Demand Flexibility Meets Affordable Housing: Multifunction Heat Pumps for Tenant and Grid Value

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ABSTRACT

Space and water heating together represent the largest residential energy end uses, driving both utility costs and grid peak load. While multifunction heating and hot water heat pump systems with thermal energy storage have demonstrated successful load-shifting capabilities in single-family homes, their performance in multifamily affordable housing remains unvalidated. Low-income tenants are especially vulnerable to rising energy costs, while property owners face tight capital budgets, limited mechanical space, and complex incentive eligibility requirements – barriers that have slowed adoption. This paper presents a field study demonstrating that demand-flexible multifunction heat pump systems can be retrofitted in affordable housing at lower capital and operating costs. Six San Jose apartment units were retrofitted with a high efficiency heat pump with smart thermal batteries capable of autonomously responding to hourly dynamic price signals. The project evaluated the technology's load-shifting potential and cost savings based on the unique energy usage patterns in affordable homes under realistic occupancy, tested reliability of signal connectivity, and reported on tenant acceptance. Across both winter and spring testing, the system successfully delivered 60–82% load-shift and approximately 30% cost savings without compromising comfort or requiring behavior changes. The results confirm the technical feasibility and cost benefits of multifunction heat pumps in multifamily housing. The paper compares capital and operating costs with alternative heating systems and discusses how utility program design can address barriers to wider adoption. The findings inform new utility program designs and incentive offerings that can accelerate adoption and unlock load-flexibility-driven bill savings in affordable housing communities.

Introduction

Space and water heating together account for approximately 61% of residential site energy consumption in the United States and are major contributors to winter electric peak demand (Energy Information Administration 2023). As heat pump adoption expands nationwide, it presents a challenge to home electric infrastructure often requiring expensive electric panel and service upgrades. Furthermore, unmanaged load growth can strain the distribution system and trigger infrastructure upgrades, increasing utility costs for ratepayers (Neubauer et al. 2019). Integrated heat pump systems with integrated thermal energy storage (hereinafter "IHP+TES systems") present a promising solution to cover two major end uses with a single, smaller heat pump system which can be retrofitted in existing homes without home electric infrastructure upgrade.

In addition to the above, affordable multifamily housing faces its own set of challenges with heat pump adoption. Residents in low-income housing often experience disproportionately high energy costs due to lower-performance building envelopes and they are less able to absorb bill volatility associated with time-varying rates (York et al. 2022; ACEEE 2024). Multifamily property owners also face capital constraints, split incentives, operational complexity, and space constraints that can slow adoption of advanced heating technologies (Johnson & Mackres 2013; Cluett & Amann 2015). Therefore, technology solutions such as the IHP+TES systems that can both avoid panel upgrades and deliver ongoing energy cost savings are particularly relevant to multifamily housing stakeholders.

Affordable multifamily housing presents distinct physical, financial, and operational conditions that may limit direct transferability of those findings. This paper addresses that gap by evaluating demand-flexible IHP+TES systems deployed in an affordable multifamily building. The study examines peak load reduction, cost impacts, system performance, connectivity reliability, and tenant acceptance under real-world operating conditions.

Development and Demonstration Gap

Residential thermal energy storage (TES) for heating and hot water is an emerging technology with few commercially available products and a lack of field studies in affordable multifamily applications. Field studies in single-family homes have demonstrated the potential to shift load, reduce energy costs and meet occupants comfort needs (Grant et al. 2025; Casillas et al. 2024). However, multifamily housing presents unique challenges, including space, electrical, capital constraints, and different occupancy and resident ownership status.

Existing multifamily apartments are on average half the size of existing single-family homes, and optimized for rental space, leaving very little space for mechanical systems (EIA RECS 2020). Existing water heaters are often slim units in narrow closets, low-boy units installed under the counter or in a split closet water heater/furnace closet, which are more suitable to be replaced by split rather than integrated heat pump water heaters (Houssainy et al. 2022). Many multifamily apartments use hydronic air handlers fed by gas water heaters, such as FirstCo Aquatherm and Apollo Hydroheat, which are expensive to convert to a conventional split heat pump (Nadel et al. 2025). Existing apartments also have limited electrical capacity, often 100A or less, making retrofits with conventional heat pumps challenging (Quinn et al. 2024).

Multifamily property owners face financial constraints making them less likely to retrofit mechanical systems. Low-income tenants also can least afford potential energy bill increases, and property owners are wary of increasing the risk of tenants defaulting on rent due to higher energy bills. These constraints result in slower adoption of heat pump solutions in multifamily housing (York et al. 2022; American Council for an Energy-Efficient Economy 2024).

