occupied, with only 9.4% owner-occupied. This pattern holds for buildings with in-unit systems as well: roughly 90% are renter-occupied and less than 10% are owner-occupied. Under California Civil Code § 1941.1, property owners are legally required to provide a functioning hot water supply, establishing them as the primary decision-makers for water heater maintenance and replacement (California Legislative Information n.d.). Given the high rate of renter occupancy, this legal obligation has significant implications for program design and policy targeting.

[1] Building vintage bins represent the portion of housing stock built during the entire decade, 1940-1949, 1950-1959, etc.

Table 1 summarizes the key characteristics of California multifamily buildings and water heating systems.

**Table 1: California Multifamily Existing Water Heating Characteristics**

| | | Small Apartment Buildings (2-4 units) | Large Apartment Buildings (5+ units) | Total Multifamily |
|---|---|---|---|---|
| Number of Housing Units (millions) | | 1.09 | 3.08 | 4.17 |
| Fuel Type | Gas[2] | 0.75 | 2.02 | 2.77 |
| | Electricity | 0.34 | 1.06 | 1.40 |
| Location | In-Unit | 0.64 | 1.02 | 1.66 |
| | Central | 0.44 | 2.06 | 2.50 |
| Central Water Heater Age | Less than 2 years | 0.04 | 0.09 | 0.13 |
| | 2 to 4 years | 0.05 | 0.16 | 0.21 |
| | 5 to 9 years | 0.18 | 0.33 | 0.51 |
| | 10 to 14 yrs | 0.12 | 0.95 | 1.07 |
| | 15 to 19 years | 0.05 | 0.28 | 0.33 |
| | 20 or more years | 0.00 | 0.25 | 0.25 |

Source: (EIA RECS 2020)

[2] Includes Natural Gas and Propane as Fuel Type

Central water heaters in California multifamily buildings are most often found to be between 10-14 years old and have storage capacities of 50 gallons or more. Many of these buildings use multiple water heaters. Gas and other non-electric fuel sources dominate in California multifamily buildings.

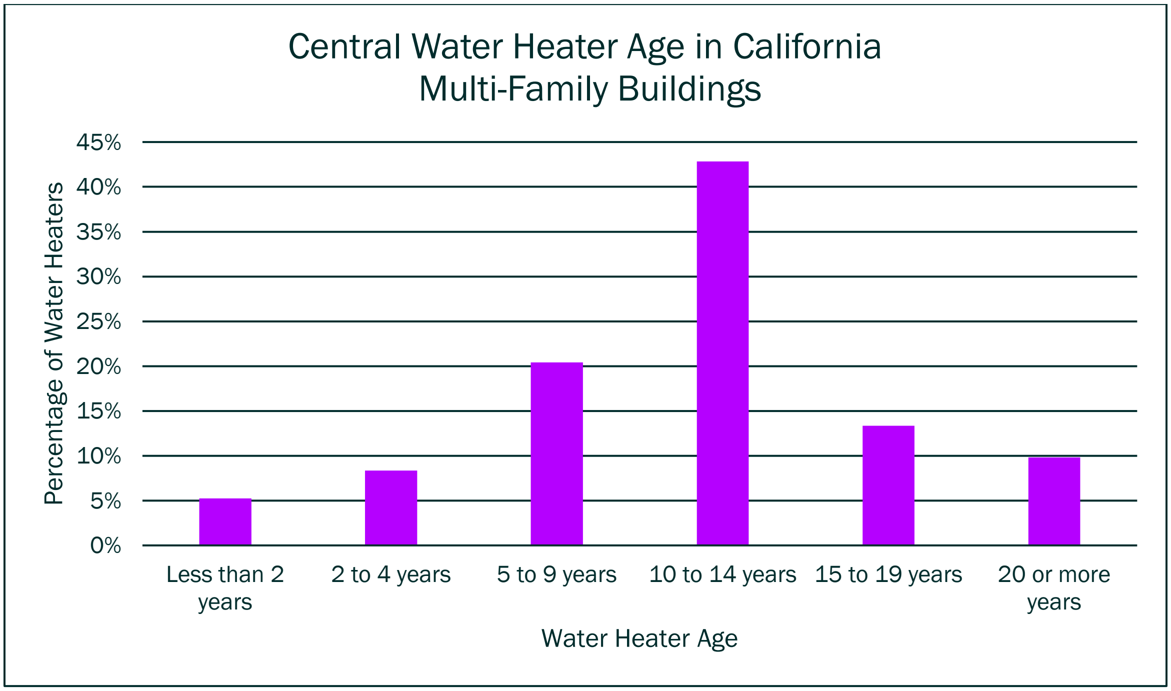


**Figure 5: Age of central water heaters in CA multifamily buildings. Source: EIA RECS 2020**

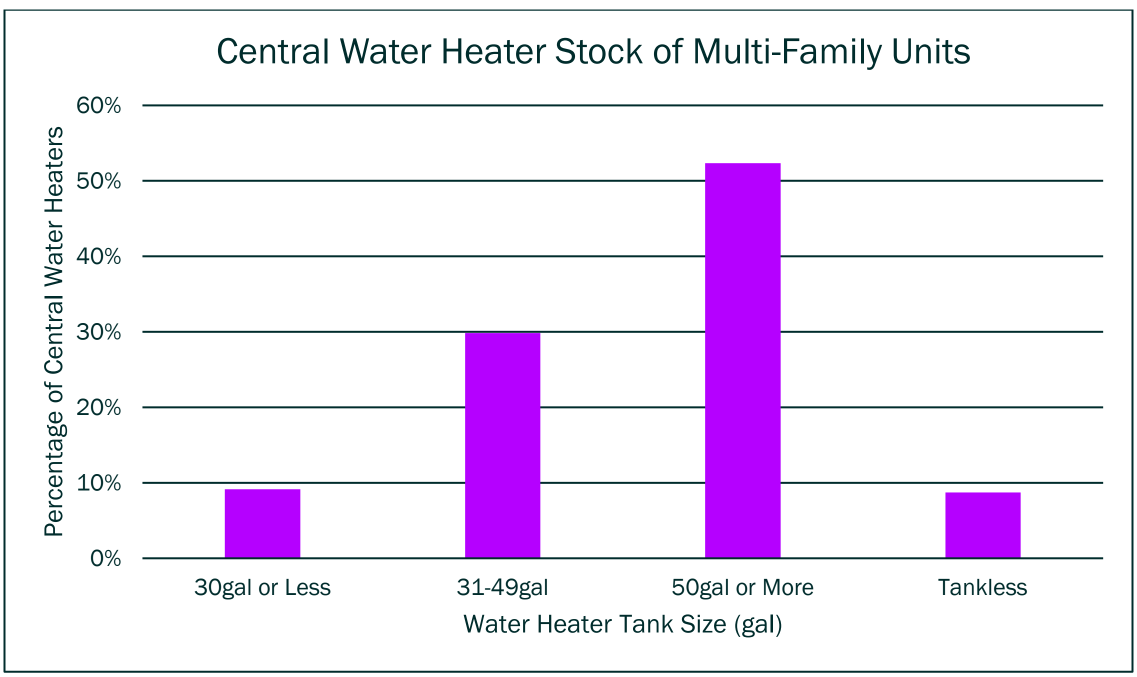


**Figure 6: Central water heater sizing in California multifamily buildings. Source: EIA RECS 2020.**

### KEY INSIGHTS ON CALIFORNIA'S MULTIFAMILY HOUSING STOCK

- Multifamily buildings represent a significant portion of California's housing stock (32% of the total), with an increasing average age due to a slowdown in new construction (National Renewable Energy Laboratory 2024).
- Central water heating systems are more prevalent in older buildings, corresponding with the peak in multifamily construction during the 1970s (U.S. Energy Information Administration 2020).
- The widespread use of central water heating systems, particularly in older multifamily buildings where aging equipment remains in operation, indicates a substantial opportunity for energy savings through reductions in recirculation and standby losses.
- In California multifamily buildings, over 90% of units with central water heating are renter-occupied, with only 9.4% owner-occupied. This underscores the importance of equitable program design for future retrofits and upgrades that ensure benefits reach renters indirectly while addressing the concerns of building owners.

## Evaluation of Current Products

While PCM-based water heating technologies are still emerging in the U.S. market, a growing number of solutions are now available for both in-unit and centralized distribution applications. These systems vary widely in configuration, PCM material type, application method, storage capacity, physical footprint, and market availability, reflecting the sector's early commercialization stage and lack of standardization.

The table below provides a comparative overview of selected PCM thermal energy storage systems (TESS), focusing on the smallest available units from each manufacturer. These examples are illustrative and not intended as endorsements or a comprehensive market survey.

**Table 2: Overview of Baseline Electric (no PCM included) and PCM TESS in the marketplace.**

| Technology | Manufacturer | Summary of Product | Cost | Load- Shifting Capabilities |
|---|---|---|---|---|
| **Baseline (no PCM) Electric Water Heater with Storage** | A.O. Smith Signature Line[3] | 28-gallon lowboy unit. Compact profile for space-constrained installations. UEF 0.89, 90 lbs. Dimensions: H: 30”, Diameter: 20” | $499 | None |

[3] (A.O. Smith Signature 100 28-Gallons Lowboy Electric Water Heater n.d.)

| Technology | Manufacturer | Summary of Product | Cost | Load- Shifting Capabilities |
|---|---|---|---|---|
| **Baseline (no PCM) Tankless Electric Water Heater** | A.O. Smith Signature Line[4] | Wall-mounted, 6.2 gallons per minute (GPM), standard heating elements. UEF 0.93, 19.75 lbs. Dimensions: H: 18.1", W: 17", D: 6.13" | $731 | None |
| **Battery Energy Storage System[5]** | Tesla[6] | Powerwall 3: 13.5 kWh usable capacity, integrated inverter, wall-mounted design. 287 lbs. Dimensions: H: 44", W: 24", D: 6". | $9,100-$15,000[7] | Yes – via app-based scheduling and grid services integration |
| | LG Energy Solution[8] | RESU Prime 10H: 9.6 kWh capacity, lithium-ion chemistry, modular design for residential applications. Compatible with solar PV and smart inverters. 246 lbs. Dimensions: H: 20", W: 32", D: 12". | Custom quote required | Yes – supports TOU optimization and demand response through inverter controls |
| **Electric Water Heater with PCM Storage** | Sunamp[9] | Thermino 20: A+ UK energy rating, 10-year warranty. Dual heat exchanger enables additional thermal input, such as HPWH and solar thermal sources. 137 lbs. Dimensions: H: 16", W: 14.5", D: 22.5" | $2,291[10] | Yes – via Modbus integration |

[4] (A.O. Smith Signature Series Tankless Electric Water Heater n.d.)

[5] Supports more than just water heating, including whole-home backup

[6] (Tesla Powerwall - Home Battery Storage n.d.)

[7] Price range generated from Tesla Powerwall 3 Design Calculator (Tesla Powerwall3 n.d.)

[8] (LG Energy Solution RESU10H Prime n.d.)

[9] (Thermino n.d.)

[10] MSRP pricing distributors use as a guideline

| Technology | Manufacturer | Summary of Product | Cost | Load- Shifting Capabilities |
|---|---|---|---|---|
| | Phasestor[11] | eStor 6kW: A+ UK energy rating, NSF 61, freeze protection. Dual heat exchanger enables additional thermal input, such as HPWH and solar thermal sources. ~150 lbs. Dimensions: H: 21.8", W: 23.2", D: 23.2" | $2,800[12] | Yes – via Wi-Fi and external controller |
| **Passive PCM TESS, requires external heat source** | Cowa[13] Thermal Solutions | COMPACT Cell 58: 13 kWh, 6.6 GPM, European B rating. Immersive sleeve is pre-installed to allow the use of an external temperature sensor. ~550 lbs. Dimensions: H: 55.1", W: 13.4", D: 23.6" | Custom quote required | Yes – external control required |
| | Insolcorp[14] Thermal Energy Storage | Small TES: 2 tons/hour, passive battery, integrates with heat pumps, heat recovery, or immersion heating. Suitable for shared residential or small commercial applications. No integrated controls. 280 lbs. Dimensions: H: 23", W: 20", D: 29" | $1,579 | Yes – external control required |
| **Central HPWH with PCM** | Nyle[15]/HTEC[16] | Pyroclast (also branded as Medusa): 375 water storage gallon equivalent, 14 kWh electric backup, 3.7 COP, DOE rated 104,800 BTU/hour. Dimensions: H: 96", W: 88", D: 38" | Custom, varies by installation scope and location. | Yes – integrated PCM enables load shifting |

## PCM SYSTEM CONFIGURATIONS

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[11] Sourced from (eSTOR the World's Most Advanced Thermal Energy Battery n.d.) and interview with Phasestor Director

[12] MSRP pricing distributors use as a guideline

[13] (cowa Heat Storage Pioneers n.d.)

[14] (INSOLCORP Thermal Energy Storage Systems (TES) n.d.)

[15] (nyle water heating systems Introducing: Pyroclast™ Integrated Heat Pump Water Heater n.d.)

[16] (Htec MEDUSA PCM Integrated Heat Pump n.d.)

Sunamp and Phasestor offer PCM-based systems suitable for in-unit installation, featuring compact footprints and integrated electric heating elements. These systems can operate independently or with other energy sources such as solar or heat pumps. Their modularity makes them viable for both individual apartments and central distribution systems. Their compact design may be well-suited for California's low-income housing stock, where 58% of households occupy units under 800 square feet.

Cowa and Insolcorp offer passive thermal energy storage units requiring an external heat source. The Cowa product is similar to the Sunamp and Phasestor as it is small and modular and could be used in an in-unit or central distribution system. The Insolcorp TES unit is designed for shared residential or small commercial use and supports flexible integration with heat recovery systems. It offers a flexible and cost-effective solution for load shifting and energy efficiency, particularly for buildings looking to reduce peak demand without significant infrastructure changes.

Nyle's Pyroclast, developed with HTEC, is a centralized HPWH solution with integrated PCM storage, engineered for high-demand buildings such as multifamily housing or dormitories. Its compact footprint allows it to fit through standard doorways—an advantage over traditional insulated storage tanks—and its integrated PCM modules reduce the need for large water volumes while maintaining high thermal output.

One notable advantage of PCM systems is their minimal water storage, significantly reducing flood risk. In the event of a system failure, the PCM solidifies around the heat exchanger, resulting in a slow, manageable leak rather than a sudden release of stored water. Manufacturers also report low concern for potable water contamination, citing the pressure differential between the water and PCM compartments. While no permitting issues have been reported, some manufacturers acknowledged that future regulations could introduce complications.

