Design and Performance of a Small Heat Pump Water Heater System

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ABSTRACT

Small heat pump water heater (HPWH) systems, which are compact and easy to install, play an important role in electrifying small multifamily buildings. They are installed in approximately 46% of all existing multifamily buildings. However, existing HPWH studies have not adequately addressed applications in this significant market sector. This study addresses the research gap by conducting laboratory testing to investigate design options and performance of a particular small HPWH system based on a residential HPWH. The study specifically investigates strategies for integrating a storage tank with a HPWH, aiming to enhance hot water supply capacity and efficiency in a cost-effective manner. The study team developed a novel testing procedure to comprehensively assess system performance, focusing on both energy efficiency and hot water supply capacity. The study also developed a performance map to compare the performance of multiple design options under different levels for hot water draw.

Based on extensive laboratory testing results, the study identified three measures for the small HPWH system to achieve satisfactory performance: highly restricted HPWH flow, use of HPWH hybrid mode, and the application of a relatively high setpoint for both the HPWH and the storage tank. Data and insights on small HPWH system performance provided by this study can be used to support future design guidelines development. Furthermore, the laboratory testing and performance evaluation methods provide a new holistic approach to characterize the performance of HPWH systems.

Introduction

High-performance heat pump water heater (HPWH) systems are needed to enable cost-effective and efficient water heating electrification in multifamily building. Small multifamily buildings constitute a large portion of the multifamily building stock. According to the National Multifamily Housing Council, approximately 10.6 million apartment units (around 46% of total units) in the United States are in buildings with 5-19 units (NMHC 2024), highlighting the vast potential for HPWH applications in this sector. However, existing studies of HPWH applications have predominantly focused on individual HPWHs and mid to large central systems. There is a remarkable lack of design examples and performance information for small central HPWH applications in small multifamily buildings. To address this gap, this study investigated design options and performance characteristics of small HPWH systems. It's important to note that large multifamily buildings can also use multiple small HPWH systems instead of a large central HPWH system to provide hot water services.

Many studies on HPWH systems have focused on assessing system efficiency of a particular system design (Rothgeb 2017; Banks 2022; Dryden 2023). In contrast, this study aims to identify high-performance system design solutions by testing various system configurations, which will be explained in the next section. In particular, the study explored methods to implement a well-recognized design strategy: using an increased storage volume to cost-effectively increase hot water supply capacity and improve HPWH operational efficiency. The added storage may buffer large hot water demand to avoid depleting the HPWH storage and triggering electric resistance heating. However, there are no guidelines on how to effectively implement this design strategy to achieve related benefits. Through laboratory testing, this study examined the performance of various options for integrating a HPWH with a storage tank and identified high-performance design options accordingly.

In evaluating system performance, this study not only quantified system efficiency, but also assessed hot water supply capacity. We developed a novel laboratory test procedure to probe system performance under a range of hot water demand profiles. This testing approach delivered insights that delineate the system's efficiency characteristics and capabilities in accommodating a broad spectrum of hot water demand profiles. The latter is particularly pertinent to HPWH applications in small multifamily buildings given the absence of sizing tools for these buildings. The new laboratory test procedure and related performance analysis method could serve as a performance assessment framework for other HPWH systems.

Study Methodology

Small HPWH System

This study investigated a small HPWH system comprised of a 50-gallon AO Smith residential packaged HPWH and a 50-gallon storage tank (referred to as primary storage in following sections). A 50-gallon electric water heater, disconnected from electric power, was used as the primary storage. Figure 1 provides a schematic of the system. Figure 2 shows a picture of the small HPWH system tested by the study.