The system deployed in this study was designed to overcome these challenges by using a single 240V/15A split heat pump water heater paired with a hot water tank and advanced controller as thermal energy storage, to deliver both domestic hot water and heat through a hydronic air handler designed for apartment applications. The system is eligible for the federal Investment Tax Credit for thermal energy storage under section 48E of the federal tax code of 30 to 40% depending on location, in addition to state and local incentives, helping address owner capital constraints (Internal Revenue Service 2025).

Finally, multifamily apartments tend to have higher occupancy and different usage patterns than single-family homes: domestic hot water energy use is often higher than heating energy use due to smaller building size, more thermally-efficient compact designs, and higher occupancy (Energy Information Administration 2023). The decision to retrofit the heating and hot water systems is made by the property owner, tenants are less invested in the change than single-family homeowners who made the decision to retrofit. The study aimed to validate how effectively the Harvest Thermal ("Harvest") system addressed these constraints and challenges, by assessing upfront and operating costs, energy, load shifting, and reliability performance, and tenant acceptance.

Methodology and Approach

Technology Overview

The demonstrated system in Figure 1 is a multifunction integrated heat pump with on-site thermal energy storage that serves both space heating and domestic hot water (DHW) from a single heat pump. A standard highly insulated hot water tank is operated as a thermal battery, allowing the heat pump to preferentially run during lower-cost hours while meeting space-heating and DHW demand during higher-cost periods. The system is designed to overcome common multifamily retrofit constraints by using a compact configuration built around a single, dedicated heat pump water-heating unit and a hydronic air handler suited to apartment installations.

The installed system consists of five primary components: (i) an outdoor heat pump water-heating unit (SANCO2) supplying high-temperature hot water suitable for thermal storage; (ii) an air handling unit (AHU) with a hydronic coil and fan controlled by the system controller; (iii) a well-insulated storage tank operated as TES for both DHW and space heating; (iv) a grid-connected controller ("Harvest Pod") that monitors tank state of charge and thermal use, forecasts demand, and schedules heat pump operation, decoupling heat pump operation from heating and hot water delivery without requiring a smart/connected thermostat. The pod features a standard 24-volt thermostat interface used for heating delivery control; hydronic heating delivery is controlled via a variable-speed circulator pump in the Harvest Pod; (v) and optional cooling integration via a conventional A/C outdoor unit using the same air handler, ductwork, and thermostat. For this study, connected thermostats were installed for monitoring purposes, while price response and TES operation were managed by the controller directly.

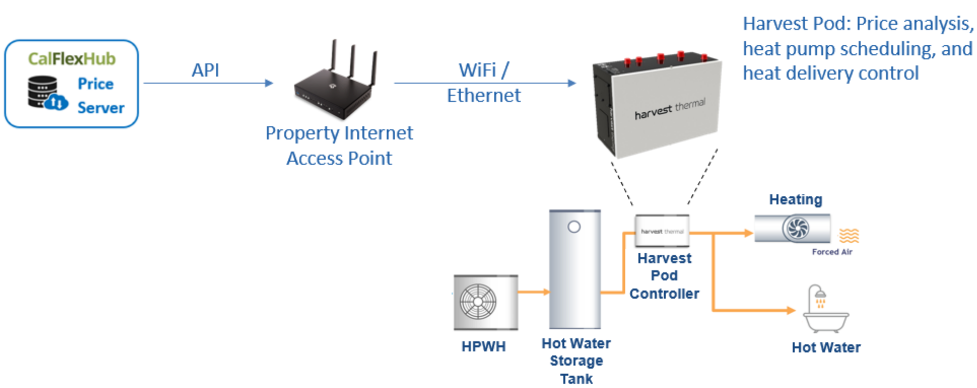

Figure 1: System and Communication Architecture

Field Demonstration Site

The field study was conducted in a two-story, six-unit townhouse-style affordable multifamily building in San Jose, California (Figure 2). Each unit's existing gas-fired combination heating and hot water system was replaced with the IHP + TES configuration. The outdoor heat pump condenser units were installed adjacent to the water heater closets (Figure 2a, 2b). Storage size was constrained by typical multifamily mechanical closets (Figure 2c); therefore, each unit used an 83-gallon tank rather than the larger 119-gallon tanks typically used for this application in single-family deployments. The Harvest Pod controller was installed within the water heater closet (Figure 2d). The project team partnered with an air-handler OEM (Mortex) to adapt a compact hydronic air handler suitable for multifamily applications and compatible with TES-based operation; the resulting cabinet air handler was designed for attic installation (Figure 2e) in a garden-style multifamily context. Six systems were installed; five units participated in the dynamic price response testing. One unit included an integrated A/C outdoor unit replacement, while the remaining participating units were heating-and-DHW-only configurations comparable to the systems they replaced.

