Flexible Load Opportunities with Commercial Heat Pump Water Heaters

Results from Six Field Deployments of Load Shift Strategies

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ABSTRACT

Hot water loads represent a significant fraction of multifamily building end-use energy consumption, and their daily demand patterns align closely with utility peak load periods. Commercial heat pump water heaters (CHPWHs) offer a compelling opportunity to address this alignment: by leveraging large thermal storage volumes as distributed thermal batteries, these systems can shift energy consumption away from peak grid periods without disrupting occupant hot water service.

The project team has deployed, monitored, and analyzed load shift operations across more than a dozen CHPWH installations on the West Coast. The load shift priorities across these deployments range from peak demand reduction to time-of-use (TOU) energy cost reduction and greenhouse gas (GHG) emissions avoidance. This paper presents results measured results from projects with diverse priorities, configurations, and control strategies, and discusses the implications for load shift deployment for CHPWH systems.

Results demonstrate that swing tank CHPWH systems—configured with elevated storage temperatures, appropriately sized thermal storage, and properly implemented controls—can reliably eliminate peak-period energy consumption for multi-hour shed windows. The findings also highlight the critical role of robust monitoring and verification (M&V) in identifying control deficiencies, maintaining long-term performance, and informing ongoing program refinement. Challenges identified across the deployment portfolio—including electric resistance backup use, end-of-shed load spikes, communication reliability issues, and control sequencing errors—underscore the importance of standardized commissioning protocols and ongoing operational oversight.

Introduction

Hot water loads represent a significant fraction of multifamily end-use energy loads and drive building load peaks that directly align with typical utility load peaks. By implementing CHPWH systems with load shift controls, the project team has deployed and measured significant reductions in energy use for domestic hot water (DHW) at critical periods. However, the load shift opportunities and results for different types and configurations of HPWH vary substantially.

The team has been deploying, monitoring, or evaluating data from over a dozen grid-responsive CHPWH systems on the West Coast, using tools specifically built to guide sizing and monitoring of these systems. These deployments span a range of load shift priorities: peak demand reduction, time-of-use energy use reduction, and greenhouse gas emissions reduction.

The controls and configurations needed to achieve each of these priorities do not always align, and navigating these trade-offs is a key emerging challenge for the sector.

This paper presents measured field results from six projects with varying system configurations and control strategies. It discusses implications for system and control configurations that maximize load shift opportunities and potential utility savings under different rate structures. The results also suggest critical monitoring and verification strategies needed to maintain effective load management and highlight maintenance and operational approaches that produce more consistent load shift outcomes. The findings offer insight into successful deployment that can accelerate adoption of this technology as a grid resource.

Multifamily Hot Water Loads: Why This Sector is a Prime Target for Load Shift

Magnitude of DHW Loads in Multifamily Buildings

Domestic hot water production has one of the largest energy footprints of all residential end-uses in the United States. According to the U.S. Energy Information Administration, water heating accounts for approximately 32 percent of site energy consumption in multifamily buildings with five or more units nationwide (U.S. EIA, 2018). Across California multifamily buildings in the 2020 Residential Energy Consumption Survey, this figure rises to approximately 45 percent of total site energy use. These figures establish DHW as a high-impact end-use and make the multifamily sector a logical target for energy efficiency, decarbonization, and demand flexibility efforts.

The adoption of CHPWHs across the multifamily market is accelerating as building codes and electrification incentives drive the replacement of gas-fired systems and transition to more efficient electrical systems. This transition has the potential to add new electrical load to the grid when gas use is offset. Without integrated demand management, this additional load could exacerbate existing grid constraints, particularly during peak periods. By designing CHPWH systems with load shift controls from the outset, the market can ensure that electrification of DHW is beneficial—not burdensome—to grid operations (Farnsworth, Lazar and Shipley, 2019).

Potential Scale of Load Shift Deployment

The multifamily building stock in the United States contains millions of units currently served by gas or electric resistance water heating. As these systems reach end of life and are replaced with CHPWHs—and as building codes accelerate this transition in new construction—the aggregate load shift potential of the CHPWH fleet could become significant. Each CHPWH system effectively functions as a distributed thermal battery with multiple hours of load shift capacity, and the aggregate of these resources across a utility service territory represents a meaningful flexible load asset.