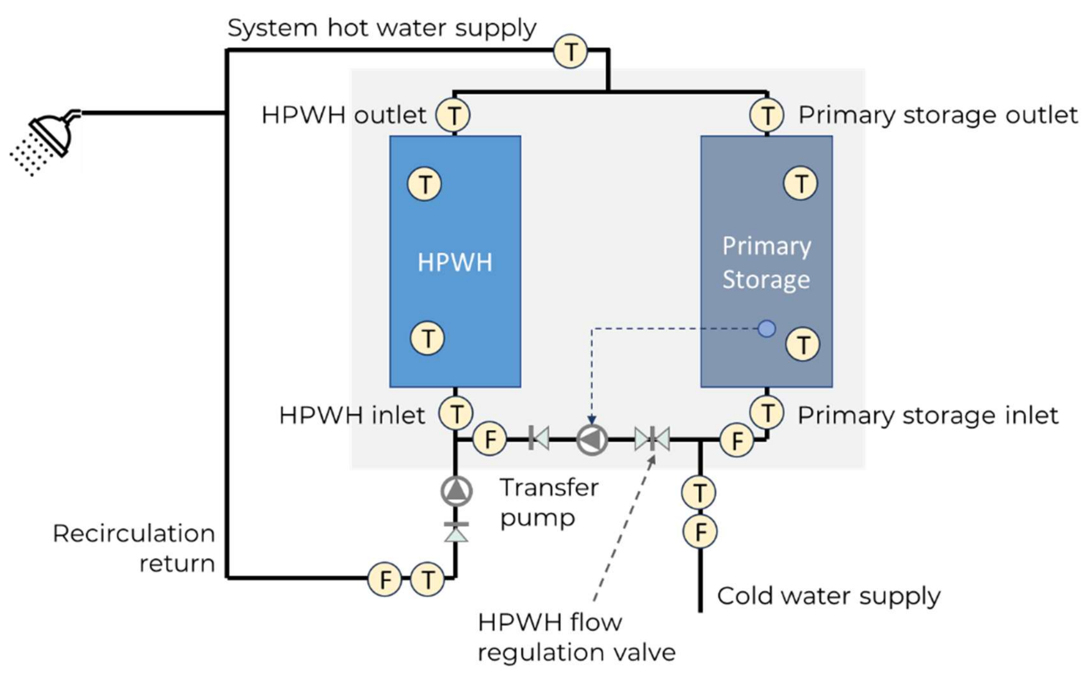

Figure 1 Schematics of the Small HPWH System used for Testing. Symbols with the letter "T" and "F" represent temperature and flow sensors, respectively, used for performance measurement.

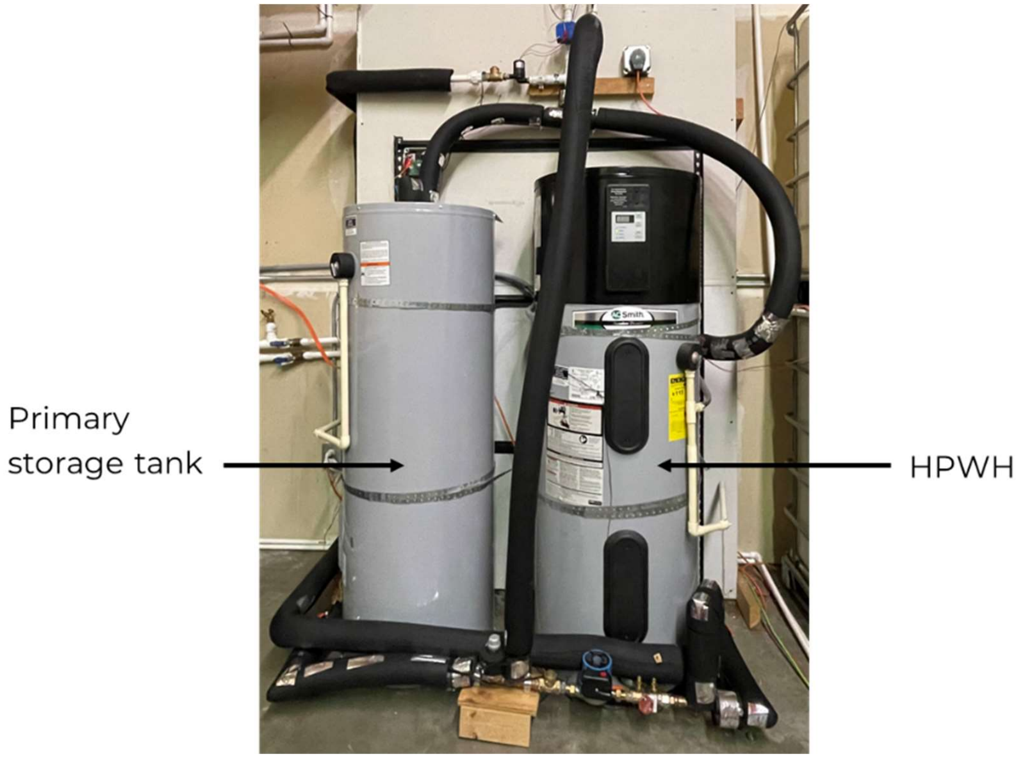

Figure 2 Small HPWH System Tested by the Study

There are multiple alternative methods to integrate the HPWH with the primary storage. Figure 1 presents a parallel design, where both the HPWH and the primary storage can concurrently supply hot water. Future studies may investigate other types of designs.