Figure 2: (a) Heat Pump Condensers in Back Alley; (b) Heat Pump Condenser on Water Heater Closet; (c) Thermal Energy Storage Tank in Water Heater Closet; (d) Harvest Pod in Water Heater Closet; (e) Air Handler in Attic

Price Communication and Response Control

During CalFlexHub test periods, systems were configured to respond to day-ahead hourly dynamic electricity prices. The controller retrieved a 24-hour hourly price forecast from the CalFlexHub price server, and a 24-hour weather forecast from an Internet-based service.

The controller combined price and weather inputs with learned household demand patterns to predict space-heating and DHW needs over the next 24 hours and to optimize heat pump operation to minimize energy cost exposure while maintaining service levels. Operationally, the controller (i) identifies relatively high- and low-cost periods from the price stream, (ii) charges the thermal battery during low-price hours with only the amount of hot water predicted to be needed until the next low-cost window, limiting unnecessary storage duration and associated thermal losses; and (iii) minimizes heat pump runtime during high-price hours while serving loads from stored hot water and running the heat pump until if and when storage is depleted. Algorithm refinements were implemented after early operation indicated that multifamily usage patterns with high DHW contribution created opportunities to improve charging/discharging behavior; these refinements were deployed prior to the spring test cycle, with additional improvements continuing after the study.

Outside CalFlexHub test periods, systems operated under standard tariff-based time-of-use controls, prioritizing tenant bill savings while preserving the same core approach of predictive charging and storage-based discharge during higher-cost hours.

A key implementation consideration in multifamily affordable housing is communications as resident Internet cannot be assumed or used for building equipment connectivity. For this deployment, dynamic price signals were delivered via API call to the CalFlexHub price server through the property's Internet access point. A mesh Wi-Fi network connected the retrofitted building to the leasing office where the Internet access point was located. Each Pod was connected to the mesh access point via ethernet wiring through a network switch. This architecture enabled centralized, property-managed connectivity suitable for tenant-occupied housing, and supported remote configuration of control modes as needed for the test.

Study Design and Instrumentation

The deployment was executed as part of the California Energy Commission–funded CalFlexHub demonstration project managed by Lawrence Berkeley National Laboratory. Dynamic price response performance was evaluated in multi-week winter (03/19/2025 – 04/08/2025) and spring (04/10/2025 – 04/24/2025) test periods in which participating units followed the hourly dynamic price stream. The analysis emphasized peak-period load impacts over defined high-price windows and overall daily shifting, consistent with CalFlexHub's standard load impact and customer cost metrics.

For measurement and verification, no additional hardware was required for the CalFlexHub evaluation. Each installed system includes integrated monitoring of thermal and electrical performance, and data were collected through the Harvest Cloud. The controller measured key variables at a 64-second interval, including: DHW draw (flow/volume proxy), space-heating thermal delivery, hot water production (heat pump thermal output), supply/return temperatures at key hydraulic points (utility inlet, DHW supply/mixing valve upstream, hydronic coil supply/return, tank-to-heat-pump return, and heat-pump-to-tank supply), and electricity consumption for the heat pump and for the combined air handler and controller/pumps.

Indoor temperature and setpoint were recorded via connected thermostats at approximately 5-minute intervals for monitoring, while local weather data were sourced from an Internet service. These data streams supported calculation of daily and hourly energy use, load shapes under baseline versus price-responsive operation, whole-system coefficient of performance (COP), and customer cost metrics under the applicable price streams.

Baseline Definition and Justification

Defining an appropriate "non-flex" baseline in the field was a challenge because TES operation is intrinsic to the IHP system and enables a smaller heat pump than would typically be installed in a non-storage configuration. Disabling storage controls would therefore not represent a realistic conventional system and could fail to meet heating and DHW service requirements, especially in winter.

To ensure a consistent reference framework for both winter and spring tests, the study used a theoretical modeled baseline that emulates a conventional heat pump system serving the same space-heating and DHW thermal loads without TES or load-shifting controls. The baseline was constructed by converting the measured delivered thermal energy (hourly space heating + DHW) to a counterfactual electricity consumption profile using the observed average COP. This thermal-load-and-COP-based baseline preserves delivered service levels while removing the temporal optimization enabled by storage, thereby isolating the incremental impact of price-responsive TES operation on load shape and cost.

Outcomes Evaluated

Using the above study design, instrumentation, and baseline approach, the evaluation quantified: (1) load shifting and peak load reduction performance under hourly dynamic prices across defined peak windows; (2) customer energy cost impacts under the dynamic price stream, alongside tariff-based operation outside test periods; (3) reliability of price signal reception and system operation in a rental multifamily connectivity architecture; and (4) occupant experience and acceptance, with emphasis on achieving flexibility without comfort compromise or required behavior change.