Online tools such as the Northwest Energy Efficiency Alliance Advanced Water Heating Specification (AWHS) Qualified Products List (QPL), Ecosizer, and the TECH Clean California Incentive Calculator provide mechanisms to estimate and quantify the load shift potential of individual systems and aggregate portfolios. These tools are critical for utilities seeking to understand the demand resource represented by the growing CHPWH fleet.

Daily Load Shape Characteristics

Multifamily DHW demand is characterized by pronounced morning and evening peaks that closely align with utility peak load periods. In typical market-rate multifamily buildings, hot water use spikes between 6–9 AM and again between 5–9 PM—exactly the periods when grid demand, energy costs, and marginal GHG emissions are typically highest. This alignment makes uncontrolled CHPWH systems a source of peak load amplification, but with load shift controls, the same systems can become a source of peak load reduction.

Notably, not all multifamily building types exhibit the same load shape. Senior housing buildings, for example, often show a single midday peak and a lower peak magnitude than typical market-rate buildings. Understanding the specific load shape of a given occupancy type is essential for designing effective load shift controls and estimating load shift potential (Spielman et al., 2023). This information can also guide prioritization of load shift deployment in multifamily buildings for the most impact.

Characteristics of CHPWH Systems

System Configurations

Commercial CHPWH systems are designed around several primary configurations. All load-shifting sites in the current deployment portfolio utilize the swing tank configuration, which is also the most prevalent in the broader CHPWH market. The swing tank design is defined in the NEEA Advanced Water Heating Specification (AWHS) and consists of a primary single-pass heat pump that heats cold incoming water to storage temperature, with a separate, smaller electric resistance or heat pump "swing tank" piped in series downstream to handle recirculation loop reheat. This arrangement allows the primary HPWH to operate on cold incoming water at maximum efficiency, without needing to continuously maintain recirculation loop temperature.

Most load-shifting sites in the portfolio use CO2 (R-744) refrigerant-based heat pumps, including the Mitsubishi HEAT2O (QAHV) and the Laars eTherm—the first US-manufactured CO2 CHPWH. One site uses the Nyle e360 with R-513a refrigerant in a swing tank configuration, demonstrating that the load shift approach is not limited to CO2 systems. Other configurations, including parallel loop tank and return-to-primary temperature maintenance systems, are deployed in the market and represent additional opportunities for load shift. Unitary systems—where individual heat pump water heaters serve single dwelling units or small clusters—are a growing market segment. (These systems represent load shift challenges not addressed in this analysis.) Because of their load diversity, flexible controls, and large thermal storage potential, central systems with large storage tanks offer significant load shift potential per unit of installed capacity.

There are three main types of CHPWH system configurations. All the projects discussed in this analysis are swing tank configurations.

Swing Tank Configuration

In the swing tank design, the primary heat pump heats cold incoming municipal water and returns it to the top of the primary storage tanks at target storage temperature (typically 150–180°F). Recirculation water is piped back to the swing tank, a separate, smaller tank in series with the primary storage. This facilitates the operation of the primary tank at a higher storage temperature without destratification and precludes the need for the primary HPWH to heat recirculation water directly. This design supports high-efficiency, high-temperature-lift operation of the primary HPWH and is well-suited for large thermal storage volumes. This configuration is shown in Figure 1 below.