### INSTALLATION AND COST BARRIERS

As these systems are new to the US, manufacturers did not have installation cost data to share. A CalNEXT partner shared their experience retrofitting multifamily buildings to CHPWH systems with the project team. They discussed the challenges of displaced tenants when a water heating system is upgraded. Where will the tenants live during construction? Who will incur the expense of relocating them? If the retrofit is complicated, as is the project team's design proposed in further sections of this report, demolition, plumbing, drywall, and other modifications can require the alignment of multiple contractors.

Despite their technical promise, cost remains a primary barrier to adoption. As one manufacturer explained, "PCMs are proprietary products, not commodities," and are expected to remain more expensive than conventional equipment for the foreseeable future.

Additionally, while some products carry high-efficiency ratings in European markets, their absence from the U.S. ENERGY STAR database may limit eligibility for rebates and incentives, further constraining market uptake. Manufacturers emphasized they would like to see their products included in incentive programs. Although these PCM systems can be bundled with efficient products and included in legacy electric efficiency programs, load shifting or battery incentive programs may also be applicable.

- PG&E's WatterSaver program is a residential load-shifting initiative that automatically heats water during off-peak hours to reduce energy costs and grid strain, offering participants financial incentives for enrollment and ongoing participation. PCM products with an integrated heat source may be eligible to participate if they support CTA-2045 or are compatible with a Distributed Energy Resource Management System platform, allowing WatterSaver to access performance data and verify load shifting (WatterSaver n.d.).
- Manufacturers are also assessing eligibility requirements for the CPUC's Self-Generation Incentive Program (SGIP), which supports emerging distributed energy resources on the customer's side of the utility meter, including energy storage systems (SGIP Equipment Reviews Standard Operating Procedure (New Equipment and Factory/Field Discharge Data Reviews) n.d.).

### Review of Current Modeling Approaches

Several tools are currently available for modeling DHW systems, specifically central HPWHs. The project team reviewed the following modeling and simulation tools to assess applicability to PCM TESS: California Energy Commission's (CEC) CBECC-Res tool, Ecotope's EcoSizer and EcoSim tools, and OpenStudio, including OpenStudio HPXML (OS-HPXML). A summary of these tools and their capabilities is presented in Appendix D.

The primary advantage of the EcoSim and OS-HPXML tools is their ability to leverage OpenStudio while requiring a limited set of user inputs. Although highly flexible, OpenStudio presents a steep learning curve for new users and can be a significant time commitment for experienced users developing models from scratch due to the extensive number of inputs required to construct a model.

To address this, the National Renewable Energy Lab (NREL) has developed a suite of scripts that streamlines the modeling-building process. Using these scripts, users can easily develop prototypical multifamily building models with CHPWHs based on lookup tables populated with values from ASHRAE 90.1, Department of Energy sources, and additional references. Users can edit specific characteristics once the model is generated, including water heater details. Notably, the tool does not include a built-in list of water heaters or CHPWH equipment, allowing users to specify attributes for the evaluated equipment. The software reports hourly heat loss, heat loss rate, and energy due to the off- and on-cycle loss coefficients to the ambient temperature.

In recent years, researchers at Lawrence Berkley National Lab (LBNL) have developed models of PCM TESS using Modelica, an open-source object-oriented modeling language. (Helmns, et al. 2021). In one study, LBNL researchers used Modelica to model HVAC and DHW integrated PCM TESS in a multifamily unit. While this proof-of-concept study focused on in-unit water heating equipment, conversations with LBNL researchers revealed that the Modelica models may be well adapted to central water heating systems. However, integration of the Modelica-based PCM models with existing building energy models is not easily achievable, demonstrating the need for future work on the integration of PCM models.

Because none of the existing tools reviewed can currently model the proposed distributed PCM system, the project team developed a system energy model to evaluate the proposed design and leveraged Ecotope's EcoSizer and EcoSim to size and model the energy consumption of the baseline CHPWH scenarios.

## Distributed PCM System Design

This report section details the development of distributed PCM TESS applications for central water heating systems in multifamily buildings. More specifically, the focus is on PCM TESS as a solution for reducing recirculation losses in central DHW systems.

### Distributed PCM Concept

Figure 7 below illustrates the concept of distributing PCM TESS throughout the DHW system, with a single PCM module shown in each apartment for simplicity. However, there are cases where it may be beneficial to have a single PCM module serving multiple apartment units. The benefits and drawbacks of the different configurations are discussed in the section below.

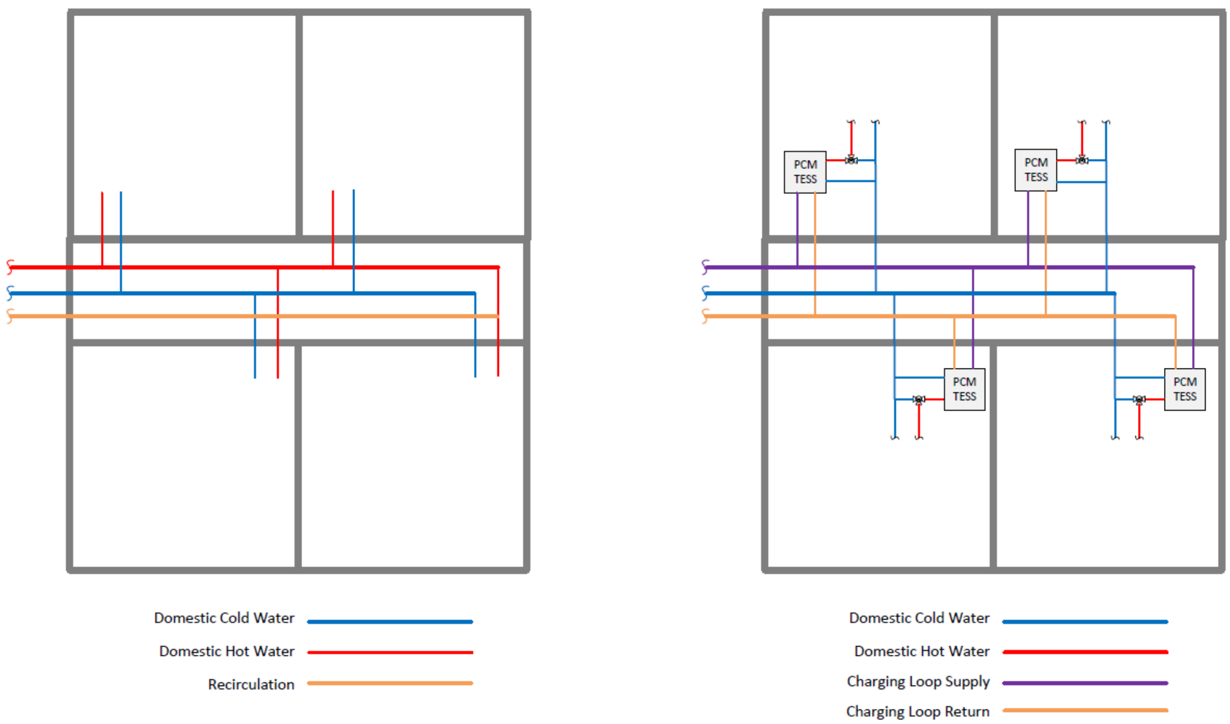



**Figure 7: Conceptual layout of distributed PCM TESS for one typical DHW recirculation system layout.**

Final engineering drawings of the proposed distributed PCM system can be found in Appendix E.

### Example Building Details

The project team used information and data from a real-world example building to evaluate the proposed distributed PCM TESS concept. The example building includes 28 apartments (27 one-bedroom units and 1 two-bedroom unit) in climate zone 10. Details and characteristics of the example building are documented below in Table 3. Some details, like recirculation losses, are unknown, so estimates based on data from prior studies and industry standards are used instead. This specific building was chosen as the basis of the design for a few reasons. First, its size (28 units) falls within the middle range of multifamily buildings in California. Also, the distribution system includes a simple, single recirculation loop.

Table 3: Building Characteristics of Example Building

| Building Characteristics | Example Building 1 |
|---|---|
| Climate Zone | 10 |
| Number of units | 28 |
| Size of units (1-bed, 2-bed, etc.) | 1-bed (27) & 2-bed (1) |
| Laundry (common or individual) | Common |
| Mixing Valve Type | Thermostatic Master Mixing Valve |
| MMV Minimum Flow | 2.0 GPM |
| MMV Temperature Range (F) | 90°F – 120°F (110°F Recirculation Loop Setpoint) |
| Recirculation Pipe Size | 3/4 in |
| Maximum Allowable Flow Through Recirculation | 5 GPM |

## Baseline & Proposed Scenarios

In order to compare the benefits, drawbacks, operational energy, and incremental costs of incorporating PCM TESS into the example building, the project team developed four scenarios: two baseline scenarios and two distributed PCM scenarios.

**Baseline Boiler.** In this scenario, the project team considers replacing a central direct-fired water heater with a like-kind boiler. This scenario is common with equipment failure or end-of-life, particularly in emergency replacement situations. In this scenario, the existing hot water storage remains in place, and PCM TESS is not integrated into the distribution system. This scenario is considered to be the baseline boiler scenario.

**Baseline CHPWH.** In the second baseline scenario, the existing central water heater is upgraded to a CHPWH. Information from the actual project is used to evaluate this scenario's energy consumption and capital costs. Additional hot water storage and an electric swing tank are necessary with this upgrade. Like the Baseline Boiler scenario, PCM TESS is not integrated into the distribution system during the upgrade, so the recirculation system runs continuously.

**Boiler + Proposed PCM Storage.** In this scenario, we consider the impact of incorporating PCM TESS into the distribution system during a boiler replacement. With the integration of PCM storage throughout the distribution system, the recirculation loop does not need to run continuously. Instead, it runs intermittently to charge the distributed PCM modules. In this scenario, the project team estimates the impact of the distributed PCM on the recirculation losses, the boiler's capacity, and the central storage needs.

**CHPWH + Proposed PCM Storage.** Similar to the Boiler + Proposed PCM Storage scenario, the project team assesses the impact of incorporating distributed PCM with a CHPWH. In this scenario, we explore the impact on the CHPWH capacity, central storage needs, recirculation configuration (e.g., the need for a swing tank), and the impact of distributed PCM TESS on load shifting capabilities.

Table 4: Baseline and proposed PCM scenarios

| | Baseline Boiler | Baseline CHPWH | Boiler + PCM Storage | CHPWH + PCM Storage |
|---|---|---|---|---|
| **Hot Water Generation** | Boiler | CHPWH | Boiler + Optional Electric (PCM) | CHPWH + Optional Electric (PCM) |
| **Storage Type** | Central (Water) | Central (Water) | Central (Water)+ Distributed (PCM) | Central (Water)+ Distributed (PCM) |
| **Load Shift Capable** | N/A | Yes | N/A | Yes |
| **Recirculation System Operation** | Continuous | Continuous | Intermittent/ Optimized | Intermittent/ Optimized |

## System Engineering & Design

The project team developed the proposed system with the following design parameters and considerations in mind: simultaneous charging & discharging, back-up heating source, central storage needs, PCM TESS characteristics, charging flow rates, charging loop temperatures, charging loop heat loss, and DHW loads.

**Simultaneous PCM Charging & Discharging:** The project team identified two design criteria around charging and discharging: 1) the ability to simultaneously charge and discharge the PCM modules, and 2) the ability to charge all PCM modules in the system simultaneously. Several PCM modules that are currently available include dual heat exchangers. This allows for decoupling the distribution system into a process (charging) side and a delivery (discharging) side, illustrated further by the detailed figure in Appendix E. In other words, water does not flow directly from the water heater to the fixtures. Instead, the main distribution and recirculation loop is closed and used for charging the distributed PCM modules. DCW then passes through the second heat exchanger on the discharge side of the PCM to generate DHW supplied to the fixtures. The main benefit of the dual heat exchanger is that it allows for simultaneous charging and discharging of the PCM modules. However, a drawback of this design is that it relies on the PCM module to bring DCW up to temperature, which may necessitate electric resistance backup for high-use units. While these designs were developed for a dual heat exchanger, this system will also work with water-based distributed thermal energy storage and a single heat exchanger, which is an added benefit.

Piping the PCM modules in parallel rather than in series allows for simultaneous charging of all PCM modules rather than consecutive charging. The design accomplishes this by adding an additional branch from the PCM module back to the recirculation loop.

**Back-up Heating Source:** PCM models with integrated electric resistance elements are preferred for this application. The electric heating can serve as a backup during increased or peak usage. It can also provide backup if the central plant's capacity is insufficient at low outdoor temperatures or needs to be taken offline for maintenance.

**Central Storage Needs:** In traditional CHPWH system designs, additional central storage is necessary when sizing the central plant for load shifting. This additional storage volume adds to upfront costs and can be a barrier for existing buildings with space-constrained mechanical rooms. Central storage (also described as a buffer tank) is still necessary in the proposed distributed PCM design to decouple the CHPWH or boiler runtime with the charging cycles (i.e., store hot water produced by the heat pump or boiler when the charging loop is not running). However, the volume of central storage is significantly reduced because of the additional distributed PCM storage. The existing storage tank(s) may even be sufficient. One operational strategy to reduce the central storage requirements is to simultaneously run the distribution/charging loop when the heat pump is running, or vice versa, turn on the heat pump when the charging loop is running. Benefits of reducing the central storage include lower first costs, reduced standby losses, and a smaller physical footprint. The tradeoffs of central storage volume and heat pump/boiler capacity are evaluated and further discussed below in the System Evaluation section.

**PCM TESS Characteristics:** The project team established additional design parameters and criteria based on conversations with PCM TESS manufacturers and experts. The following table documents key design parameters related to PCM.

**Table 5: Thermal Properties of PCM**

| Parameter | Value | Additional Notes |
|---|---|---|
| Melting point of P58 PCM material | 136°F (58°C) | P58 is the most common PCM material and changes phase from solid to liquid at 58°C |
| Minimum PCM charging temperature | 145°F (63°C) | A general rule of thumb is to supply water to the PCM at 5°C above the PCM material's melting point |

| Parameter | Value | Additional Notes |
|---|---|---|
| Maximum PCM charging temperature | 176°F (74°C) | PCM manufacturers report a maximum temperature that can be passed through the PCM material based on material chemistry |

In summary, the most common salt-hydrate PCM available is known as P58. This material has a melting point of 58° C or 136°F. When the material reaches this temperature, it changes phase from a solid to a liquid. During the transition, latent energy is stored within the material, and the temperature of the material remains at 136°F. After this transition, the material will absorb sensible energy in the form of heat, similar to water-based storage. PCM manufacturers and experts shared a general rule of thumb to charge the PCM with water about 5° C above the PCM's melting point. This is important because it sets the floor for the water temperature produced by the central plant. Additionally, there is a maximum temperature the PCM can be charged to before the chemical composition & performance of the material is impacted. The maximum temperature reported by manufacturers is 176°F for P58 material.