HPWH performance is greatly affected by hot water draw volume. An adjustable valve was installed to regulate draw flows through the HPWH to achieve optimal performance. When there was a draw, the valve restricted cold water makeup flow into the HPWH and increased cold water makeup flow into the primary storage. The study varied the level of flow restriction to assess its corresponding impact on system performance.

A transfer pump was used to move hot water from the HPWH to the primary storage, which can then be used to satisfy demand. When operating, the pump transfers cold water from the bottom of the primary storage tank to the lower section of the HPWH storage and simultaneously moves hot water from the top of the HPWH to the primary tank's upper section. Transfer pump operation was controlled based on temperature readings obtained from a sensor attached to the primary storage. The transfer pump was turned on only when there was enough cold water in the primary storage so that it can effectively buffer the load on the HPWH. The transfer pump was turned off when the measured temperature was above a control threshold, indicating the primary storage was adequately filled with hot water. It is worth noting that transfer pump flows were also regulated by the HPWH flow regulation valve.

In this design, the recirculation return was connected directly to the HPWH cold water inlet. The next phase of the study will assess system performance for designs having the recirculation returning to the system cold water supply or the primary storage cold water inlet.

System Design Elements and Options

The design of this small HPWH system involves the following elements:

- **HPWH flow restriction**: The HPWH flow restriction valve shown in Figure 1 was used to reduce water flow into the HPWH, rerouting flow into the storage tank during hot water draws. This valve also acted as a limiting element for the transfer flow rate. For this study, a device called a circuit setter, which can be observed in Figure 2, was used for HPWH flow restriction. Circuit setters are calibrated flow regulation valves designed to balance water flows in hot water distribution systems. Other types of flow control valves may also be used for this purpose.
- **Transfer pump control**: The storage system depended on the operation of a transfer pump to receive hot water from the HPWH. The activation of the pump was based on temperatures detected by a sensor placed on the storage tank. The study placed the temperature sensor at the bottom of the storage tank and analyzed how this position affected system performance. Future research will examine alternative sensor locations. The temperature range within which the pump operated, known as the control deadband, was defined by specific temperature setpoints. The pump kicked in when the introduction of cold water lowered the tank's temperature below the deadband's lower threshold. It stopped when the inflow of hot water raised the temperature to the deadband's upper limit. Two deadband settings were tested: 95°F - 115°F and 100°F - 120°F. The former resulted in the pump activating sooner, which led to earlier engagement of the HPWH. The exploration of additional settings for the pump's temperature control will be a task for future studies.
- **Transfer flow rate**: Transfer flow rate determined the velocity at which cold water was transferred from the storage tank to the HPWH and had a large impact on resistance heating activation. Transfer flow rate was governed by both pump power and HPWH flow restriction. The latter allowed for a broad spectrum of flow rates, enabling a thorough assessment of their impact on the system's overall performance.
- **HPWH operation mode**: The AO Smith HPWH used in this study featured three heating operation modes: efficient, hybrid, and electric. The efficient mode prioritized heat pump utilization, resorting to electric resistance heating solely under conditions of significant hot water depletion from the HPWH's storage. Although this mode is characterized by high efficiency, it offers comparatively low recovery rates. Conversely, the hybrid mode was designed to meet substantial demand by enhancing electric resistance heating usage, aiming for higher recovery rates. The electric mode, which exclusively relies on electric resistance heating, was not explored in this study.
- **HPWH temperature setpoint**: Individual HPWHs are typically set at 125°F in configurations without a mixing valve. Nevertheless, the temperature of hot water transferred to the storage was observed to be marginally reduced, a consequence of mixing with colder water in the storage tank and thermal losses incurred through piping and the tank's jacket. Such conditions resulted in diminished hot water delivery temperatures and reduced storage capacity. To address this, this study also explored the feasibility of employing an elevated HPWH temperature setpoint of 130°F.
- **Recirculation**: This study assessed system performance with and without supporting recirculation operation. As explained in the prior section, there are three ways to connect recirculation return into the small HPWH system. This study focused on the option where

the recirculation return goes directly to the HPWH. Other design options will be investigated in the next phase of the study.