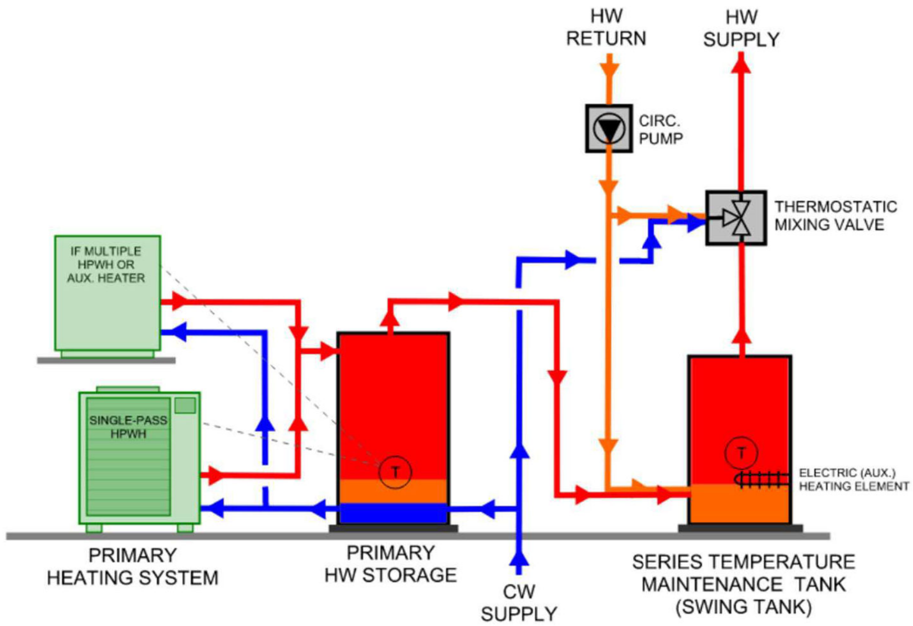

Figure 1: CHPWH System Swing Tank Configuration

Parallel Loop Tank

In the parallel loop tank configuration, recirculation return water is directed to a separate storage tank that operates in parallel with the primary storage, rather than in series. This system can provide similar load shift benefits to a swing tank configuration.

Return to Primary

In the return-to-primary configuration, recirculation return water is piped directly back to the primary storage tanks. This arrangement is simpler but requires the primary HPWH to handle recirculation reheat load directly. The project team has not deployed load shift in this configuration yet. Unitary systems are typically configured in this way.

System Characteristics That Support Load Shift

CHPWH systems are designed to operate 12–16 hours per day under normal conditions, relying on thermal storage to meet peak hot water demands without continuous operation. This inherent operating pattern creates a natural foundation for load shifting: the hours during which the system would normally operate can be shifted away from utility peak periods, and the thermal storage can be pre-charged during off-peak hours to supply hot water during the peak period.

The large thermal storage volumes typical of commercial CHPWH systems—ranging from several hundred to over a thousand gallons at the sites in this portfolio—are the primary enabler of multi-hour load shift windows. A well-designed system can store sufficient thermal energy during a pre-peak load-up period to supply a building's hot water demand for several hours without any HPWH operation.

Design Tools

Several tools support the design of load shift-capable CHPWH systems:

- •Ecosizer: A free online tool developed by the project team and funded by SCE, SMUD, and ORNL for sizing central CHPWH systems in multifamily and commercial buildings. This tool is widely used by designers and manufacturers. Ecosizer incorporates load shift sizing functionality, allowing designers to specify a load shift schedule and the percentage of days they want to fully shift.
- •AWHS Qualified Products List (QPL): The NEEA Advanced Water Heating Specification defines requirements for consistent, reliable CHPWH installations and maintains a QPL of products meeting performance thresholds. Version 8.2 of the AWHS will include methods for estimating load shift potential of QPL-listed products.
- •TECH Clean California Incentive Calculator: An online simulation tool that estimates annual GHG emissions reductions from CHPWH load shifting, used to qualify systems for the TECH Clean California incentive program.

Projects Referenced in this Analysis

The team has been deploying load shift controls in several multifamily projects to assess performance outcomes. The following six projects are referenced in this paper.

Site 1: Affordable Senior Housing Retrofit, Seattle, WA (Published)

The Bayview Tower project in Seattle, Washington, is the first US installation of a load shift-capable commercial CHPWH system. A 100-unit affordable senior housing high-rise, Bayview Tower retrofitted an aging electric resistance water heating system with a Mitsubishi HEAT2O (QAHV) CO2 heat pump in a swing tank configuration with 855 gallons of primary storage. The project was a collaboration between the project team, BPA, SkyCentrics, Seattle City Light, and Steffes (Spielman, 2022; Spielman et al., 2023).

Load shift controls were developed and refined over approximately 18 months of experimental testing. The project demonstrated that adjusting the active tank temperature sensor location (from middle to bottom for load-up, and from middle to top for shed) was the most significant contributor to load shift success, enabling the system to store maximum thermal energy before a peak period and coast for extended periods without HPWH operation. Results from the optimal summer control schedule demonstrated approximately 97% peak demand reduction during the 3-hour morning and evening shed windows.

The project also highlighted the importance of system commissioning and control refinement. Initial control schedules achieved only partial success with evening shed events, as high midday water usage depleted storage before the evening load-up period could be completed. Three control modifications—raising storage setpoint, increasing HPWH capacity during load-up, and extending the load-up window from 1 hour to 6–8 hours—were required to achieve consistent success with both morning and evening shed events.