**Charging Flow Rate:** The proposed designs rely on the existing distribution and recirculation piping, so the charging loop flow rate is limited by the allowable water flow through the existing distribution and recirculation system in a retrofit application. The existing recirculation piping in the example building is 3/4 inch, so the maximum water flow through the recirculation while maintaining appropriate velocity and pressure drop is 5 GPM.

**Charging Loop Temperatures**: The PCM charging rate is based on convective heat transfer and can be calculated using the water flow rate along with the supply and return water temperatures. In the case of P58 PCM, the return water temperature from the distributed PCM modules back to the central plant will be just below its melting point, 136°F. Because the flow rate is constrained by the size of the existing recirculation piping, increasing the supply water temperature is one way to boost the PCM charging rate and reduce the runtime of the charging loop. As shown in Figure 8, the charging rate increases linearly with supply temperature. However, this also leads to increased heat loss through the recirculation piping due to conductive heat transfer through the walls of the piping to the ambient air. A tradeoff is discussed below. Based on the maximum water flow of 5 GPM and supply/return water temperatures of 166° F and 136° F, respectively, the charging rate of the distributed PCM system is limited to 75,000 BTU/hr.

Another key consideration is the temperature range of currently available equipment. Boiler output temperatures vary from 140°F to 180°F. The project team is aware of only one heat pump boiler on the market capable of producing hot water up to 170°F. Most HPWHs that do not require a swing tank are limited to supply temperatures between 120°F and 140°F. Some $CO_2$ split-system HPWHs can reach up to 155° F but operate inefficiently when the temperature difference (delta T) between inlet and outlet water is small. This often necessitates using an electric swing tank or multi-pass HPWH to manage higher return water temperatures, expected to be just below the melting point (136° F) during PCM charging.

One emerging solution is propane (R-290) air-to-water heat pumps, which can achieve higher supply temperatures. However, these systems introduce additional challenges, as most HPWHs are not well-suited for high return water temperatures.

**Charging Loop Heat Loss**: To assess the impact of the rate of recirculation losses on the system operation and energy consumption, the project team evaluated a range of recirculation losses from 50 Watts/apartment to 200 Watts/apartment. The default assumption in Ecotope's EcoSim tool is 100 Watts/apartment, just under 9,500 BTU/hr.

Table 6: Levels of recirculation heat loss in Watts per apartment

| | Low | Medium | Medium-High | High |
|---|---|---|---|---|
| Recirculation Losses (Watts/apartment) | 50 | 100 | 150 | 200 |

In Figure 8 below, the red line represents the rate at which the PCMs charge based on the supply water temperature. As the supply water temperature increases, the charging rate increases. The black and gray lines represent the rate of heat loss as the supply temperature increases for four levels of heat loss.

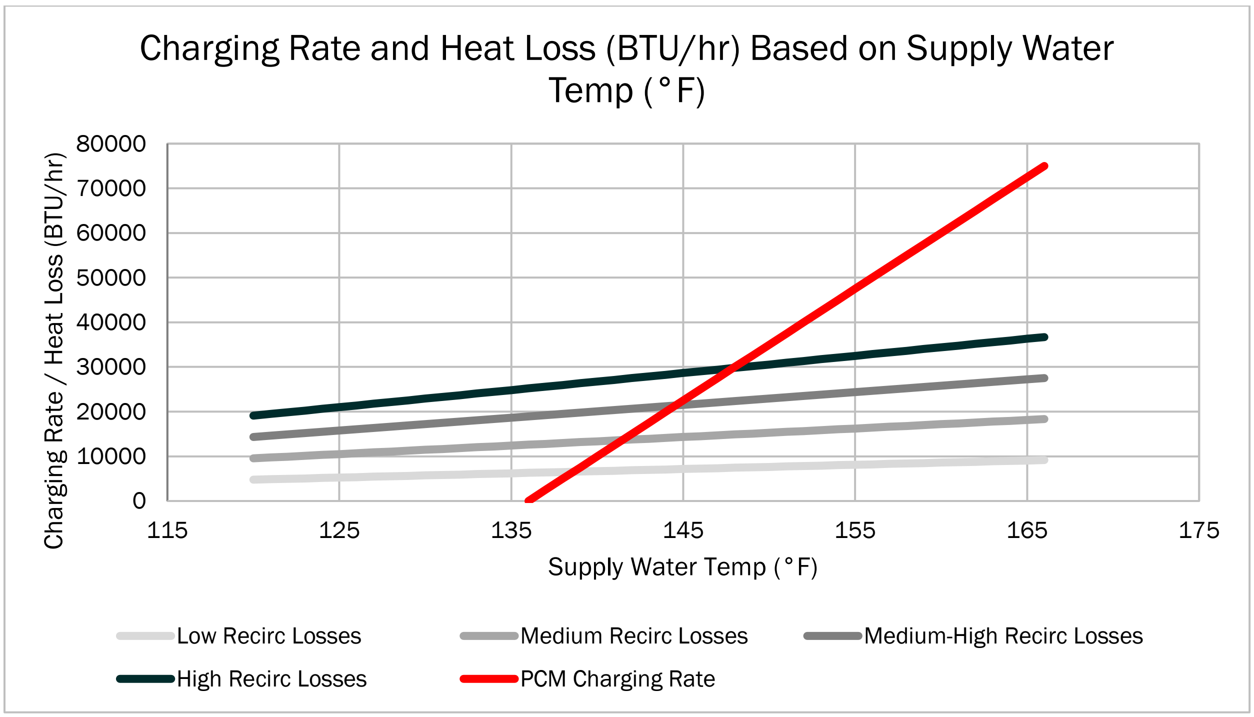



Figure 8: Charging rate and heat loss in BTU per hour based on supply water temperature

**DHW Loads:** There are several literature sources for peak and average hot water loads in multifamily buildings, as well as approaches to sizing DHW systems. The project team reviewed the DHW loads reported in the ASHRAE Handbook of Fundamentals HVAC Applications Chapter 51 (ASHRAE 2023), an Ecotope study on DHW loads (Heller and Oram 2015), the CBECC Software, (CEC 2025) and the California eTRM. Each source reports slightly different numbers for sizing DHW equipment and storage capacity. An overview of these sources and values can be found in Appendix F. Using older data sources on hot water load can lead to oversizing equipment, which in turn can lead to inefficient equipment operation and may result in higher first costs.

The project team used the California-specific peak loads in EcoSizer to estimate the daily average DHW load for the 28-unit building. Furthermore, the team constructed a DHW daily load profile by extracting a DHW load profile from the CBECC tool and normalizing it to the total daily DHW load. Figure 9 below illustrates the daily average DHW load used to size the boiler and CHPWH systems and analyze the proposed PCM system design.

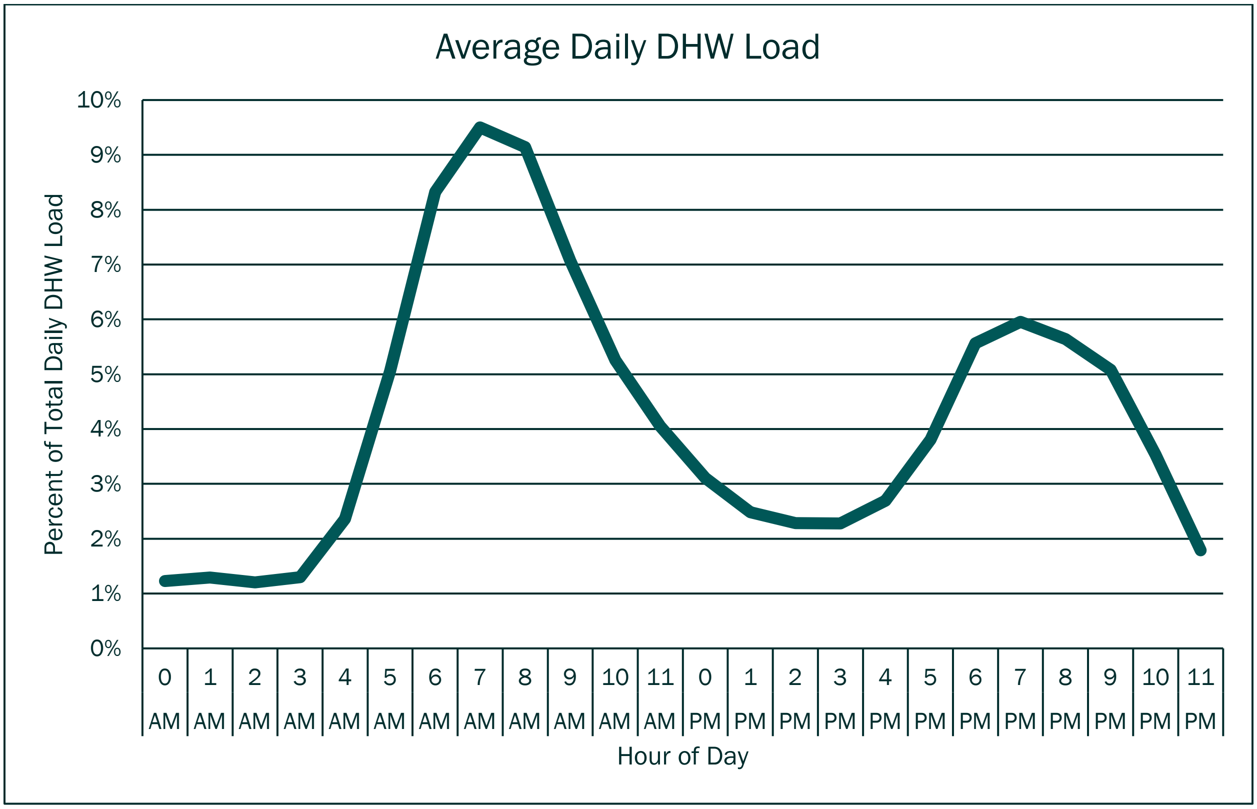



**Figure 9: Average DHW load profile.**

## System Evaluation

The project team modeled the proposed distributed PCM system design in Excel to demonstrate proof of concept. Ecotope's EcoSim tool was used to model the Baseline CHPWH scenario, while Excel was used to model the Baseline Boiler and both Boiler + PCM Storage and CHPWH + PCM Storage scenarios. To assess the performance under varying climatic conditions, the project team evaluated the system performance using the California Measurement Advisory Council (CALMAC) (California Measurement Advisory Council 2025) weather data for two locations: Lake Tahoe, representing a "cold" climate, and San Francisco, representing a "warm/mild" climate.

Using the aforementioned sizing and energy modeling tools, the project team quantified the required water heater or CHPWH capacity, central (water) and distributed (PCM) storage capacity, swing tank size and capacity (if needed), and the recirculation operational hours and associated standby heat losses for each of the baseline and optimized scenarios.

Based on the final engineering designs, the project team evaluated the following:

- **Changes in energy use** (gas and electric) from standby losses (recirculation) and equipment efficiencies.
- **Operational cost impacts** due to changes in system efficiency and shifting load outside of peak TOU pricing.
- **First cost impacts** of the necessary system components for each scenario, including the central plant and storage requirements, additional distributed PCM storage, and system components such as mixing and isolation valves.
- **Total system benefit and avoided GHG emissions** from increased energy efficiency and load shifting capabilities.

### CHANGES IN ENERGY USE

While this analysis does not evaluate the impact of other efforts to reduce the rate of recirculation system heat loss (e.g., replacing or upgrading insulation, installing digital master mixing valves to reduce recirculation flow, replacing manual balancing valves with thermostatic balancing valves, or upgrading to variable speed recirculation pumps to modulate flow), the project team assessed the impact of the existing recirculation losses on the proposed system design.

Table 7: Impact of existing recirculation losses on energy savings from proposed distributed PCM design

| Existing Recirculation Losses | Low: 50 W/apt | Medium: 100 W/apt | Med-High: 150 W/apt | High: 200 W/apt |
|---|---|---|---|---|
| Recirculation operation (hours) | 8 | 9.2 | 11 | 13.6 |
| Recirculation pump savings (kWh) | 252 | 232 | 204 | 163 |
| Recirculation savings (MMBTU) | 15.2 | 21.8 | 14.8 | -15.3 |
| Reduction in recirculation losses (%) | 36% | 26% | 12% | -9.1% |

The results presented in Table 7 above indicate buildings with high existing recirculation losses (200 W/apartment) will not see savings with the proposed PCM design. This is due to the increased supply water temperature (166°F) circulating through the system. While increasing the supply water temperature increases the rate at which the distributed PCMs charge, it also increases the rate of heat loss from the pipes to the ambient air. Increasing the supply water temperature from 120°F to 166°F in a 28-unit building with medium recirculation losses raises the recirculation losses from 9,554 BTU/hr to 18,343 BTU/hr or 192%. This, in turn, increases the overall load on the central plant and the runtime of the charging loop. **If the rate of heat loss doubles but the charging time is** not reduced to less than half, then the increased rate of heat loss negates the savings from reducing the charging time.