Results/Findings

Load Reduction

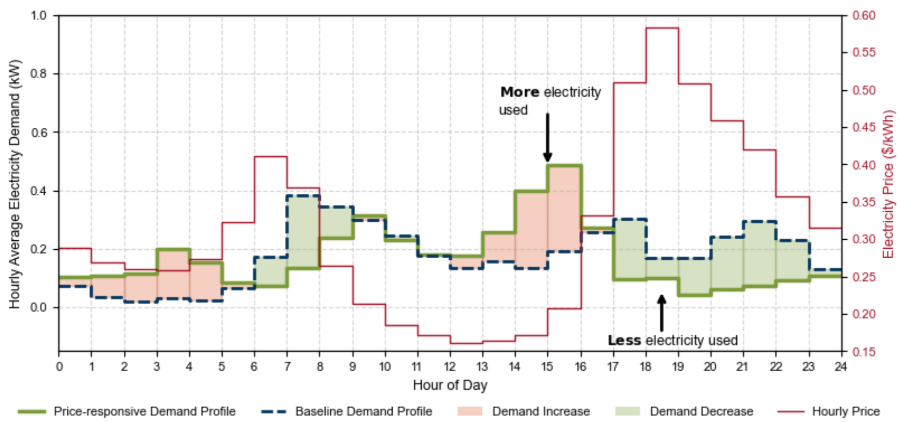

Figure 3: Baseline vs. Hourly Price Response Enabled Electricity Demand Profiles for Winter Testing, Averaged Across all 5 Homes

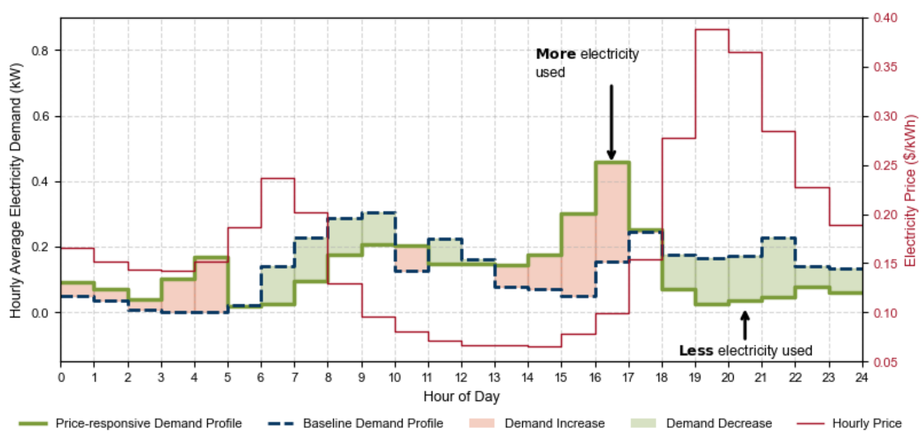

Figure 4: Baseline vs. Hourly Price Response Enabled Electricity Demand Profiles for Spring Testing, Averaged Across all 5 Homes

Across winter and spring multi-week test periods, the IHP + TES systems consistently shifted the majority of combined space-heating and domestic hot water electricity use away from the highest-priced hours under an hourly dynamic price signal. Averaged across the five participating units, as summarized in Table 1, peak-period load reductions during the six highest-priced hours reached 0.15 kW in winter and 0.12 kW in spring, corresponding to 67% and 72% reductions relative to the modeled baseline. Reductions during the two-hour and four-hour high-price windows were of similar magnitude, with spring two-hour reductions reaching as high as 82% relative to baseline. The similarity in seasonal load reduction percentages reflects the dominant role of domestic hot water in driving flexibility in this multifamily building. While space-heating demand declined substantially in spring, evening hot water use remained relatively consistent, sustaining significant shift potential across both seasons.

The average hourly demand profiles in Figures 3 and 4 illustrate that winter evening heat pump operation was largely shifted to pre-4 PM hours, with limited morning shifting because heating and DHW demand did not ramp up until near the end of the early-morning peak window. In spring, systems shifted most evening operation out of the 6–10 PM high-price period, with a visible pre-charging spike in late afternoon as the controller maximized thermal storage ahead of peak pricing. Morning shifting was minimal during the spring test window due to low coincident heating and DHW demand during early peak hours.