Site 2: Supportive Housing, Sacramento, CA

This project is a 100-unit permanent supportive housing project located in South Sacramento, converted from a former hotel under California's HomeKey program. The project replaced the existing gas water heating system with a Laars eTherm CO2 CHPWH system, the first US-manufactured CO2 heat pump water heater and the first CHPWH with integrated load shift controls as a standard manufacturer package. The project was supported by SMUD incentives, TECH Clean California funding, and the Low-Income Weatherization Program (LIWP), with project coordination by Redwood Energy and engineering by the project team.

The Laars eTherm system at this project consists of one 70 kW (design condition) CO2 HPWH with 1,000 gallons of primary storage in a swing tank configuration. The system is designed to operate under SMUD's Time-of-Day rate schedule, with load-up in the early afternoon and an 8-hour daily shed window extending beyond the 4–9 PM peak period. A key finding of the project involves the interaction between storage sizing and incentive program requirements: SMUD's tiered incentive structure targeted 1,500 gallons of storage, while Ecosizer modeling indicated that 1,000 gallons would be sufficient for the required shed window. Based on the sizing tool results, a 1,000 tank was installed, despite a reduction in incentive payments based on sizing criteria. The monitoring study is providing data to inform SMUD's program design regarding the appropriate storage sizing threshold.

Performance monitoring via EcoDash has confirmed that the system is successfully shifting load through the full 8-hour shed window on a daily basis. Analysis of "advanced load-up" (at elevated temperatures above the standard load-up setpoint) indicates a COP reduction of approximately 0.2–0.5 points compared to standard load-up operation, suggesting that advanced load-up is not cost-effective for this system and that control optimization should focus on standard load-up with sufficient duration rather than elevated temperature load-up. Estimated annual savings from load shifting total approximately $9,600 per year, including TOU energy cost reduction and summer demand charge avoidance.

This study is ongoing. Final M&V results will be published upon completion of the monitoring period.

Site 3: Affordable Transitional Housing, Portland, OR

This project is an 85-unit affordable transitional housing development in Southeast Portland, owned and operated by Central City Concern. The site served as a demonstration for the Portland General Electric (PGE) Smart Grid Test Bed, with the primary objective of validating dispatchable load shift capability using CTA-2045 EcoPort communication. The CHPWH system consists of a Mitsubishi QAHV in a swing tank configuration with 490 gallons of primary storage and a 120-gallon Rheem E50 swing tank.

Load shift metrics were evaluated using three methods: the Ecosizer simulation engine, the NEEA Load Shift Commissioning Test, and field monitoring data. A key finding is that the NEEA Load Shift Commissioning Test and Ecosizer modeling overestimated real-world thermal shift capacity by approximately 10–15% compared to field performance. This overestimation is attributed to the idealized initial conditions assumed by commissioning tests (fully charged tank, maximum stratification) that are not consistently achievable in actual operation, as well as parasitic thermal losses and the imprecision of real-world load-up timing.

Communication reliability was the primary operational challenge at this site. The project team encountered cellular reception issues, UCM firmware bugs, and signal timing problems that intermittently prevented load shift signals from reaching the CHPWH system. The team ultimately transitioned to a LoRaWAN network UCM to resolve cellular connectivity issues. When the communication system was functioning correctly, the CHPWH successfully maintained shed windows without HPWH operation.

This study is ongoing. Full results will be published upon completion of the PGE Smart Grid Test Bed program.

Site 4: New Multifamily Housing, Portland, OR (PGE Smart Grid Test Bed)

This project is a newly constructed 219-apartment, 438-occupant multifamily building in Portland, Oregon, owned by Security Properties. The site served as a second demonstration site for the PGE Smart Grid Test Bed. The CHPWH system consists of three Nyle e360 heat pumps using R-513a refrigerant in a swing tank configuration, with four 750-gallon AO Smith primary storage tanks and a 119-gallon Bock swing tank with 54 kW of electric resistance capacity.

This project is notable as the only R-513a refrigerant system in the current load shift portfolio, demonstrating that the swing tank load shift approach is not limited to CO_2 systems. When communication and controls were functioning correctly, the HPWHs remained off for the entire duration of scheduled shed periods.

The project encountered significant challenges with both communication reliability (cellular reception in the below-grade mechanical room) and control sequencing (the system was operating in load-up mode continuously rather than only during scheduled load-up periods, causing persistent short-cycling). Short-cycling of the Nyle e360 units degrades system efficiency through two mechanisms: the inherent mixing of lukewarm water into storage that occurs each time the heat pump cycles on, and the reduced COP associated with short cycle lengths. The team is working with Nyle to resolve these control issues.