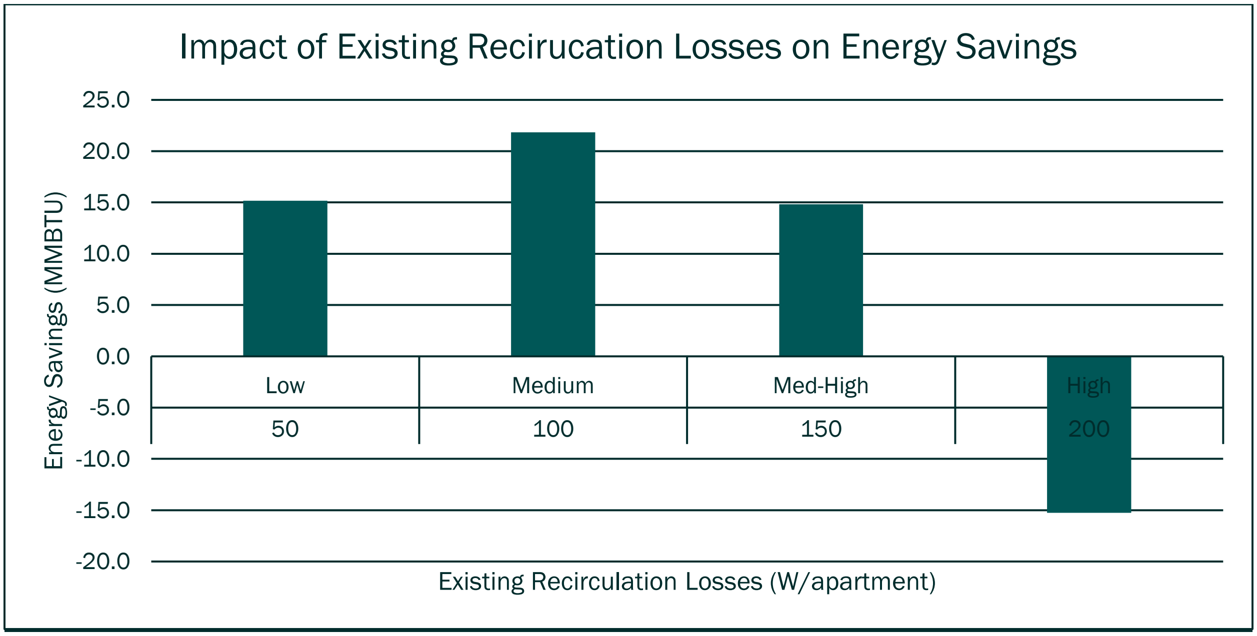



**Figure 10: Impact of existing recirculation losses on energy savings from proposed distributed PCM design**

The project team evaluated the proposed system design throughout the following sections, assuming a medium rate of recirculation heat loss at 100 W/apartment or 9,554 BTU/hr for the 28-unit example building. Recirculation operation and subsequent losses are independent of the central plant heat source; thus, the values in the table below are relevant to both boiler and CHPWH scenarios. The team did not model whole-building energy, so results do not include the interactive effects on heating and cooling energy from reducing recirculation losses; it is expected that a reduction in recirculation losses may contribute to decreased AC use during the cooling season and increased heating during the heating season.

Table 8 below presents the findings from the analysis on the impact of the proposed design on the recirculation operation, heat losses, and total DHW load. Implementing the proposed design has the potential to reduce the recirculation operation from 24 hours per day down to 9.2 hours per day, reducing losses through the recirculation of hot water by 26% leading to an 8% reduction in total DHW load.

**Table 8: Estimated energy savings associated with the proposed distributed PCM system**

| | Baseline Scenarios | PCM Storage Scenarios | Savings |
|---|---|---|---|
| Recirculation Operation (hours) | 24 | 9.2 | 62% |

| | Baseline Scenarios | PCM Storage Scenarios | Savings |
|---|---|---|---|
| Annual Recirculation losses (MMBTU) | 84 | 62 | 26% |
| Total DHW Load (BTU/day) | 753,377 | 695,629 | 8% |
| Recirculation load as percent of total DHW load (%) | 30% | 24% | N/A |

Boiler energy consumption and savings, presented in Table 9 below, were calculated assuming an efficiency of 85%. The reduction in recirculation losses leads to savings of 24.8 MMBTU annually.

**Table 9: Estimated energy consumption of boiler baseline and proposed PCM scenarios**

| | Boiler Baseline | Boiler + PCM Storage | Savings |
|---|---|---|---|
| Annual energy consumption (MMBTU) | 323.5 | 298.7 | 24.8 |

The time of day when electric energy is consumed is critically important for understanding the impact of TOU electric rates on energy costs, GHG emissions, and TSB. The project team developed an Excel-based energy model of the proposed PCM system design to understand the system dynamics and predict hourly energy consumption. Ecotope's EcoSim tool was used to model the system energy consumption of the CHPWH baseline scenario.

The project team used the EcoSizer outputs (Appendix D) from the baseline model to evaluate the same DHW load in the proposed PCM system. To generate a load profile, the team extracted a yearly load profile from the CBECC tool, calculated the average load for each hour of the day over the year, and then fit the total daily load to the load profile. The CBECC tool and EcoSim use "shuffling" techniques to vary the daily load profile over a year. This technique was not incorporated into the Excel-based model the project team developed. Instead, the load profile is consistent each day of the simulation. This does not capture the variability that the system will experience but allows for sizing and assessing average conditions. When the DHW load varies and peaks above average, the integrated electric resistance elements in the PCM units will provide hot water as a fail-safe. However, the impact of the supplemental electric back-up is not included in the modeling because the model was based on an average DHW load and does not account for peaks.

To evaluate the system, the project team assumed a simplified sequence of operations. In this simplified case, the charging loop runs on a time-based schedule, charging the PCMs two times a day: one charging cycle leading up to the morning DHW peak and the second leading up to the afternoon/evening peak. Recirculation losses only occur when the charging loop is running.

The CHPWH compressor only runs during off-peak times and when the available hot water in the central storage/buffer tank is not at full capacity. The run-time of the compressor is based on the heat pump capacity (determined by the outdoor temperature) and the amount of hot water needed in the buffer tank. The heat pump output is calculated by multiplying the compressor run time by the heat pump capacity. The system energy consumption is then calculated each hour by dividing the heat pump output by the COP of the heat pump based on the outdoor temperature each hour. Pumping energy is also considered when the charging loop is running. To evaluate the proposed design, the project team used performance data from the heat pump water heater capable of producing 170°F water at 30°F outdoor air temperature and 160°F water at 18°F outdoor air temperature. The team also assumed a capacity reduction of 50% to account for the impact of a small temperature lift between the entering water temperature and leaving water temperature.

Figure 11 shows the PCM charging state based on the PCM charging cycles and the discharging rate, a function of the DHW load profile.

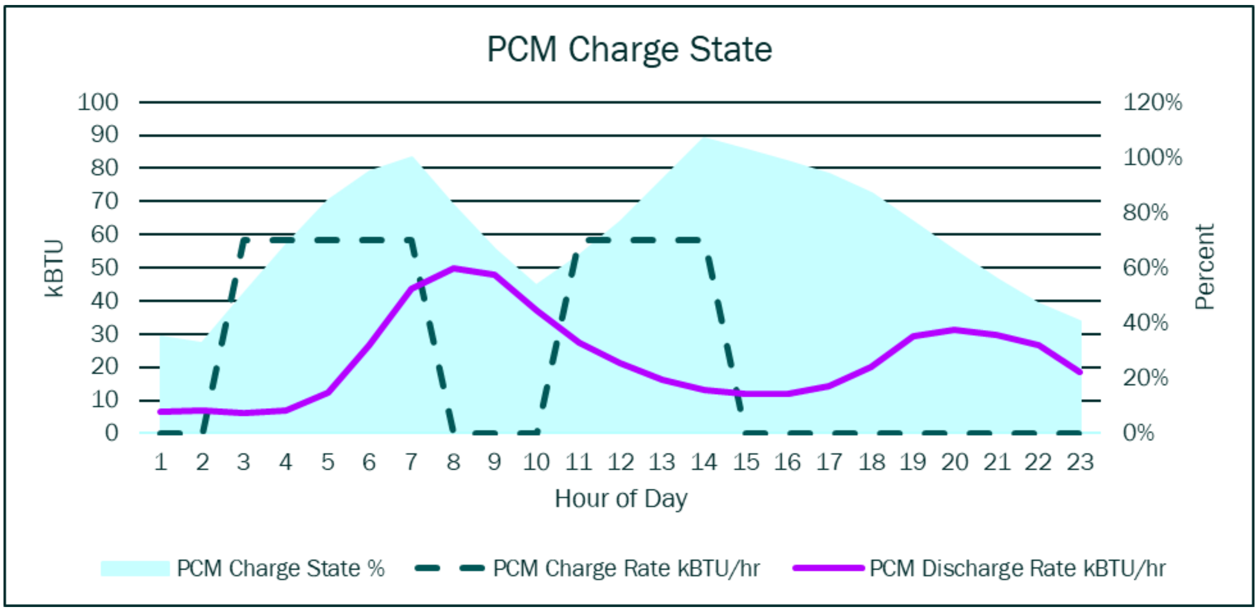



**Figure 11: PCM charge state (%) based on charging and discharging rates.**

The annual, peak, partial peak, and off-peak energy use in kWh for baseline and proposed PCM scenarios are presented in Table 10 below, along with the average system COP. Across both climate zones, the proposed system demonstrated higher overall energy consumption compared to the baseline scenarios. This increase is primarily attributed to a lower average coefficient of performance (COP) in the proposed PCM-based system, which averaged 2.05, versus 2.56 in the baseline central plant configurations. The reduced system COP directly contributed to the observed rise in energy use, highlighting a key tradeoff in the proposed design.

Table 10: Estimated energy consumption of CHPWH baseline and proposed PCM scenarios

| Annual Energy Consumption and System COP | CHPWH Baseline | | CHPWH + PCM Storage | |
|---|---|---|---|---|
| | San Francisco | Lake Tahoe | San Francisco | Lake Tahoe |
| System COP | 2.57 | 2.54 | 2.16 | 1.93 |
| Peak Energy Use (kWh) | 6,178 | 8,027 | 0 | 0 |
| Partial Peak Energy Use (kWh) | 3,149 | 3,840 | 0 | 0 |
| Off Peak Energy Use (kWh) | 21,297 | 23,796 | 34,467 | 38,750 |
| Annual Energy Use (kWh) | 30,623 | 35,662 | 34,467 | 38,750 |

### OPERATIONAL COST IMPACTS

Cost savings for the boiler scenarios are calculated assuming a natural gas rate of $22.22/McF (dollars per thousand cubic feet) and a conversion factor of 1.038 (U.S. Energy Information Administration 2024, U.S. Energy Information Administration 2025). Based on energy consumption and savings (see Table 11), the proposed PCM system has the potential to save $530 annually.

Table 11: Estimated operational cost and cost savings of boiler baseline and proposed PCM scenarios

| Annual Cost | Boiler Baseline | Boiler + PCM Storage | Savings |
|---|---|---|---|
| Annual energy cost | $6,925 | $6,394 | $530 |

High energy costs for California rate payers emphasize the importance of ensuring that energy-saving measures are utilized to their full potential. Energy modeling has illustrated the effects of installed location, climate, and HVAC interactions on the energy savings achieved with TESS PCM.

With TOU electricity rates available through some California utility providers, customers can choose how they are billed for electricity usage. This enables residents and/or building owners to leverage cheaper energy during defined off-peak periods and reduce usage during peak periods, which provides additional system-wide benefits to grid operators. In multifamily buildings with central DHW systems, building owners are most often responsible for paying the utility bills associated with the central DHW system. They can leverage TOU rates for additional operational cost savings related to load shifting. Table 13 shows theoretical cost savings for customers with both low-capacity HPWH with large storage capacity and high-capacity HPWH with lower storage capacity installing a TESS PCM system.

The table below presents Peninsula Clean Energy's (PCE) TOU rates (Penninsula Clean Energy 2025) used to calculate customer cost savings for the CHPWH scenarios.  While Liberty Utilities, the electric utility serving the Lake Tahoe region, has its own TOU rate structure, the on-peak and off-peak periods differ significantly from the PCE on-peak and off-peak periods, so PCE TOU rates were used to assess energy cost savings for both regions.

**Table 12: Time of use rate structures for San Francisco and Lake Tahoe locations**

| TOU Rate | Start Time (24 hour) | Stop Time (24 hour) | PCE TOU Rate[17] ($/kWh) |
|---|---|---|---|
| Summer On-Peak | 16:00 | 21:00 | 0.55731 |
| Summer Part-Peak 1 | 15:00 | 15:59 | 0.369 |
| Summer Part-Peak2 | 21:01 | 0:00 | 0.369 |
| Summer Off-Peak | 0:01 | 14:59 | 0.28331 |
| Winter On-Peak | 16:00 | 21:00 | 0.24926 |
| Winter Part-Peak 1 | 15:00 | 15:59 | 0.21132 |
| Winter Part-Peak 2 | 21:01 | 0:00 | 0.21132 |
| Winter Off-Peak | 0:01 | 14:59 | 0.18595 |

The table below presents the findings on electric energy cost savings based on a time-of-use rate and a fixed rate. While total annual energy consumption increased in the proposed PCM scenarios, the enabling of load shifting led to small but positive energy cost savings on a TOU rate. As expected, the fixed rate savings are negative with the increased electric use.

[17] Includes PG&E surcharges and generation rates

Table 13: Estimated operational cost savings of CHPWH baseline and proposed PCM scenarios

| Annual Electric Costs | San Francisco | Lake Tahoe |
|---|---|---|
| TOU Rate Savings | $160.55 | $380.83 |
| Fixed Rate Savings | -$1,064.59 | -$813.59 |

### FIRST COST IMPACTS

The project team collaborated with project partners at Dynamic $H_2O$ to size the central plant and estimate the first costs of the baseline and proposed scenarios. The estimates below reflect material costs only and do not include labor associated with the proposed distributed PCM system. To evaluate the added cost of distributed PCM TESS, the MSRP of unit was used.  Additional components required for optimization, such as additional ball valves, Y-strainers, expansion tanks, residential mixing valves, T&P valves, check valves, and unions, were also included in the cost estimate.

For the boiler baseline and proposed PCM scenario, the central plant was sized based on the average daily DHW load and target runtime. Oversized boilers, particularly in systems with variable or lower-than-expected demand, are prone to short-cycling—frequent on-off cycling that can reduce equipment lifespan, increase maintenance needs, and lower overall efficiency. Table 14 presents the central plant size and estimated first costs (excluding labor) for the baseline and proposed scenarios. The estimated costs of the baseline scenario include replacing the existing boiler with a like-kind boiler. The estimated costs of the boiler with distributed PCM storage include replacing the boiler with like-kind, plus the additional cost of the distributed PCM modules and components. It is most likely that the existing central storage will remain, so the cost of central storage is not included in either the boiler baseline or PCM scenarios. The incremental cost is estimated to be $30,400.

Table 14: Sizing and estimated first costs for boiler baseline and proposed PCM scenarios

| | Boiler Baseline | Boiler + PCM Storage |
|---|---|---|
| Water Heater Capacity (kBTU/hr) | 150 | 150 |
| Storage Volume Required (gal) | 200 | 200 |
| Distributed PCM Storage (equivalent gal) | N/A | 400 |
| Distributed PCM Electric Element (kW) | N/A | 18.3 |
| Equipment Cost ($) | $18,400 | $48,800 |

The project team relied on the system energy modeling and Ecotope's EcoSim modeling tool to understand the central plant system dynamics and sizing trade-offs. The figures below demonstrate the trade-off between heat pump capacity and central storage volume based on a set charging loop schedule. For simplicity, the heat pump output in the figures is treated as constant; however, in reality, the heat pump output will vary with outdoor temperature conditions. The first figure indicates that significantly more storage is necessary with a smaller capacity heat pump. The second figure indicates a higher-capacity heat pump that runs concurrently with the charging loop and requires significantly less storage at the central plant.