Cost Savings

In addition to reducing peak demand, the systems shifted measurable amounts of energy from higher-priced to lower-priced hours. During winter testing, an average of 0.9 kWh per day was shifted out of peak periods. This resulted in average customer savings of $0.30 per day, or 23% relative to baseline under the CalFlexHub dynamic price. Spring performance was similar in magnitude but delivered higher percentage savings. An average of 0.7 kWh per day was shifted, yielding $0.17 per day in savings, equivalent to 30% relative to baseline. These results show that even modest daily energy shifts of less than 1 kWh can translate into meaningful percentage bill reductions under dynamic pricing. Assuming five months with savings as measured in the winter test (heating and hot water load), and seven months with savings as measured in the spring test (hot water only), this would represent $82 in annual bill reductions under dynamic pricing compared to a non-load shifting heat pump baseline.

Harvest calculated energy cost savings over the first 10 months of operation, using the same methodology and PG&E's E-Elec tariff instead of CalFlexHub dynamic price, and found average resident savings vs. existing gas combi systems retrofitted with a new gas water heater of 29% over that time period. This corresponds to $148 in annual bill reduction vs. new gas combi systems based on 12 months monitoring by Harvest. Detailed cost and energy savings metrics are summarized in Table 1 (Refer to Table I in Appendix for additional metrics).

Impact of Occupant Usage Patterns

System performance varied substantially across households due to differences in hot water use and space-heating demand. In winter, daily electricity consumption ranged from 2.4 to 8.0 kWh per day across units (Averaged metrics across all units are summarized in Table 2, for detailed metrics refer to Table II in Appendix).

The highest-demand unit averaged 103 gallons per day of hot water use and 61 kBTU per day of space heating, resulting in the highest electricity consumption. In contrast, the lowest-demand unit used 44 gallons per day of hot water and only 2 kBTU per day of space heating, with correspondingly low electricity use. These usage differences directly affected savings outcomes. Higher-demand households achieved larger absolute load reductions and greater dollar savings, while lower-demand households achieved similar percentage reductions but smaller dollar savings.

In spring, overall average electricity consumption declined to an average of 2.9 kWh per day, reflecting much lower space-heating loads. However, domestic hot water demand remained relatively consistent, continuing to provide steady load-shifting potential even as heating demand dropped.

System Performance

Dynamic price response did not compromise system efficiency. Across all units and both test periods, the whole-system coefficient of performance, inclusive of fan, pump, controls, and thermal storage losses, averaged 3.3. Individual unit COP values ranged from 2.86 to 3.67 in winter and from 3.01 to 3.61 in spring, demonstrating stable and high-efficiency operation despite varying load profiles and storage cycling. The ability to shift nearly 1 kWh per day of space and water heating load during winter while maintaining a whole-system COP above 3.0 highlights that load flexibility was achieved without sacrificing energy performance.

Reliability of price signal reception and system operation was high throughout both test periods. Average load shapes closely tracked the hourly dynamic price signal, indicating successful communication between the Pods and the CalFlexHub price server. No signal interruptions were observed, and there were no disruptions in space-heating or hot-water delivery. No instances of unmet load were attributable to price-responsive control.

User acceptance findings were consistent with the technical performance results. Because the thermal battery performs load shifting in the background without thermostat setbacks or required behavior changes, participants did not report noticing differences between baseline and price-responsive operation. Early participant interviews conducted under a related program indicated that residents were unaware of transitions between baseline and price-responsive modes. The only participant concern was potential bill impacts during testing, since the dynamic price signal used for the demonstration was not fully aligned with each resident's retail tariff; this was mitigated through participant compensation.

Table 1: CalFlexHub load impact metrics summary, all units, across both test periods

Metric	Unit	Winter					
		Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Mean
24-hr Energy Cost with Price Responsive Control	$/day	1.76	0.99	0.62	1.51	0.50	1.07
Above as Percentage of the Baseline 24-hour Energy Cost	% of baseline energy cost per day	79%	75%	78%	74%	80%	77%
6-hr High Price Period Load Reduction	kW	0.21	0.14	0.12	0.17	0.12	0.15
Above as percentage of baseline load	% of baseline load	64%	68%	81%	58%	77%	67%

Metric	Unit	Spring					
		Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Mean
24-hr Energy Cost with Price Responsive Control	$/day	0.63	0.30	0.30	0.55	0.21	0.40
Above as Percentage of the Baseline 24-hour Energy Cost	% of baseline energy cost per day	64%	81%	61%	80%	64%	70%
6-hr High Price Period Load Reduction	kW	0.24	0.05	0.14	0.07	0.12	0.12
Above as percentage of baseline load	% of baseline load	77%	58%	73%	52%	89%	72%

Table 2: Heating and hot water usage metrics mean across all units, across both test periods