The hardware cost to enable load shift communication was under $1,000 per site for the UCM and EcoPort interface components, though the total project cost for establishing monitoring and communication was approximately $25,000–$30,000, reflecting the engineering and commissioning effort required. This study is ongoing.

Sites 5 and 6: Senior Housing Sites, San Francisco, CA

Two senior low-income housing buildings in San Francisco served as demonstration sites for the CalNEXT program, administered by Southern California Edison. Each building is served by multiple Mitsubishi HEAT2O (QAHV) units in a swing tank configuration, with load shift controls aligned with PG&E time of use pricing (load-up from 12:00–15:59; shed from 16:00–21:00 on designated days). The two sites represent 120 and 135 units respectively.

Results demonstrated that the systems were able to shift load during the TOU peak window, with one site using less energy on average during the first four hours of the shed period and the other using less energy across all five shed hours, compared to control days. A key challenge at these sites was the grid-like parallel/series plumbing arrangement of primary storage tanks, which may have reduced effective storage capacity and complicated system balancing relative to the parallel-piped storage at Site One.

While energy use was reduced during peak pricing periods, maximum power consumption during the peak period was not consistently reduced—a critical limitation under PG&E's rate structure, which includes monthly demand charges based on maximum power draw during the 16:00–21:00 window. Staging the QAHVs to turn on sequentially is a recommended strategy for future control sequences. This study is ongoing.

Load Shift Mechanisms

Elevated Storage Temperature

One of the most effective mechanisms for increasing effective thermal storage capacity is to increase the storage temperature during load-up. By heating storage tanks to temperatures above the normal setpoint (e.g., raising storage from 140°F to 150–165°F before a peak period), the system stores additional thermal energy in the same tank volume. This energy is delivered to occupants at the normal delivery temperature through a thermostatic mixing valve. The result is an increase in the effective storage capacity—measured in gallons of hot water available at delivery temperature—without adding physical tank volume.

At the Site One demonstration, raising the storage setpoint from 138°F to 150°F during load-up, combined with extended load-up duration, was a key factor in achieving successful multi-hour shed events (Spielman et al., 2023). The Site Two deployment with the Laars eTherm similarly uses elevated storage temperature as a primary load shift mechanism, though field results indicate that "advanced load-up" at higher temperatures reduces system COP by approximately 0.2–0.5 points compared to standard load-up, introducing a trade-off between storage density and efficiency that must be considered in program design.

Increased Storage Capacity

Additional physical storage volume directly increases the thermal battery capacity of the system and extends the maximum shed duration. The Site Two demonstration in Sacramento (SMUD territory) provides an instructive example of how storage sizing interacts with incentive program design: SMUD's incentive program offered higher rebates for systems installing more than 15 gallons of storage per bedroom, setting a target of approximately 1,500 gallons for the 100-unit building. However, Ecosizer modeling indicated that approximately 650–1,000 gallons would be sufficient to shift load through the 4–9 PM peak window. The monitoring study was designed in part to evaluate whether the smaller storage volume was sufficient, providing data-driven feedback to SMUD for program refinement.

Control and Communication Equipment

Effective load shift requires communication infrastructure to deliver load shift signals to the CHPWH system. The industry has standardized around the CTA-2045 (EcoPort) communication protocol, which provides a physical port and command set for demand response. This standard protocol enables interoperability between utility DERMS platforms and CHPWH systems from different manufacturers.

The hardware required to enable CHPWH load shift communication—including a cellular or hardwired modem, Universal Communication Module (UCM), and EcoPort interface—is minimal in cost, typically under $1,000 per site for necessary components. However, establishing reliable communication, particularly in below-grade mechanical rooms or areas with poor cellular reception, has been a persistent challenge across the deployment portfolio. Lessons learned from the Site Three and Site Four deployments suggest that hardwired or LoRaWAN communication is more reliable than cellular UCMs in challenging locations, and that communication architecture should be specified and tested during the design and commissioning phase rather than addressed reactively.

Types of Load Shift Protocols

Time-of-Use Energy Management

Under time-of-use (TOU) rate structures, energy costs vary by time of day, with peak-period prices significantly higher than off-peak prices. CHPWH load shifting under TOU programs aims to minimize energy consumption during high-cost periods by pre-charging thermal storage during low-cost hours and coasting through peak periods on stored energy. This approach directly reduces operating costs for building owners and residents.