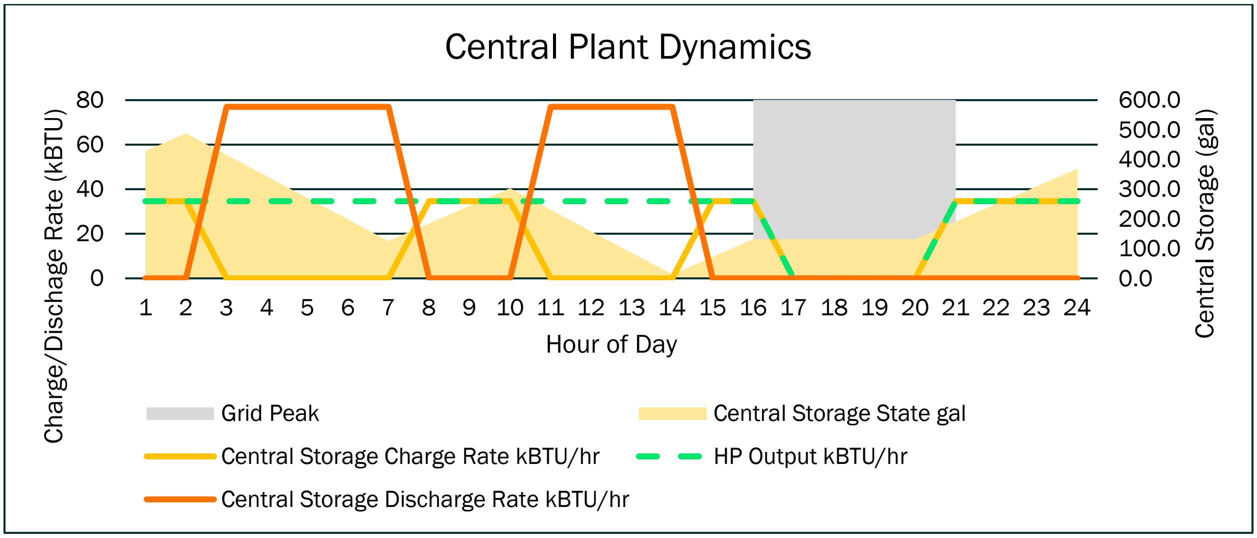



**Figure 12: Central hot water storage based on 34.6 kBTU/hr heat pump and PCM charging rate**

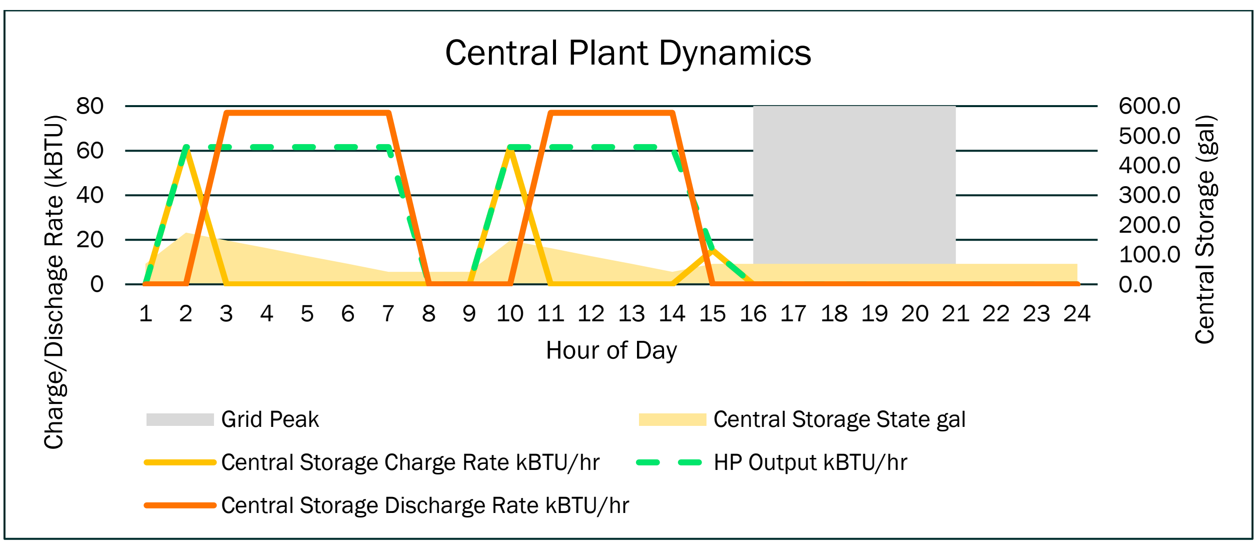


**Figure 13: Central hot water storage based on a 62.2 kBTU/hr heat pump and PCM charging rate.**

Ecotope's EcoSizer tool was used to size the CHPWH Baseline scenarios, and the system engineering model developed for this project was used to size the CHPWH in the proposed PCM scenario. Central plant sizing and estimated first costs are presented in Table 15 below.

Three baseline scenario options are presented in Table 15 below to demonstrate the trade-off between heat pump capacity and central storage needs with and without load shifting capability. Baseline Option 1 has a lower capacity heat pump (61.6 kBTU/hr) with greater central storage (350 gal), while Baseline Option 2 has a higher capacity heat pump (92.4 kBTU/hr) with less central storage (180 gal) required. Neither option is sized for load shifting, while Baseline Option 3 demonstrates the central storage volume necessary (550 gal) to shift the heat pump load outside of grid peak times. The CHPWH in the proposed PCM scenario was optimally sized to meet the DHW load, shift energy use outside of the grid peak, and reduce central storage or buffer tank volume. In this scenario, the majority of the storage (480 gal) is distributed throughout the building as PCM TESS with a small buffer tank at the central plant.

**Table 15: Sizing and estimated first costs for CHPWH baseline and proposed PCM scenarios**

| | CHPWH Baseline - Option 1 | CHPWH Baseline - Option 2 | CHPWH Baseline - Option 3 | CHPWH + PCM Storage |
|---|---|---|---|---|
| Load shift capable? | No | No | Yes | Yes |
| Heating Capacity (kBTU/hr) | 61.6 | 92.4 | 92.4 | 61.6 |
| Central Storage Volume (gal) | 350 | 180 | 550 | 180 |
| Swing Tank Volume (gal) | 40 | 40 | 40 | N/A |
| Swing Tank Electric Capacity (kW) | 6 | 6 | 6 | N/A |
| Distributed PCM Storage (equivalent gal) | N/A | N/A | N/A | 480 |
| Distributed PCM Electric Element (kW) | N/A | N/A | N/A | 18.3 |
| Equipment Cost ($) | $67,00 | $85,500 | $89,700 | $86,000 |

Results indicate variability in the first cost of the baseline systems based on heat pump capacity, central storage volume, swing tank volume and capacity, and load shifting capability. Baseline Option 1, with a lower capacity heat pump and greater storage, is the lowest first-cost option. However, this option is incapable of load shifting, and the central storage requirements may pose a challenge for existing buildings with space-constrained mechanical rooms. Baseline Option 3 requires more (200 gal more) storage at the central plant and a higher capacity heat pump to shift load effectively. The proposed system with distributed PCM is comparable in first cost to baseline Option 3. While there is an added cost from the distributed PCM TESS, the CHPWH capacity and the central storage volume can be reduced.

#### TOTAL SYSTEM BENEFIT & AVOIDED GHG EMISSIONS

Since 2024, the CPUC requires that all energy efficiency measures use Total System Benefits (TSB) as the primary metric to track program performance, rather than conventional energy savings metrics, which do not directly represent system-wide impacts. The calculation of TSB considers many factors, and specific cost values are assigned to every hour of every month in which avoided costs are expected to occur. This can vary seasonally and daily, where specific periods provide more benefits than others. Factors that affect TSB include avoided costs associated with generation, transmission, distribution, gas infrastructure, building vintage, end use, utility service territories, climate zone, and GHG emissions. (CPUC 2021)

Using the CPUC Avoided Cost Calculator, hourly system-wide energy costs were determined and analyzed for the Lake Tahoe and San Francisco locations. These costs were then applied to hourly energy savings estimates from Baseline Option 1 to calculate theoretical system benefits associated with the proposed distributed PCM system in the 28-unit example building. GHG emissions were also estimated using the avoided cost calculator.

**Table 16: GHG Emissions and Total System Benefits**

| Evaluation Metric | San Francisco | Lake Tahoe |
|---|---|---|
| Total System Benefits (USD) | $604.70 | $737.45 |
| GHG Savings (metric tons) | -0.04 MT | 0.80 MT |

*2024 Avoided cost calculator v1b inputs include PG&E as the utility for 2026, climate zones 16 (Lake Tahoe) and 3a (San Francisco). Source: CPUC 2024 ACC Electric Model v1b

Table 16 above presents TSB and GHG savings. While the modeling resulted in greater total annual energy consumption in the proposed PCM scenario, results indicate positive TSB for both locations, demonstrating the larger benefits of shifting load outside of peak utility times.

### Summary of System Evaluation

- Analysis and energy modeling confirmed opportunities in some applications for energy and cost reductions and optimized operation of existing recirculation systems and CHPWHs.
- The central heating system's delivery capacity and the specific PCM material define the optimal and maximum operational recharge temperature. PCM manufacturers provide operational ranges and maximum supply temperatures in their technical specifications.

- The timing of the recharge recirculation can be set to optimize the efficiency of the central heating system, storage capacity, TOU rates, and water usage patterns. The time it takes to charge the PCM modules is limited by three factors: 1) the supply temperature to the PCM, 2) the flow through the PCM modules, and 3) the heat transfer efficiency.

- The charging loop flow rate and subsequent PCM charging time are limited by the size of the recirculation piping in a retrofit application. In a new construction application, the recirculation piping design can be optimized to maximize recirculation operation and heat delivery reduction. The proposed distributed PCM system design may be better suited for new construction applications where the size of the recirculation piping is not a limiting factor.

- Energy savings depend on the existing recirculation losses. Energy savings from reducing charging loop runtimes can be negated by the increased losses associated with the higher supply temperatures required by the P58 PCM material. Existing buildings with high recirculation losses are not good candidates for the proposed distributed PCM system prior to intervention to reduce recirculation losses. Improvements in PCM technology (e.g., PCM materials with lower melting points) may lead to wider application to buildings with high existing heat loss.

- Retrofitting existing boiler systems with the proposed PCM design has the potential to save $530 annually, reducing system energy consumption and costs by 8% in buildings with medium existing recirculation losses. Energy and cost savings for CHPWH applications depend upon the climate zone, CHPWH efficiency, and the electric utility rate structure. The CHPWH + PCM Storage scenario's energy consumption is greater than that of the baseline scenarios due to decreased CHPWH efficiency at the higher supply temperature and lower delta T between the supply and return temperatures. However, even with an overall increase in energy consumption, the ability to shift load outside of peak grid times demonstrates small cost savings ranging from $180 to $360 with a TOU rate plan.

- Adding distributed PCM storage to a central boiler plant adds an estimated $30,000 in incremental first costs. However, for CHPWH upgrades, the estimated first costs of the proposed PCM system are on par with the estimated first costs of a CHPWH upgrade capable of load shifting. This is due to reduced CHPWH heating capacity and central storage volume requirements.

- The current state of PCM TESS and CHPWH technology creates challenges for optimized distributed PCM system designs. The high melting point temperature of the most common PCM material requires high supply water temperatures, leading to increased rates of heat loss through distribution piping. Higher rates of heat loss negate the benefits of reducing recirculation or charging loop run times, particularly for buildings with high existing recirculation losses. One manufacturer interviewed through this project does offer PCM material that melts at 48°C or 118°F. Using PCM TESS with this lower-melting-point material may address some of the challenges of the more common P58 material.

- Additionally, the distributed PCM design application is limited by the maximum supply temperature and lower COP of commercially available heat pump models in the US at the high supply and return water temperatures associated with the design. Although, we are starting to see new heat pump technology come to market that can efficiently produce high supply water temperatures (160°F-170°F) with a small delta T. As technology continues to evolve and more equipment becomes available that can efficiently produce higher supply water temperature at a lower delta T, opportunities for the distributed PCM system will expand.

- The volume of central storage required to load shift in a typical CHPWH system design can often pose challenges for existing buildings with space-constrained mechanical rooms. The proposed distributed PCM system design addresses these issues by repurposing distribution and recirculation piping into a PCM charging loop, eliminating the need for swing tanks and reducing central storage volume needed to load shift from 550 gallons to 180 gallons, or 67%. This is significant, as a 200-gallon insulated storage tank is roughly 34 inches wide by 77 inches tall (Rheem 2025) and requires a minimum of 8 square feet of floor space, not including necessary clearances. While additional storage is added through distributed PCM TES, the energy density and compact form factor of the PCM TES allows for flexibility in install location (i.e. mounting it on a shelf in a closet). The proposed design eliminates the need for two additional storage tanks of this size, enabling electrification of DHW for buildings with space-constrained mechanical rooms. Energy modeling showed that the proposed system results in modest energy savings for buildings without significant existing heat loss and estimated first costs that are on par with CHPWH upgrades sized for load shifting.
- The project team developed a design that accommodates two scenarios: 1) a PCM located within an individual unit, serving only that unit, and 2) a PCM installed in a corridor utility closet, serving multiple units. Each approach has benefits and drawbacks, and the choice is highly dependent on the building layout and available space for PCM installation. From a first-cost and installation perspective, a shared PCM system is generally more cost-effective. It reduces the overall number of PCM modules and associated expenses, minimizes the number of plumbing components, lowers labor hours and costs, and limits tenant disruptions. However, shared systems will require more complex piping configurations. Conversely, in-unit PCMs may be preferable when each unit has a single take-off from the main hot water loop that can be easily intercepted.

Buildings best suited for the proposed distributed PCM system design typically have space-constrained mechanical rooms that cannot accommodate the large central storage tanks required for load shifting. Performance of the distributed PCM system depends on the existing system's level of recirculation losses. The proposed system performs optimally in buildings with medium or low recirculation losses, as high recirculation losses lead to increased energy consumption when the distributed PCM system is implemented. Additionally, buildings best suited for the proposed system will have utility closets where PCM thermal energy storage modules can be installed throughout the facility. Or locations within apartments units where a PCM module can be wall-mounted or placed on a shelf.

## Recommendations for PCM TESS Advancement

This report concludes with actionable recommendations for manufacturers, program implementers, and policymakers to support broader adoption of PCM TESS technologies. Technical findings, stakeholder feedback, and market analysis inform these recommendations. The project team also developed a strategic roadmap for PCM market development, which is included in Appendix H.