Metric	Unit	Winter Mean	Spring Mean
Hot water used per day	Gallons per day	63	55
Hot water energy consumption per day	kBTU per day	34	30
Heating delivered per day	kBTU per day	44	4
Electricity used by system per day	kWh per day	5.3	2.9
Coefficient of performance for whole system, including losses	Ratio	3.30	3.30

Discussion

Overall, the results demonstrate that IHP + TES systems can be a valuable load flexibility resource in delivering substantial peak demand reduction for the grid and meaningful cost savings for the customers in affordable multifamily housing while maintaining occupant comfort, operational reliability, and high system efficiency. From a grid perspective, the observed 60–82% peak-period load reductions indicate that integrated thermal storage can significantly moderate electrification-driven load growth associated with heat pump adoption.

The findings also highlight that affordable multifamily buildings represent a significant source of demand flexibility. Although physical space constraints in multifamily units limited thermal storage capacity relative to typical single-family installations, the systems nevertheless achieved substantial percentage of load reductions. In this study, significant and consistent domestic hot water usage provided year-round opportunities for load shifting, even during periods when space-heating demand was minimal. The demonstrated systems operated autonomously, without requiring thermostat setbacks, behavioral changes, or active participation from tenants. By performing load shifting in the background through thermal storage, the IHP + TES systems avoided comfort or service tradeoffs.

The study also has few limitations. The demonstration was conducted in a single six-unit building in a mild climate with relatively small heating loads. Larger buildings, colder climates, or buildings with different occupancy patterns may produce different load shapes and flexibility potential. In addition, the analysis relied on a modeled COP baseline representing a conventional heat pump without storage rather than a measured baseline. While this approach allowed isolation of the storage-driven flexibility effect, additional studies across a broader set of buildings and climates would further validate these findings.

Cost Comparison

The economic feasibility of the IHP + TES system was evaluated by comparing its operating cost against a counterfactual gas-fired combination system delivering the same space-heating and domestic hot water loads. The pre-incentive installed cost of the IHP + TES system was approximately $26,000 per unit for the five units without air conditioning and $34,000 for the unit where an existing A/C condenser was replaced by a new A/C condenser as part of the installation. This unit's heating needs could be met by the SANCO2 alone, therefore requiring no supplemental heat. This made a regular A/C condenser sufficient and more cost-effective than a heat pump. Multiple incentive programs significantly reduced these costs. The systems were eligible for incentives from TECH Clean California Small Multifamily, two California Energy Commission EPIC program grants including one administered through the CalFlexHub project, the California Low-Income Weatherization Program, and an incentive from the local community choice aggregator San José Clean Energy. In addition, the system qualified for a 30% federal investment tax credit under Section 48E of the federal tax code for thermal energy storage (Internal Revenue Service 2025). After applying these incentives, the net cost to the property owner was approximately $2,000 per unit for systems without A/C and $7,000 for the unit with A/C. Table 3 below summarizes how the Harvest Thermal's IHP + TES system costs compare against traditional retrofits or new systems.

Table 3: Cost Comparison Table for IHP + TES against traditional technology

System Type	Installed Cost per Unit (Pre-Incentive)	Installed Cost per Unit (Post-Incentive)	Expected Service Life*	Demand Flexibility Capability
Existing System replacement (Gas Combi System + New Gas Water Heater)	$3,000-$5,000[1]	$3,000-5,000	15–20 years	None
Conventional Heat Pump + Water Heater Retrofit	$22,000[2]	$10,250[3]	15–20 years	Low
Harvest IHP + TES (this project)	$26,000 ($34,000 with AC)	~$2,000 ($7,000 with AC)	18 years	High

To estimate operating cost impacts, the IHP + TES system performance was compared against a theoretical gas-fired combination system delivering the same thermal energy for space heating and domestic hot water. The counterfactual system efficiency was based on the federal minimum efficiency standard of 0.627 Uniform Energy Factor for a 50-gallon replacement gas

[1] Standard commercial prices from internet search on 6/2/2026, we did not get a quote for a gas water heater replacement.
[2] Contractor quote for the same project with HPWH and multi-split HVAC
[3] Assuming $2,000 in federal tax credits (25C), $6,500 from San Jose Clean Energy rebates, and $3,250 from the Bay Area Multifamily Building Enhancements (BAMBE) program.

water heater with a high-draw usage pattern. The existing systems in the building were similar 50-gallon gas combination systems serving both heating and hot water loads. Air handler fan and circulator pump energy consumption were assumed to be comparable between the two systems. Although the IHP + TES system uses higher-efficiency ECM fan and pump motors, the gas system was assumed to operate for fewer hours because it delivers warmer supply air. Fan energy represents approximately 2% of the IHP + TES system's total electricity consumption, making this difference negligible in the overall comparison.