Sites Five and Six deployments in San Francisco (PG&E territory) used a schedule aligned with PG&E TOU pricing, with load-up from 12:00–15:59 and shed from 16:00–21:00 on designated days (Spielman et al., 2024). The Site Two deployment in Sacramento (SMUD territory) is designed to operate within SMUD's Time-of-Day rate structure, with estimated annual TOU savings of approximately $8,400–$9,600 for the 100-unit building, including both energy cost reduction and summer demand charge savings.

Demand Peak Management

Under rate structures with demand charges—where customers are billed for their maximum power draw during a defined peak window—load shifting must not only reduce energy consumption during the peak period but must also limit peak power draw during shed events. A persistent challenge across the deployment portfolio is the load spike that occurs at the end of a shed period when storage is partially depleted and the HPWH restarts at full capacity. This spike can trigger demand charges that partially or fully offset the energy cost savings from the shed.

Staging strategies—turning on multiple HPWHs sequentially rather than simultaneously at the end of a shed—are a promising approach to mitigating end-of-shed load spikes. The NEEA QPL sequence of operations recommends staging as a standard practice for multi-unit systems. Implementing and verifying staging behavior has been a focus of ongoing work at several sites in the portfolio.

Dispatchable Load Shift

Dispatchable load shift refers to the ability of a utility or aggregator to issue real-time load shift commands to CHPWH systems in response to grid conditions, rather than operating on a fixed schedule. This capability—enabled by CTA-2045 EcoPort and OpenADR communication protocols—allows CHPWHs to function as grid-responsive distributed energy resources (DERs) that can provide load up, shed, and critical peak commands on demand.

The Site Three and Site Four deployments in the Portland General Electric (PGE) Smart Grid Test Bed demonstrated the technical feasibility of dispatchable CHPWH load shift using CTA-2045 communication. In both cases, when the hardware and communication system were functioning correctly, the systems successfully responded to load shift commands and maintained shed windows without HPWH operation. The primary challenges encountered were communication reliability and control sequencing, rather than fundamental hardware limitations.

It should be noted that a short-term dispatch window requesting immediate load management will be limited by the condition of the storage system in a CPWH system at the time the signal is received. If the tank is already partially depleted, there will be less stored capacity for load shift deployment. Longer lead times like day ahead notification of published TOU rates allows the system to prepare for a specific load shift event by preloading the hot water storage tank in advance of the peak period.

Tracking System Performance: M&V Capabilities

EcoDash System

The EcoDash monitoring platform is the primary data collection and visualization tool used across the CHPWH load shift portfolio. EcoDash collects one-minute interval data from temperature sensors, power meters, flow meters, and other instrumentation installed at each site, and uploads data daily to a cloud-based dashboard for real-time monitoring and analysis.

EcoDash provides several key capabilities for load shift M&V, aligned with the guidelines in the AWHS:

- Real-time visualization of tank temperatures, system power, and hot water usage, allowing the project team to monitor load shift performance and identify issues as they arise.
- Calculation of System COP per the AWHS Equipment Method, enabling comparison of field performance against QPL-predicted values.
- Calculation of load shift metrics including Thermal Shift Capacity, Electrical Shed Capacity, and Seasonal Peak Load Reduction.
- Automated fault detection and alerting, enabling rapid identification and response to control sequencing errors, sensor failures, and other operational issues.
- Historical trend analysis for identifying patterns of underperformance and informing control optimization.

The integration of monitoring into the standard controller package—as demonstrated by the Laars eTherm—significantly reduces the cost and complexity of adding EcoDash monitoring. When monitoring instrumentation is included in the standard system design and factory-installed in the controller, the marginal cost of connecting the system to EcoDash is minimal. The project team has been working directly with several CHPWH manufacturers to incorporate M&V capabilities directly into OEM controllers.

Fault Detection and Operational Monitoring

A consistent finding across the deployment portfolio is that ongoing monitoring is essential for maintaining effective load shift performance. Control sequencing errors, communication failures, sensor malfunctions, and changing building conditions can all degrade load shift effectiveness over time if not identified and corrected. At several sites, monitoring data revealed that controls were not operating as intended—in some cases, load-up temperature sensors or setpoints were being applied under normal operating conditions, causing the system to continuously over-charge storage and short-cycle the heat pump equipment.

The EcoDash system's fault detection capabilities have been critical for identifying these issues. At the Site Four apartments in Portland (an ongoing study), monitoring data revealed control sequencing errors that were causing persistent short-cycling of the Nyle e360 heat pumps, degrading system efficiency during much of the initial monitoring period. EcoDash data enabled the team to diagnose the issue and coordinate with the manufacturer to implement corrective firmware updates.