1. **Improve Compatibility Between PCM and Heat Pump Technologies**
   ***Audience: Manufacturers, Technology Developers***
   PCM-based technologies can enhance the performance of HPWHs by enabling distributed thermal storage, reducing the need for large central tanks, and supporting electrification and load management in multifamily buildings. Current PCM materials, such as P58, have high melting points that require elevated supply temperatures. These temperatures are often incompatible with existing HPWH technologies, which operate most efficiently with large temperature differentials and lower return water temperatures. Manufacturers should invest in developing PCM materials with lower melting points to improve compatibility with current HPWH systems, including $CO_2$-based and emerging propane air-to-water heat pumps. Collaborative R&D efforts should focus on validating PCM-HPWH integration through lab testing and field demonstrations to support future product development and inclusion in incentive programs.

2. **Conduct a statewide field study comparing DHW recirculation system performance in HTR/DAC and non-DAC multifamily buildings**
   ***Audience: Program Administrators, Researchers, Policymakers***
   DACs and HTR populations often reside in older multifamily buildings with aging infrastructure, inefficient recirculation systems, and limited access to retrofit opportunities. These conditions can lead to disproportionately high energy losses, elevated utility costs, and inconsistent hot water delivery—factors that directly impact tenant comfort, affordability, and health. While prior studies have documented heat loss in multifamily buildings, none have systematically compared the performance of DAC buildings with that of non-DAC buildings. A statewide metered field study is needed to fill this gap and inform equitable program design. This study should:
   - Quantify differences in recirculation heat loss, pump operation, and system efficiency across building types and community contexts.
   - Evaluate how building layout, style, age, and envelope condition influence heat loss and retrofit feasibility.

3. **Promote PCM TESS as a Space-Saving Solution for Multifamily Retrofits**
   ***Audience: Manufacturers, Designers, Program Implementers***
   PCM modules offer high energy density in compact forms, enabling the downsizing of central storage and reclaiming usable space—addressing one of the most significant barriers to CHPWH retrofits in multifamily buildings. Many multifamily buildings, especially older ones, have limited mechanical room space and structural constraints, making it challenging to install the large central storage tanks required by conventional CHPWH systems. These constraints often prevent electrification upgrades, even when funding and incentives are available.

4. **Invest in workforce engagement and training to support innovative system design**
   ***Audience: Manufacturers, Workforce Development Agencies, Trade Associations, and Program Implementers***
   The proposed distributed PCM system design fundamentally reimagines central DHW recirculation systems by transforming them into recharging loops. This shift introduces new design principles, installation practices, and operational requirements that differ significantly from conventional water heating systems. To ensure successful deployment, manufacturers should actively engage with workforce development agencies, trade associations, and program implementers to build awareness and technical capacity across the industry. Training efforts should focus on the benefits of PCM distribution—including space savings, load shifting, and improved system efficiency—and provide hands-on guidance for installing and maintaining these novel systems. Because this design represents a departure from traditional DHW configurations, early and ongoing engagement with contractors, designers, and installers is essential.
   Workforce Development Agencies, Trade Associations, and Program Implementers should also continue monitoring technological developments and share updates to ensure alignment with evolving best practices and equipment capabilities. By investing in workforce education and collaboration, manufacturers can accelerate market readiness, reduce installation barriers, and support the long-term success of PCM in California's multifamily sector.

5. **Integrate PCM into California Incentive Programs**
   ***Audience: Manufacturers, Program Administrators***
   PCM integrated systems offer a compelling solution for California's decarbonization goals. However, as many of these products are new to the US, they do not meet all requirements for inclusion in California incentive programs, which limits visibility, affordability, and market adoption.
   - Manufacturers of in-unit PCM systems should integrate the CTA-2045 communication protocol to enable participation in load-shifting programs like WatterSaver.
   - For central distribution systems, collaboration with modelers is needed to integrate PCM into tools like Open Studio, which qualifies technologies for incentive programs. Inclusion in programs such as TECH Clean California would reduce first costs and accelerate market adoption.

## References


n.d. *A.O. Smith Signature 100 28-Gallons Lowboy Electric Water Heater.* Accessed November 1, 2025. https://www.lowes.com/pd/A-O-Smith-Signature-28-Gallon-Lowboy-6-year-Limited-4500-Watt-Double-Element-Electric-Water-Heater/1000216777?msockid=286c2e3ae5e2647c1a473b90e41c65c3.

n.d. *A.O. Smith Signature Series Tankless Electric Water Heater.* Accessed November 1, 2025. https://www.lowes.com/pd/A-O-Smith-Signature-240-Volt-32-kW-2-8-GPM-Tankless-Electric-Water-Heater/1000601629.

n.d. *Advanced Water Heating Initiative.* Accessed August 2025. https://newbuildings.org/nbi-key-markets/advanced-water-heating-initiative/.

ASHRAE. 2023. "ASHRAE Handbook of Fundamentals—HVAC Applications."

Association for Energy Affordability (AEA). n.d. *Central Heat Pump Water Heater Monitoring for Multifamily Properties Part 2.* TECH Clean California. https://techcleanca.com/pilots/multi-family-pilot/.

n.d. *Bay Area Air District Clean Air For All.* Vers. Rules & Compliance Rule Development. Accessed October 10, 2025. https://www.baaqmd.gov/rules-and-compliance/rule-development/building-appliances.

Bay Area Air Quality Management District. n.d. *Building Appliances Rule Implementation.* Accessed August 7, 2025. https://www.baaqmd.gov/rules-and-compliance/rule-development/building-appliances.

Cadeo. n.d. "Domestic Hot Water Recirculation." *ACEEE Hot Water Forum.* https://www.aceee.org/sites/default/files/pdf/conferences/hwf/2019/4b-baker.pdf.

Caleffi Hydronics Solutions. 2017. "Recirculating Domestic Hot Water Systems." *Idronics.* July. Accessed 2025.

n.d. *California Air Resources Board.* Accessed October 9, 2025. https://ww2.arb.ca.gov/our-work/programs/zero-emission-space-and-water-heater-standards.

California Legislative Information. n.d. "California Law Code Section." Accessed 2025. https://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=CIV&sectionNum=1941.1.

California Measurement Advisory Council. 2025. *CALMAC California Waether Files.* 10 08. Accessed 10 08, 2025. https://www.calmac.org/weather.asp.

n.d. *CalNEXT.* Accessed 10 18, 2023. https://calnext.com/.

CEC. 2025. "CBECC-Res Compliance Software Project."

n.d. *cowa Heat Storage Pioneers.* https://www.cowa-ts.com/en/.

CPUC. 2021. "California Public Utilities Commission." https://www.cpuc.ca.gov/.

Daher, Mazen, Agatha Kazden, Siva Sankaranarayanan, Merry Sweeney, and Tim Kohut. 2024. "Electrification of Centralized Water Heating in an Affordable Housing Community: Lessons Learned from a Pilot Demonstration."

Ecotope. 2023. *Central Heat Pump Water Heater Design Guide: Solutions and Tools for Designing Central Heat Pump Water Heater Systems in Multifamily and Other Commercial Buildings.* Energy Trust of Oregon. Accessed 2025. https://www.energytrust.org/fact-sheets/new-buildings-design-guide-for-central-heat-pump-water-heaters/.

ESTCP. 2019. "Phasestor Latent Energy Storage System."

n.d. *eSTOR the World's Most Advanced Thermal Energy Battery.* Accessed September 12,

2025. https://phasestor.com/products/estor/.
Green, Evan, and Jonathan Heller. 2022. *Domestic Hot Water Distribution .* Bonneville Power Administration.
Heller, Jonathan, and Shawn Oram. 2015. *RCC Pilot Project: Multifamily Heat Pump Water Heaters in Below Grade Parking Garages in the Pacific Northwest.* Ecotope, Inc.
Helmns, Dre, David Blum, Armando Casillas, Anand Prakash, Jonathan Woolley, David Vernon, Caton Mande, Michael Woodcox, and Spencer M Dutton. 2021. *Towards a Techno-Economic Analysis of PCMIntegrated Hybrid HVAC Systems.* Conference Paper, West Lafayette: Lawrence Berkeley National Laboratory.
n.d. *Htec MEDUSA PCM Integrated Heat Pump.* https://htecpackagedsystems.com/medusa-heat-pump.
n.d. *INSOLCORP Thermal Energy Storage Systems (TES).* https://insolcorp.com/thermal-energy-storage/.
Khanolkar, Amruta, Mischa Egolf, and Noah Gabriel. 2023. *Statewide 120-Volt Heat Pump Water Heater Field Study.* New Buildings Institute, TECH Clean California. https://techcleanca.com/quick-start-grants/2021-quick-start-grant-recipients/new-buildings-institute/.
Kitner, P, and B Larson. 2019. "Literature Review of Multifamily Central DHW Distribution Losses."
Kruis, Neal, Bruce Wilcox, Jim Lutz, and Chip Barnaby. 2019. "Development of Realistic Water Draw Profiles for California Residential Water."
Lawrence Berkeley National Laboratory, Emanant Systems, LLC, Western Cooling Efficiency Center, and NestWorks LLC. 2021. "Towards a Techno-Economic Analysis of PCMIntegrated Hybrid HVAC Systems."
n.d. *LG Energy Solution RESU10H Prime.* Accessed December 1, 2025. https://www.lghomebattery.com.au/resu10hprime.
National Renewable Energy Laboratory. 2024. *NREL ResStock.* March. Accessed July 30, 2025. https://resstock.nrel.gov/.
New Buildings Institute. 2025. "Central Heat Pump Water Heater Market Research (2023-2025)."
NY/E Water Heating Systems. 2025. *Using Phase Change Material as Thermal Energy Storage to Simplify Heat Pump Water Heating.* May 12. Accessed August 2025. https://heatwater.com/phase-change-material-for-water-heating/.
n.d. *nyle water heating systems Introducing: Pyroclast™ Integrated Heat Pump Water Heater.* https://heatwater.com/pyroclast/.
Omaghomi, Tortseju, Steven Buchberger, Timothy Wolfe, Jason Hewitt, and Daniel Cole. 2024. *Peak Water Demand Study.* IAPMO.
Paine, Mabell Garcia. n.d. "Viridis Consulting with Heather Village." *2022 Quick Start Grant Recipients.* https://techcleanca.com/quick-start-grants/2022-qsg-recipients/viridis-consulting-heather-village/.
Rheem. 2025. "Large Volume Storage Tank - Jacketed - Specification Sheet." *Rheem.* March. Accessed December 2025. https://www.rheem.com/product/rheem-large-volume-storage-tank-jacketed-st200a/related-documents/285340/.
n.d. "Self-Generation Incentive Program." *Verified Equipment Lists, Publication of Equipment Review Process.* Accessed October 10, 2025. https://www.selfgenca.com/home/resources/.
Small Planet Supply. 2023. "Packaged Central Heat Pump Boiler Project."

Sunamp. n.d. "Lowering energy use and emissions in a multifamily building in Troy New York, a NYSERDA Project." *Case Studies.* Accessed October 2025. https://sunamp.com/case-studies/cutting-gas-in-a-multifamily-apartment-building-in-troy-new-york-nyserda-project/.

n.d. *Tesla Powerwall - Home Battery Storage.* Accessed December 1, 2025. https://www.tesla.com/powerwall.

n.d. *Tesla Powerwall3.* Accessed December 1, 2025. on https://www.tesla.com/powerwall/design.

n.d. *Thermino.* Accessed July 1, 2025. https://sunamp.com/en-us/products/thermino/.

TRC. 2024. "Field Study of Master Mixing Valve Energy Efficiency Potential ."

U.S. Energy Information Administration . 2020. *US EIA RECS.* Accessed August 4, 2025. https://www.eia.gov/consumption/residential/.

U.S. Energy Information Administration. 2024. *Frequently Asked Questions (FAQs).* 05 15. Accessed 10 08, 2025. https://www.eia.gov/tools/faqs/faq.php?id=45&t=8.

—. 2025. *Natural Gas Prices.* 09 30. Accessed 10 08, 2025. https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_m.htm.

VEIC. 2023. *CalNEXT Low Income Multifamily Housing Characteristics Study.* CalNEXT.

Walker, Iain. n.d. "Reduced Cost Heat Pump Space- And WaterHeating in Cold Climates ." *U.S. Department of Energy.* Accessed August 2025. https://www.energy.gov/sites/default/files/2023-06/bto-peer-2023-32261-redu-lbnl-walker.pdf.

WatterSaver. n.d. *Does My Water Heater Qualify?* Accessed October 14, 2025. https://www.watter-saver.com/equipment/.

Willner, Charlie, Jamie Hand, and Nathan Mascolino. 2024. "Delivery Efficiency Of Recirculated Domestic Hot Water Systems." *Better Buildings By Design.* Burlington, VT: Efficiency Vermont.

Zhang, Y. 2013. *MULTIFAMILY CENTRAL DOMESTIC HOT WATER DISTRIBUTION SYSTEMS.* California Energy Commission.

Zhu, Dr. Yifang, Rachel Connolly, Dr. Yan Lin, Tomothy Mathews, and Zemin Wang. 2020. *Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California.* Department of Environmental Health Sciences, UCLA, Fielding School of Public Health. https://ucla.app.box.com/s/xyzt8jc1ixnetiv0269qe704wu0ihif7.

# Appendix A: CHPWH Considerations

Appendix B provides additional considerations for CHPWH systems, highlighting space, structural, and operational constraints that influence retrofit feasibility and inform the integration of distributed PCM thermal energy storage solutions.

**Building Constraints:** CHPWH systems typically require significantly more physical space than gas-fired boilers. Central storage tanks range from 120 to several thousand gallons, and installing multiple tanks in series is common to meet demand. These tanks are heavy, challenging to maneuver, require adequate clearance for access and maintenance, and represent considerable first cost. In retrofit scenarios, mechanical rooms often lack the space or structural capacity to accommodate these systems (Ecotope 2023). Stakeholders interviewed for this project confirmed that space limitations are a critical barrier. Retrofitting a gas-fired boiler system with a CHPWH often requires increased water storage capacity. The volume of storage scales with the number of units, meaning that larger buildings may face greater challenges in accommodating the physical footprint of thermal water storage. PCM TESS could play an important role in downsizing the required storage volume.  Developers are highly responsive to first-cost savings. The ability to reduce mechanical room size or reclaim closet space is a compelling non-energy benefit of PCM integration.

A recent project involving five multifamily buildings revealed that mechanical rooms originally intended for gas boilers could not accommodate CHPWH systems due to required setbacks from windows and pedestrian pathways. This highlighted the need for modular, flexible system designs (Small Planet Supply 2023).

Additionally, these systems require adequate electrical capacity and condensate drainage infrastructure, which may not be readily available in existing buildings (New Buildings Institute 2025).