Gas costs were calculated using the average of the Baseline and Excess tiers of PG&E's G-1 residential gas tariff, with monthly updates reflecting seasonal gas price variation. Electricity costs were calculated using PG&E's E-Elec time-of-use tariff, which includes a five-hour peak period from 4–9 PM, mid-peak hours during the remainder of the 3 PM–midnight window, and off-peak hours from midnight to 3 PM.

The analysis assumes that tenants switched from their previous electricity tariffs, typically E-1 or E-TOU-C, to the E-Elec tariff. To facilitate this transition, the project team conducted two tenant information sessions, distributed multilingual user manuals in English, Spanish, and Vietnamese, and installed laminated thermostat cards with QR codes linking to the manuals. Flyers with instructions for requesting the tariff change from PG&E were also distributed to residents. Because tariff enrollment is voluntary, it is possible that some tenants did not complete the switch and therefore may not realize the full expected savings.

Both gas and electricity were already sub-metered in the building prior to the retrofit. This configuration avoided the "cost shift" issue that can occur in multifamily buildings when gas is master-metered and electricity is individually metered. In such cases, electrification of heating and hot water can inadvertently transfer energy costs from building owners to tenants. Because both energy sources were already individually metered in this project, the retrofit did not create such a cost shift.

Rate design and resident education played an important role in determining realized ratepayer value. Tenants enrolled in default time of use tariffs with limited peak to off peak price differentials faced lower benefits from load shifting. This highlights the importance of aligning demand flexible technologies with rate structures that meaningfully reward off peak consumption. While the actual payback varies per project, a peak/off-peak electricity price ratio of ideally 3, and at a bare minimum of 2, is required to make a meaningful difference on customer payback.

Incentive Program Design

The Harvest's IHP + TES technology illustrates a type of emerging technology that has the potential to bring significant benefits to consumers–both directly in the form of lower energy bills and indirectly from lower grid system costs due to load shifting and high efficiency. With sales volume in the hundreds of units annually, the technology is at an early stage of commercialization, and has not yet realized full economies of scale. Incentives are therefore crucial to offset initial higher costs and initiate a virtuous circle where rising sales enable manufacturing and supply chain economies of scale and investment into value engineering. Over time, incentives can be stepped down as the solution cost comes down, until the technology is able to compete with incumbents without incentives, a process evident in the adoption of LED lighting, rooftop solar, and electric vehicles. Harvest estimates that the technology could achieve more than 50% cost reduction over the next five years through manufacturing scale and product design optimization.

Several incentive programs are well-positioned to support promising emerging technologies like Harvest in this transition. The section 48E federal tax credit, for instance, incentivizes thermal energy storage for HVAC, an emerging technology that can provide cheaper and faster peak capacity relief on the grid than new generation, transmission and distribution. Programs like TECH Clean California, California Energy Smart Homes, Massachusetts Mass Save have also responded rapidly to technology innovation and provided flexibility for emerging technologies like Harvest to be eligible for incentives and compete on a level playing field with other heat pump technologies.

On the other hand, some incentive programs focus on incumbent technologies and do not have the flexibility necessary for innovative technologies to develop. For example, the Inflation Reduction Act funded Home Electrification and Appliance Rebates program uses SEER and HSPF eligibility thresholds that de facto exclude air-to-water heat pumps and integrated heating and hot water systems such as the technology demonstrated in this study.

Heat pump technology shows great promise for enhancing energy affordability, air quality, and pollution reduction. However, current technology will be slow to scale without innovation to bring down its cost and increase its benefits. To accelerate adoption, it is crucial that incentive programs encourage rather than discourage innovation.

Conclusion

This field demonstration shows that demand-flexible multifunction heat pump systems with integrated thermal energy storage can significantly reduce peak-period electricity demand while lowering occupant energy costs in affordable multifamily housing. Across winter and spring test periods, the systems consistently shifted heating and domestic hot water loads away from high-price hours, achieving peak load reductions of more than half relative to the modeled baseline while maintaining reliable operation and occupant comfort. Because load shifting was achieved through automated control of thermal storage, the systems required no behavioral changes or active participation from tenants, while benefiting them in the form of nearly 30% energy cost reductions.

The results indicate that affordable multifamily buildings represent an important and largely untapped source of demand flexibility. The findings also have broader implications for utility and energy affordability program design. Affordable multifamily housing may represent a scalable pathway for aligning heat pump retrofits with grid flexibility objectives, suggesting value in approaches that integrate dynamic rates, demand flexibility incentives, and multifunction heat pump technologies within building retrofit strategies. However, an average peak/off-peak price ratio of a minimum of 2 and ideally 3 is necessary for time-varying rates to make a meaningful difference on resident economics and therefore on large-scale adoption of these technologies.