Challenges Identified Across Deployments

Electric Resistance Use During Shed

Electric resistance backup heating—whether provided by the swing tank electric resistance element or an auxiliary heater—can undermine load shift effectiveness if activated during a shed period. This can occur if the system is undersized, or if the controls are not properly programed to deploy load shift strategies. If backup heating engages during a shed due to insufficient pre-charged storage, the shed event fails to achieve its intended load reduction. At several sites monitoring has revealed the potential for backup heating to be deployed due to defrost operations, balancing valve configuration problems or improperly configured control setpoints. These conditions need to be adequately addressed to prevent inadvertent use of electric resistance. Proper sizing of primary storage, combined with accurate load profiles for the specific building type, is the primary mitigation strategy. The Ecosizer tool and AWHS QPL load shift sizing methodology provide the framework for this. Note that the accuracy of system sizing estimates depends critically on input data quality—particularly hot water usage profiles that reflect the actual occupancy patterns of the building.

Load Spike at End of Shed

A recurring challenge across the portfolio is the load spike that occurs when stored thermal energy is depleted at the end of a shed period and the heat pump restarts. This spike can be particularly problematic under demand charge rate structures, where a brief high-power draw during the peak window can trigger a significant monthly charge that partially offsets the energy cost savings from the shed.

Staging of multiple heat pumps—turning them on sequentially rather than simultaneously—is an effective mitigation strategy when multiple HPWH units are installed. For single-unit systems, the options are more limited, but careful sizing to ensure that storage is not fully depleted during the shed window can reduce the magnitude of the restart load spike. Dynamic load-up timing algorithms that predict the optimal start time for load-up based on real-time tank temperature data are a promising area for future development.

Water Temperature Management

Maintaining appropriate water temperatures throughout the system is essential for both occupant safety (Legionella prevention requires periodic high-temperature maintenance above 140°F) and load shift effectiveness. Elevated storage temperatures during load-up increase effective storage capacity but also reduce HPWH efficiency, as the system must maintain higher temperature lift. The trade-off between storage density and efficiency is a key consideration in control strategy design.

At some sites, the combination of elevated storage temperatures during load-up and high recirculation loop temperatures has led to complications with the secondary heat exchanger or swing tank controls. Careful design of the temperature management system and thorough commissioning of all control setpoints are essential for avoiding these issues.

Communication Reliability

Communication reliability has been one of the most significant operational challenges across the dispatchable load shift deployments. Poor cellular reception in below-grade mechanical rooms, UCM firmware issues, and timing conflicts in communication protocols have all contributed to unreliable signal delivery at multiple sites. The Site Three deployment ultimately transitioned from a cellular UCM to an Amazon LoRaWAN network UCM to resolve cellular reception issues, though this introduced new uncertainties about long-term network reliability and cost structure.

A key lesson from the PGE Smart Grid Test Bed deployments is that communication architecture should be evaluated and tested early in the project—ideally during the design phase—and that hardwired or dedicated cellular connections are preferable to shared consumer networks for grid-critical demand response assets. The cost of hardwired communication infrastructure is modest relative to the overall system cost and provides significantly greater reliability than cellular UCMs in challenging locations.

Implications of Utility Rate Structures on Load Shift Value

The economic value of CHPWH load shifting depends critically on the rate structure applicable to the building, and different rate structures create different optimization priorities that may not always be compatible.

Time-of-Use Energy Rates

Under TOU energy rate structures, load shifting provides direct cost savings by moving energy consumption from high-cost peak periods to low-cost off-peak periods. The magnitude of savings depends on the price differential between peak and off-peak periods, the amount of energy shifted, and the COP penalty associated with load-up operation at elevated temperatures. Analysis of Site Two under SMUD's Time-of-Day rate structure estimated annual TOU energy cost savings of approximately $8,400, based on shifting essentially all hot water energy consumption out of the 4–9 PM peak window throughout the year.

Demand Charges

Under rate structures with peak demand charges, optimization priorities shift from minimizing energy consumption during peak periods to minimizing maximum power draw during those periods. These objectives may conflict: a system that successfully eliminates HPWH operation during most of a shed period but allows a brief high-power restart near the end of the shed may still trigger a significant demand charge. Deployment at Site Two is estimated to save approximately $1,200 per year in summer peak demand charges (in addition to the TOU savings identified above) by eliminating HPWH operation during the 4–9 PM peak window in summer months—but only if the shed is successful in preventing any HPWH operation during that window.