**Outdoor Installation Requirements**: CHPWH components, including the compressor, evaporator coil, fan, and refrigerant circuit, are typically installed outdoors to extract heat from ambient air. In regions where outdoor ambient temperatures fall below freezing, these components must be placed in protected, semi-conditioned spaces that maintain temperatures above freezing to ensure reliable performance and prevent system damage. Regardless of climate, all systems must be shielded from rain, snow, wind, and debris, and are ideally located in semi-sheltered buffer spaces such as parking garages or alcoves. These spaces must also provide sufficient air volume and ventilation to support proper heat pump operation (Daher, et al. 2024).

Heat pump efficiency falls off as outdoor temperatures decrease. Heat pump performance is typically rated at 47°F, 17°F, and 5°F outdoor air temperature. Lower ambient temperatures decrease the heat available for transfer and defrost cycles can reduce capacity by up to 20%. Despite these limitations, cold-climate-optimized systems can still deliver high-temperature water at subfreezing conditions, albeit with reduced efficiency (New Buildings Institute 2025).

**Occupant Considerations:** CHPWH systems can generate noise levels comparable to an everyday conversation (54–62 dB), which may be disruptive in residential settings without sound mitigation.

**Building Owner Installation & Maintenance Concerns:** A 2023 California field study on integrated HPWHs (Khanolkar, Egolf and Gabriel 2023) recommended simpler, split-system designs to reduce installation complexity. PCM TESS has emerged as a promising alternative—either as a passive thermal storage module paired with a remote heat source or as a packaged solution for load shifting. Stakeholders emphasized the importance of systems that are easy to monitor and maintain, while expressing concerns about diagnosing failures and sourcing standardized replacement parts in a market with few manufacturers.

Building owners are increasingly aware of electrification goals, but stakeholders shared that they often lack experience with CHPWH systems. These systems can be perceived as complex and unfamiliar by building owners and operators, requiring significant support for successful adoption. PCM TESS may face even more hesitation as a nascent technology.

As with any new technology or implementation design, contractor and operator education will be essential for successful deployment and long-term performance. A stakeholder with multifamily water heating retrofit experience emphasized that operators may need consistent, long-term support from manufacturers or designers, especially in early demonstration and pilot projects. They recommended that the project lead continue to stay involved with the project long after installation and a focused team that would maintain the system, as the more people interact with the controls or logistics of the system, the more room for error there is.

# Appendix B: Common Recirculation Designs

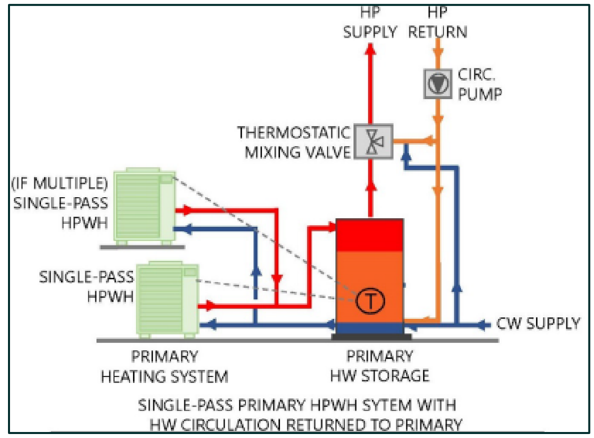



Figure 14: Single-pass primary CHPWH system with recirculation returned to primary (Green and Heller 2022).

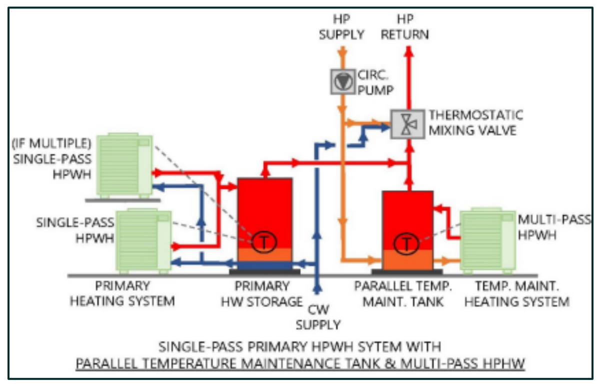



Figure 15: Single-pass primary CHPWH system with parallel temperature maintenance tank and multi-pass HPWH (Green and Heller 2022).[18]

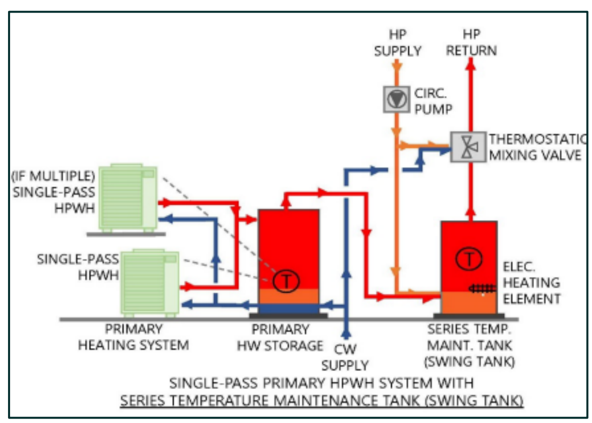



Figure 16: Single-pass primary CHPWH system with electric swing tank (Green and Heller 2022).

[18] Figures 14-16 are reference images from the 2022 Bonneville Power Authority emerging technology report "Domestic Hot Water Distribution Heat Loss". The project team believes the labels "HP SUPPLY" and "HP RETURN" have been accidentally swapped in Figures 15 and 16. Figure 14 shows the labels correctly.

# Appendix C: Review of Current Modeling Approaches

**Software and modeling tools applicable to DHW systems, including CHPWHs.**

**Table 17: Software and modeling tools applicable to DHW systems, including CHPWHs**

| Software/Tool | Description | Capabilities |
|---|---|---|
| **CBECC-Res** | Developed by the CEC, demonstrates compliance with California Residential Building Energy Standards, requires a software download | • Built-in HPWH model library<br>• User inputs for HPWH tank size and insulation R-value |
| **EcoSizer** | Developed by Ecotope, estimates sizing of central water heating systems based on commercial heat pump water heaters in multifamily and commercial buildings | • Option to use custom or built-in code/market research based peak gallons per day per person<br>• Calculates recirculation loop heat loss from flow rate and return temp<br>• Ability to add load shifting<br>• Fully online – no software download required |
| **EcoSim** | Developed by Ecotope, a standalone energy analysis tool focused specifically on multifamily commercial heat pump water heater systems | • Designed to run multiple models at once for comparison<br>• Built-in HPWH model library<br>• User inputs for tank size and insulation<br>• Detailed demand side inputs<br>• Outputs for energy loop segment pipe loss and net energy recirculation load |
| **OS-HPXML** | Developed by NREL, runs residential EnergyPlus simulations using an HPXML file for the building description | • User inputs for tank size and insulation<br>• Detailed demand side inputs<br>• Output for component load: internal gains which include water heater tank losses in the conditioned space |
| **OpenStudio** | Developed by NREL, a collection of software tools to support whole building analysis | • Any HPWH can be modeled if the user has the specs<br>• NREL developed scripts to simplify the modeling process<br>• User inputs for tank size, on/off parasitic heat fraction, and recovery time<br>• Outputs for water heat loss energy and rate<br>• Modelica can be integrated into model PCM |

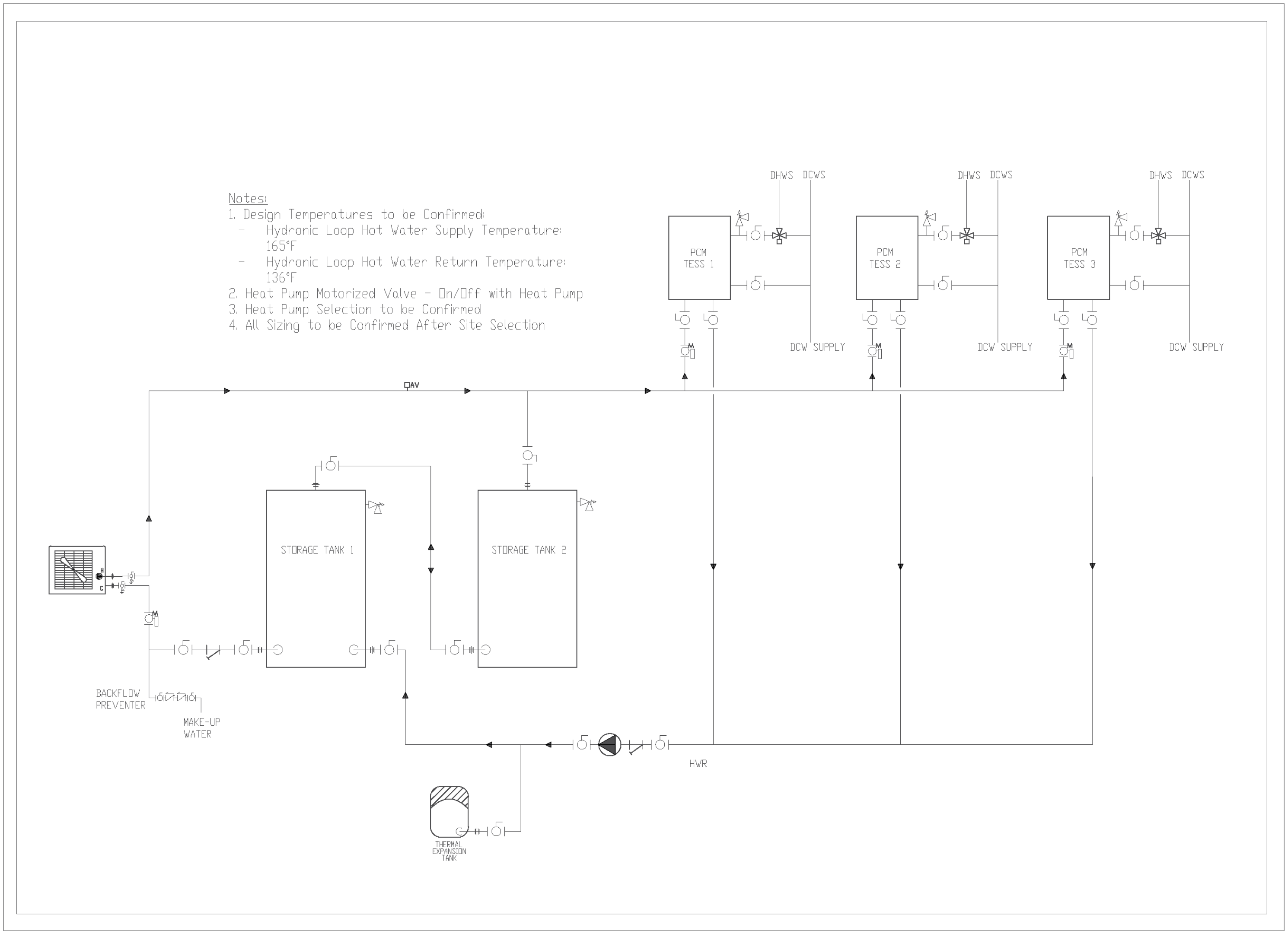
The CEC's CBECC-Res tool demonstrates compliance with the residential energy code. The tool includes modeling capabilities for modern heat pump water heaters in multifamily buildings. It can also be used to model demand response capabilities; however, this is currently only applicable to single-family homes or multifamily buildings with in-unit HPWHs, not central DHW systems. The tool includes a built-in library of heat pump models from which users can select. This feature simplifies user inputs and limits the equipment that can be modeled. The current CBECC-Res tool user manual does not include any information on PCMs.

Ecotope's EcoSizer tool can optimize heat pump and storage capacity for CHPWH systems. The online tool includes a sleek user interface where users can select from various system configurations, peak design loads, and load shifting capabilities. It also allows users to customize the input for expected recirculation heat losses. However, it does not currently include sizing for PCM TESS.

Ecotope's EcoSim tool can be used to analyze the energy consumption of CHPWH systems. EcoSim uses OpenStudio and Energy Plus as the primary simulation engines. Inputs for EcoSim are entered on several Excel spreadsheets, one defining the building characteristics and one defining the DHW system. The tool can model HPWHs, but like the CBECC tool, EcoSim also has a list of models for the user to choose from. EcoSim has an optional set of inputs that allows the user to define details of the system's demand side. EcoSim makes it easy to run multiple models at once, making it ideal for directly comparing systems. Some objects in the model can be auto sized, but that does not currently extend to HPWHs. A note in the user guide mentions that the EcoSizer methodology could be added to EcoSim in the future. There are outputs for net energy recirculation load, the hourly net energy loss of the recirculation loop, and Energy Loop Segment Pipes Loss, the annual sum of the recirculation loop energy losses. Currently, there is no ability to model PCM in EcoSim.

Developed by NREL, OS-HPXML is used to develop OpenStudio models for residential buildings. It has a highly detailed input list, allowing the user to specify the exact location of the water heater. The user can also select the equipment in the model, such as dishwashers, clothes washers, etc. Unlike EcoSim, OS-HPXML is not focused on a specific system and requires users to input details about general building information. One limitation of the tool is that it is designed to model single-family homes and individual units in multifamily buildings. Like the CBECC-Res tool, it cannot currently model central DHW systems in multifamily buildings.