To support future design guidelines development, this study evaluated the impact of these design elements on system performance. Table 1 provides the options considered by the study for each design element. Different combinations of these options were tested to identify high-performance design solutions. Please note that options presented in Table 1 are for the first phase of design option exploration and do not represent an exhaustive list of possible options for the design elements. Future efforts will consider other options based on the findings from this study.

Table 1 Options of system design elements

System Design Element	Options
HPWH flow restriction level (FRL)	1. None: draw flow = 0.51 Gallons Per Minute (GPM), transfer flow = 2.8 GPM 2. Low: draw flow = 0.34 GPM, transfer flow = 1.9 GPM 3. Medium: draw flow < 0.1 GPM, transfer flow = 0.5 GPM 4. High: draw flow = 0 GPM, transfer flow = 0.2 GPM (The above flow rates are for the HPWH.)
Transfer pump control dead band	1. Normal: 95°F - 115°F 2. High: 100°F - 120°F
HPWH operation mode	1. Efficient mode 2. Hybrid mode
HPWH setpoint	1. Normal: 125°F 2. High: 130°F
Recirculation return	1. No recirculation 2. Into the HPWH 3. Into cold water supply pipe (not yet tested) 4. Into the storage tank (not yet tested)

Scoping Laboratory Testing

The main objective of the laboratory testing was to assess major performance trends across a variety of design options, with the purpose of identifying high-performance solutions. The study required testing numerous design options, each under different hot water usage conditions. Given the resources at hand, the laboratory tests were conducted in an unconditioned space, not a controlled laboratory setting. The instruments used for measuring performance had an accuracy of +/-5%, not meeting federal testing standards, but adequate for understanding the key performance impacts of the design options. These preliminary tests, termed scoping laboratory tests, will inform more rigorous future testing.

There are no standard laboratory tests for HPWH systems, so a new testing procedure was developed, informed by Zhang (2020), which suggested multifamily HPWH systems be sized to meet peak demand within a 3–4-hour period. The testing process consisted of a 3-hour hot water draw schedule. Five (5) 3-hour hot water draw schedules were applied to the small HPWH system for each design consideration. Each draw schedule consisted of six (6) draws of equal volume, evenly spaced in time. Total hot water draw volumes were 40, 60, 80, 100, and 120 gallons. Testing results based on this series of 3-hour draw schedules with increasing draw volume provide two types of performance information: HPWH system efficiency under varying demand levels and the maximum hot water demand that can be met by the system. The latter is of particular importance to understand the number of dwelling units that can be served by the small HPWH system.

Hot water draw flow rate was consistently around 1.0 GPM, with total volume adjusted by changing the duration of the six draws. A water reclaim system was introduced to recycle the hot water, which was cooled to approximately 65°F through evaporative cooling and a small cooler before being cycled back into the system. Although water pressure variations led to slight deviations in actual total draw volumes from targets, these were not significant enough to affect the scoping tests' goal of identifying major performance trends.

For tests incorporating recirculation, the setup included a recirculation loop with a heat loss of about 3,100 BTU/hour. This translates to roughly 115 watts per dwelling unit if the system served eight (8) multifamily units, a figure within the range found in existing buildings. This aspect of the test helped simulate real-world conditions and evaluate system performance under typical operating losses.

Performance Assessment

Domestic hot water systems are required to fulfill the hot water needs of building occupants. Accordingly, the primary performance metric for small HPWH systems is their capacity to supply hot water. There is an absence of established standards or specifications for minimum hot water supply temperatures. This study adopted a threshold temperature of 115°F to evaluate if the supplied water volume met satisfactory temperature levels. We then compared the volume of hot water supplied at this satisfactory temperature against the volume drawn to calculate the percentage of hot water demand that the small HPWH system could meet. The hot water supply capacity for a given HPWH system design configuration was defined as the maximum hot water demand met at over 95% satisfaction.