For buildings under PG&E's commercial rate structure, as demonstrated at the San Francisco senior housing sites (Sites Five and Six), demand charges represent a significant portion of the total monthly bill, making control strategies that prevent any peak-period HPWH operation more valuable than those that merely reduce average energy consumption during the peak window.

GHG-Aligned Dispatch

A third optimization objective—reducing GHG emissions by aligning operation with periods of high renewable energy availability—may not always coincide with the TOU or demand peak optimization objectives. In California, the marginal GHG intensity of the grid is highest during early evening peak periods, which aligns well with the TOU peak window. However, optimal GHG reduction may sometimes call for operating during mid-day solar hours rather than maximizing storage for an evening shed. The TECH Clean California program uses an annual simulation that accounts for both TOU pricing and GHG intensity to estimate the emissions reduction potential of load shift systems, providing a framework for programs that value both objectives.

Table 1. Comparison of rate structures and load shift optimization priorities across the deployment portfolio

Rate Structure	Primary Optimization Target	Key Control Challenge	Observed Sites
TOU Energy	Minimize peak-period energy consumption	Load-up timing, storage sizing	Site Two (SMUD), Sites Five and Six (San Francisco, PG&E)
Demand Charges	Eliminate any peak-period HPWH operation	End-of-shed load spike, HPWH staging	Sites Five and Six (PG&E), Site Two (SMUD summer)
Dispatchable DR	Reliable response to utility signal	Communication reliability, control sequencing	Sites Three and Four (PGE)
GHG Intensity	Align with renewable availability	Dynamic control logic, grid signal integration	Sites Five and Six (CalNEXT)

Summary And Conclusions

The CHPWH load shift deployment portfolio reviewed in this paper spans over a dozen sites, multiple system configurations, refrigerant types, utility territories, and load shift protocols. Across this diverse portfolio, a consistent set of findings emerges:

- Swing tank CHPWH systems with appropriately sized thermal storage can reliably eliminate peak-period energy consumption for multi-hour shed windows, provided that load-up timing and duration are sufficient to fully charge storage before the shed period begins.
- The load shift potential of a given system is primarily determined by available thermal storage volume, achievable storage temperature, and the building's hot water demand profile. Ecosizer and the AWHS QPL provide the tools to estimate this potential at the design stage, but field monitoring consistently reveals real-world performance 10–15% below idealized estimates.
- Communication reliability is the primary operational challenge for dispatchable load shift. Hardwired or dedicated cellular communication is strongly preferred over shared consumer networks (e.g., LoRaWAN, cellular UCMs in poor-reception locations) for grid-critical demand response applications.
- Ongoing monitoring via a platform such as EcoDash is essential for maintaining effective load shift performance. Control sequencing errors, sensor failures, and changing building conditions can degrade load shift effectiveness over time if not identified and corrected through continuous M&V.
- The economic value of load shifting depends critically on the applicable rate structure. TOU energy rates reward energy shifting; demand charge rate structures require preventing any peak-period HPWH operation; GHG-aligned dispatch may conflict with economic optimization objectives.
- Program and incentive design must account for the trade-offs between storage sizing, efficiency, and load shift depth. Requirements for storage volume that exceed what is needed for the target shed window add cost without proportional benefit. The Site Two demonstration provides an instructive example of how monitoring data can inform incentive program refinement.
- Advanced load-up at elevated storage temperatures provides additional storage density but reduces system COP by 0.2–0.5 points. Control strategies should carefully balance the benefit of increased storage capacity against the efficiency penalty of operating at higher temperatures.

The CHPWH load shift sector is maturing rapidly, with multiple manufacturers now offering systems with integrated CTA-2045 communication and load shift controls as standard features. Tools for design, performance estimation, and M&V are becoming more robust. The growing deployment portfolio provides a rich data foundation for refining program and incentive structures that accurately value the contribution of CHPWH thermal storage to grid flexibility.

Future research priorities include: dynamic load-up timing algorithms that optimize storage pre-charge based on real-time building demand and tank temperature data; staging strategies for multi-unit systems to minimize end-of-shed demand spikes; improved load profile characterization for diverse building types (senior housing, SRO units, hotel conversions); and standardized commissioning protocols that include communication testing and load shift verification as required steps. Addressing these priorities will enable the CHPWH sector to deliver its full potential as a distributed grid resource as the market continues to grow.

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