Consistent domestic hot water usage in multifamily housing can provide year-round opportunities for load shifting, even during periods when space heating demand is low. These characteristics make integrated heat pump systems with thermal storage a promising strategy for managing electrification-driven load growth while supporting energy affordability.

Future research should evaluate performance across additional climates, building types, and utility rate structures, and explore program designs that combine electrification incentives with demand flexibility objectives to accelerate adoption in multifamily housing.

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AI-assisted tools used: ChatGPT

Used for: AI assistance was used to draft short text summaries based on author-developed materials, performed light editing for clarity and coherence, and supported copy-editing, and formatting prior to final review.

Extent: Drafting brief descriptive text segments and project summaries; light editing, formatting and copy-editing for clarity and readability.

Human review: All technical analysis, results interpretation, methodology development, and final manuscript content were produced and reviewed by the authors.

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Appendix

Cost, Load, and Water Consumption Metrics

Table I: Complete CalFlexHub load impact metrics, all units, across both test periods

Metric	Unit	Winter					
		Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Mean
24-hr Energy Cost with Price Responsive Control	$/day	1.76	0.99	0.62	1.51	0.50	1.07
Above as Percentage of the Baseline 24-hour Energy Cost	% of baseline energy cost per day	79%	75%	78%	74%	80%	77%
24-hour energy cost with price responsive control divided by 24-hour total energy consumption	$/kWh	0.26	0.26	0.26	0.26	0.27	0.26
Above as percentage of the weighted average 24-hour energy price in the baseline case	% of baseline weighted average price	85%	78%	72%	82%	70%	80%
2-hr High Price Period Load Reduction	kW	0.06	0.16	0.04	0.31	0.13	0.14
Above as percentage of baseline load	% of baseline load	41%	61%	72%	58%	66%	59%
4-hr High Price Period Load Reduction	kW	0.14	0.16	0.07	0.23	0.13	0.15
Above as percentage of baseline load	% of baseline load	68%	70%	74%	58%	74%	66%
6-hr High Price Period Load Reduction	kW	0.21	0.14	0.12	0.17	0.12	0.15
Above as percentage of baseline load	% of baseline load	64%	68%	81%	58%	77%	67%
Metric	Unit	Spring					
		Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Mean
24-hr Energy Cost with Price Responsive Control	$/day	0.63	0.30	0.30	0.55	0.21	0.40
Above as Percentage of the Baseline 24-hour Energy Cost	% of baseline energy cost per day	64%	81%	61%	80%	64%	70%
24-hour energy cost with price responsive control divided by 24-hour total energy consumption	$/kWh	0.13	0.13	0.13	0.12	0.12	0.13
Above as percentage of the weighted average 24-hour energy price in the baseline case	% of baseline weighted average price	70%	77%	61%	82%	59%	71%
2-hr High Price Period Load Reduction	kW	0.24	0.07	0.13	0.09	0.16	0.14
Above as percentage of baseline load	% of baseline load	80%	72%	91%	67%	92%	82%
4-hr High Price Period Load Reduction	kW	0.23	0.08	0.16	0.10	0.12	0.14

Metric	Unit	Spring					
		Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Mean
Above as percentage of baseline load	% of baseline load	78%	67%	81%	59%	89%	75%
6-hr High Price Period Load Reduction	kW	0.24	0.05	0.14	0.07	0.12	0.12
Above as percentage of baseline load	% of baseline load	77%	58%	73%	52%	89%	72%

Table II: Complete Heating and hot water usage metrics, all units, across both test periods

Metric	Unit	Winter					
		Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Mean
Hot water used per day	Gallons per day	103	56	44	80	32	63
Hot water energy consumption per day	kBTU per day	56	30	24	43	18	34
Heating delivered per day	kBTU per day	61	93	2	52	12	44
Electricity used by system per day	kWh per day	8.0	6.7	2.7	6.8	2.4	5.3
Coefficient of performance for whole system, including losses	Ratio	3.55	3.44	3.06	3.67	2.86	3.30
Metric	Unit	Spring					
		Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Mean
Hot water used per day	Gallons per day	97	42	42	65	30	55
Hot water energy consumption per day	kBTU per day	53	23	23	35	16	30
Heating delivered per day	kBTU per day	4	2	2	10	2	4
Electricity used by system per day	kWh per day	4.5	2.3	2.2	3.9	1.7	2.9
Coefficient of performance for whole system, including losses	Ratio	3.61	3.14	3.31	3.37	3.01	3.30