System energy efficiency was based on the coefficient of performance (COP) calculated at the system level according to the following formula:

$$COP_{system} = \frac{E_{draw} + E_{recirc} + \Delta E_{stored}}{Energy_{input}}$$

The three variables in the numerator represent: thermal energy supplied by the system for draws, thermal energy provided by the system for recirculation, and increase in the thermal energy stored in both the HPWH tank and the primary storage tank. The denominator, system energy input, accounts for the electrical energy consumed by the HPWH as well as the transfer pump. The energy usage of the transfer pump was considerably less than that of the HPWH and was consequently deemed negligible.

To calculate the hot water supplied by the system for draws and recirculation, the study relied on measurements of water flow and temperature. Assessing changes in stored energy requires detailed temperature distribution measurements within the HPWH and profile storage tanks. However, such measurements are complex to execute and beyond the scope of this study. The challenge of accurately assessing changes in stored energy is common in HPWH studies, yet many do not sufficiently address it. Instead, a testing procedure was established to maintain the

HPWH tank and the primary storage at full capacity with hot water at both the start and end of each test, thereby rendering changes in stored energy insignificant.

The procedure included a preparatory step involving hot water draws to activate the HPWH and transfer pump, bringing both the HPWH tank and the primary storage to their respective temperature setpoints. During the tests, the six hot water draws not only provided data but also activated HPWH and transfer pump operations, ensuring that the tanks returned to their temperature setpoints. It is important to acknowledge that this method was not without flaws. There could be a tank temperature discrepancy of up to 2°F between the initial and final states of the HPWH and primary storage, introducing a degree of inaccuracy in the Coefficient of Performance (COP) assessment.

Performance of small HPWH system design options were compared to a baseline based on only using the HPWH alone to meet hot water demand. The comparison revealed if and how the addition of a 50-gallon storage could improve performance in energy efficiency and hot water supply capacity.

Testing Results

Examples of detailed test results

Figure 3 shows the measurement results for a test with 80-gallon total draw without recirculation. The system was configured to have the HPWH in efficient mode, HPWH flow restriction at level 2, and both HPWH setpoint and transfer pump control deadband at normal levels as specified in Table 1.

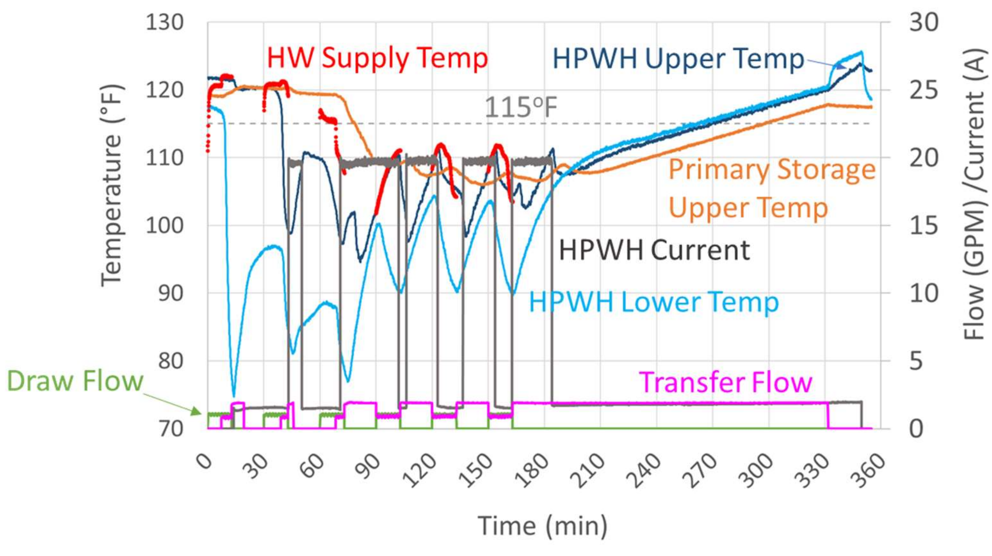

Figure 3 Measurement results of an 80-gallon draw test without recirculation, HPWH in efficient mode with a setpoint of 125°F, HPWH flow restriction at level 2