# Appendix D: Final Engineering Drawings




VEIC | DynamicH2O | Whole Systems Energy Consulting

PROJECT

DHW HEAT PUMP PROJECT

NOT FOR CONSTRUCTION

DRAWING TITLE

Central Heat Pump with Distributed PCM

DATE

10/07/2025

SCALE

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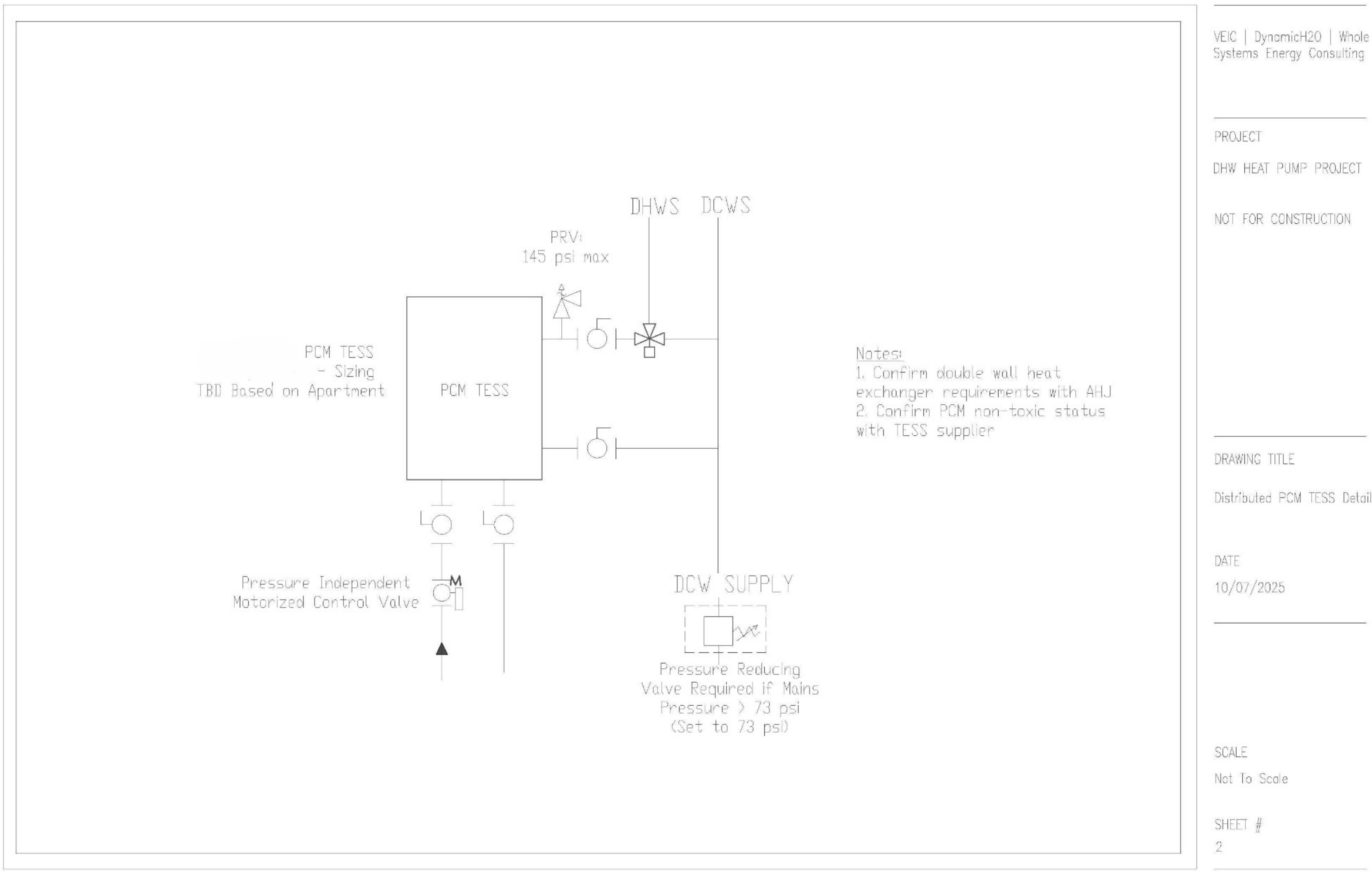
1


DHWS
DCWS
PRV:
145 psi max
PCM TESS
- Sizing
TBD Based on Apartment
PCM TESS
Notes:
1. Confirm double wall heat
exchanger requirements with AHJ
2. Confirm PCM non-toxic status
with TESS supplier
Pressure Independent
Motorized Control Valve
M
DCW SUPPLY
Pressure Reducing
Valve Required if Mains
Pressure > 73 psi
(Set to 73 psi)
VEIC | DynamicH2O | Whole
Systems Energy Consulting
PROJECT
DHW HEAT PUMP PROJECT
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Distributed PCM TESS Detail
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# Appendix E: DHW Loads and Load Profiles in Multifamily Buildings

**Table 18: Overview of source for DHW loads in multifamily buildings.**

| Source | Description | Average Hot Water Load |
|---|---|---|
| ASHRAE Handbook of Fundamentals, HVAC Applications, Chapter 51 Service Water Heating, Table 6 | Table 6 Hot-Water Demands for Various Types of Buildings, Apartment houses, 20-50 units | 40 gal/day/apartment |
| ASHRAE Handbook of Fundamentals, HVAC Applications, Chapter 51 Service Water Heating, Table 7 | Table 7 Hot-Water Demand and Use Guidelines for Apartment Buildings (Gallons per Person at 120°F Delivered to Fixtures), Medium Use, Average Daily | 30 gal/day/person |
| Ecotope Market Rate with Low Flow Fixtures | Based on measured data from an Ecotope Inc. project, 100+ unit building project. Data uses the 100% quantile for the peak draws during the given time periods.[19] | 25 gal/day/person |
| CA Title 24 CBECC-Res Software | Peak gallons per day calculated based on the expected 98th percentile of the specific combination of apartment sizes & occupancy rates | Varied – based on a combination of number of apartments, apartment sizes, and occupancy rates |
| CA eTRM | | 39 gal/day/apartment |
| IAPMO Water Demand Calculator | Adopted into the 2022 California Plumbing Code (CPC) as Appendix M. Offers an alternative method for size peak water demand in residential applications. | Varied – based on probabilistic functions of peak hour water use and fixture use and flow rates (Omaghomi, et al. 2024). |

[19] https://ecosizer.ecotope.com/sizer/

Figure 17 and Figure 18 show the average daily load profiles from ASHRAE HVAC Applications Chapter 51 and the average hot water profiles by occupancy used in the CBECC-Res software (Kruis, et al. 2019).

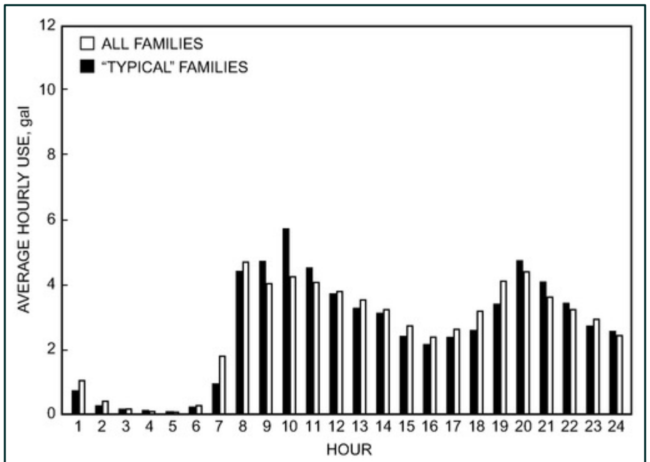


**Figure 14. Residential Average Hourly Hot-Water Use**

**Figure 17: Average daily load profile from ASHRAE HVAC Applications Chapter 51.**

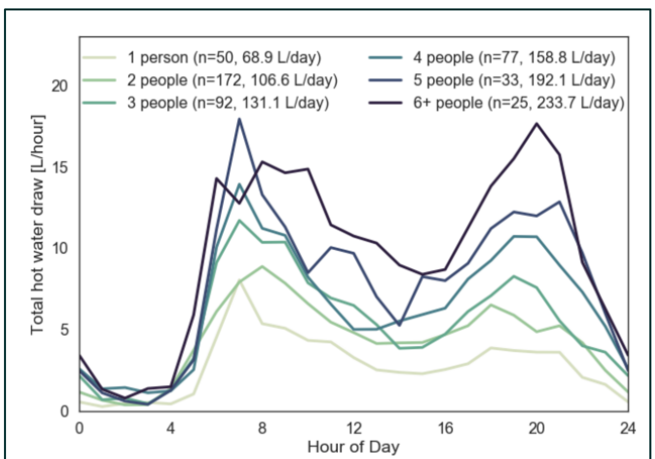


*Figure 4: Average hot water profile by occupancy level across all day types*

**Figure 18: Average hot water profile by occupancy level (Kruis, et al. 2019).**

# Appendix F: EcoSizer Results Report

ECOSIZER INPUTS https://ecosizer.ecotope.com

## Building Type
**Multifamily**

## Building Load
**49.6** People

## Apartments
**28** Units

## Daily Hot Water Usage
**32.1** Gallons per Day per Person

## Total Hot Water
**1,590.56** Gallons per Day

| | | |
|---|---|---|
| **Studio:** | **0.0** Units | **1.37** Occ. Rate |
| **1 Bed:** | **27.0** Units | **1.74** Occ. Rate |
| **2 Bed:** | **1.0** Units | **2.57** Occ. Rate |
| **3 Bed:** | **0.0** Units | **3.11** Occ. Rate |
| **4 Bed:** | **0.0** Units | **4.23** Occ. Rate |
| **5 Bed:** | **0.0** Units | **3.77** Occ. Rate |

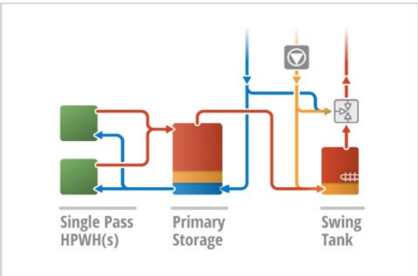
## Water Temperature

| Design Cold | Supply | Hot Storage |
|---|---|---|
| **50.0** °F | **120.0** °F | **150.0**°F |

## Advanced Options

| Aquastat Fraction | Drawdown |
|---|---|
| **40.0** % | **85.0** % |

Temperature Maintenance System:
Swing Tank




Recirculation Loop

**Heat Loss**
**100** Watts / Apt

**Temperature Maintenance System Safety Factor**
**1.75**

ECOSIZER RESULTS https://ecosizer.ecotope.com

### Primary Sizing Curve

This graph represents the trade off between storage volume and heating capacity. The Ecosizer method result is the green curve in the graph. The system sized from your inputs is the blue. Pick any point above the green curve to determine your system sizing.


### System Size

The selected minimum heating capacity shown below is the **minimum** needed average output capacity of the selected equipment at the design cold air temperature in your climate zone. Note that you must also account for manufacturer specific defrost penalty.

**Tank Volume**

**306.2** Gallons

**Heating Capacity**

**68.3** kBTU/hr

**Swing Tank Volume**

**40** Gallons

**Swing Resistance Element**

**4.9** kW · **16.7** kBTU/hr

**CA Title 24 Swing Tank Volume**

**80** Gallons

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# Appendix G: Roadmap

## Overview of PCM TESS Technology

Phase Change Material Thermal Energy Storage Systems (PCM TESS) offer compact, high-density thermal storage using latent heat. They enable load shifting, reduce equipment sizing, and support low-carbon heat sources—ideal for space- and grid-constrained multifamily buildings.
Key benefits include:

- Decouple heat generation from demand
- Reduce peak demand and utility costs
- Enhance system flexibility and performance
- Improve space efficiency and resiliency

**In-Unit Solutions**

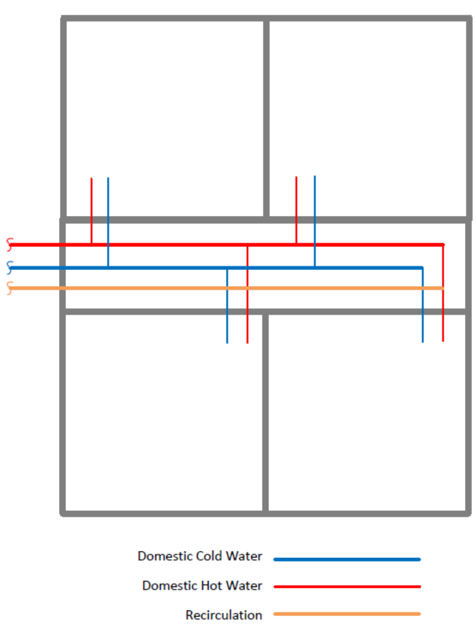
Compact, flexible PCM water heater- standalone electric or connected to another thermal source; resident-controlled.

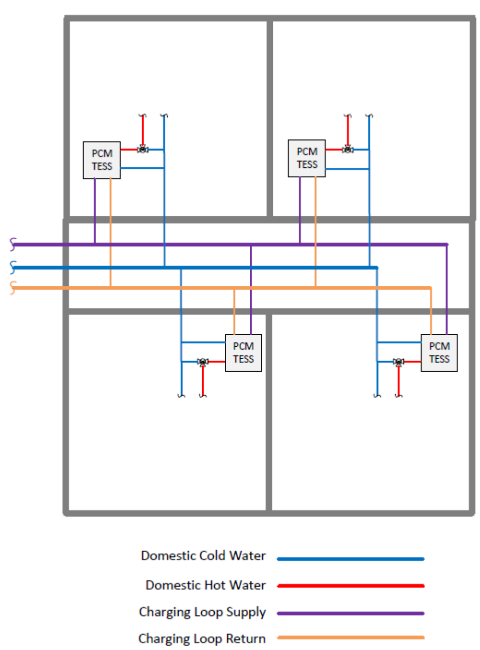
**Central DHW Solutions**

Space-saving, load shifting, central HPWH with integrated PCM storage; high-performance and retrofit-ready.

## Using Distributed PCM Thermal Energy Storage to Enable CHPWH Upgrades

PCM thermal energy storage distributed throughout a central DHW system offers a promising strategy to address the significant heat losses and several key barriers to central heat pump water heater (CHPWH) adoption. By decoupling the timing of heat generation from hot water demand, PCM TESS can enhance system flexibility, reduce equipment sizing, and improve performance in space and climate-constrained applications.



## Roadmap to Adoption

Following the CalNEXT PCM TESS market study and development of preliminary concept designs, the following steps are recommended to accelerate market adoption of PCM TESS integrated water heating.

1. **Improve Compatibility Between PCM and Heat Pump Technologies**
   ***Audience: Manufacturers, Technology Developers***
   Develop lower-melting-point PCM materials to align with HPWH operating ranges. Validate integration through lab and field testing to support product development and incentive eligibility.

2. **Conduct a statewide field study comparing DHW recirculation system performance in HTR/DAC and non-DAC multifamily buildings**
   ***Audience: Program Administrators, Researchers, Policymakers***
   Older multifamily buildings in DAC and HTR communities often have inefficient recirculation systems and limited retrofit options, leading to high energy losses, costs, and inconsistent hot water delivery. A statewide metered study is recommended to compare these buildings with non-DAC properties and assess how design and age affect heat loss and retrofit feasibility.

3. **Promote PCM TESS as a Space-Saving Solution for Multifamily Retrofits**
   ***Audience: Manufacturers, Designers, Program Implementers***
   Highlight PCM's compact form and high energy density to reduce central storage needs and enable electrification in buildings with limited mechanical space.

4. **Engage and Train the Workforce**
   ***Audience: Manufacturers, Workforce Development Agencies, Trade Associations, and Program Implementers***
   Educate contractors and designers on PCM system design, installation, and benefits. Build technical capacity through early engagement and hands-on training.

5. **Integrate PCM into California Incentive Programs**
   ***Audience: Manufacturers, Program Administrators***
   Ensure PCM systems meet program requirements by adding communication protocols (e.g., CTA-2045) and ensuring compatibility with modeling tools. Support inclusion in programs like TECH Clean California and WatterSaver.