The green line shows the six draw events evenly spaced in time. The red line shows the hot water supply temperature during draws. In this case, the graph shows that this temperature fell below the 115°F threshold temperature, indicated by the light gray dotted line, during the third draw. The dark grey line shows the measured HPWH current. When the HPWH current was approximately 20A, electric resistance heating was activated. The graph shows that electric resistance heating was activated right after the second draw, when the HPWH upper tank temperature (the dark blue line) decreased significantly. The measured HPWH upper tank temperature and primary storage upper tank temperature (orange line) allow us to evaluate hot water availability in these tanks. By comparing measured HPWH upper tank temperature to measured HPWH lower tank temperature (turquoise line), we can assess HPWH tank stratification status.

Figure 4 shows the measurement results for another test with 80-gallon draws without recirculation. In this test, the system was configured to have the HPWH in hybrid mode, HPWH flow restriction set at level 4, and both the HPWH setpoint and the transfer pump control deadband set at the high level specified by Table 1. Compared to the test measurement results shown in Figure 3, the system was able to meet all six draws with hot water at a temperature higher than 115ºF. The amount of electric resistance heating is noticeably less than the measurements shown in Figure 3, which leads to a longer recovery time. As evidenced by the graphs, the increased heat pump operation did lead to a longer recovery time: HPWH operation stopped at approximately 420th minute for Figure 3 test and 320th minute for Figure 4 test.

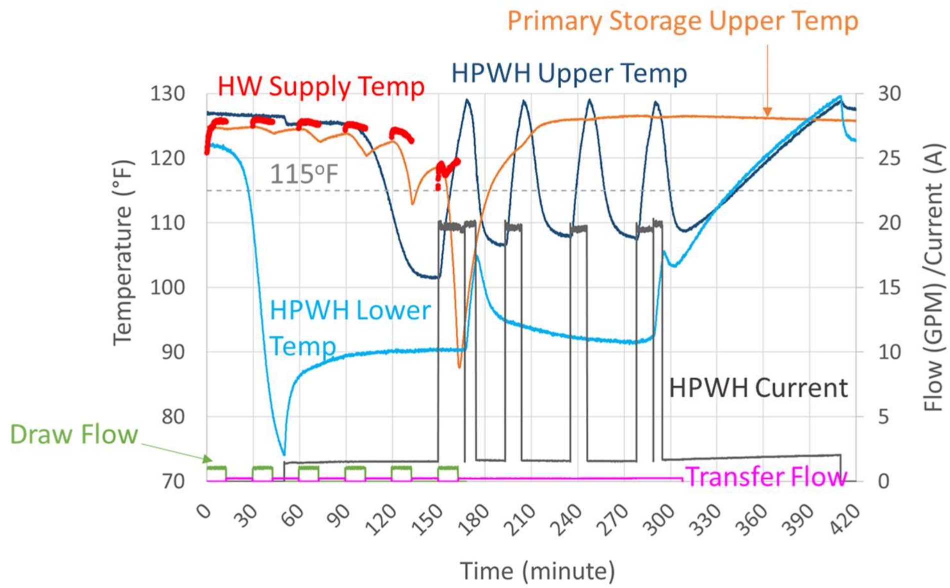

Figure 4 Measurement results of an 80-gallon draw test without recirculation, HPWH in hybrid mode with a setpoint of 130ºF, HPWH flow restriction at level 4

Performance analysis based on measurement results revealed that the system COP was 1.3 for the Figure 3 test and 2.0 for the Figure 4 test. The Figure 3 test only met 44% of the demand while the Figure 4 test met 100% of the demand. These test results show the system can be more efficient by having the HPWH in hybrid mode than in efficient mode.

Baseline

The study developed a performance map to characterize energy efficiency and hot water supply capacity performance under five different hot water draw conditions. Figure 5 shows the performance map of the baseline design: using HPWH alone to provide hot water services.

The top chart of the performance map depicts performance in relation to system COP, hot water supply volume above the 115°F threshold, and the correlation between them under five levels of hot water draws. The bottom chart of the performance map shows the percentage of hot water demand that was met with hot water supply volume above the 115°F threshold. Together, the two charts provide a holistic perspective of each design option's performance. The performance map also allows effective comparison in both energy efficiency and hot water supply capacity between different design options, as to be demonstrated in following sections.

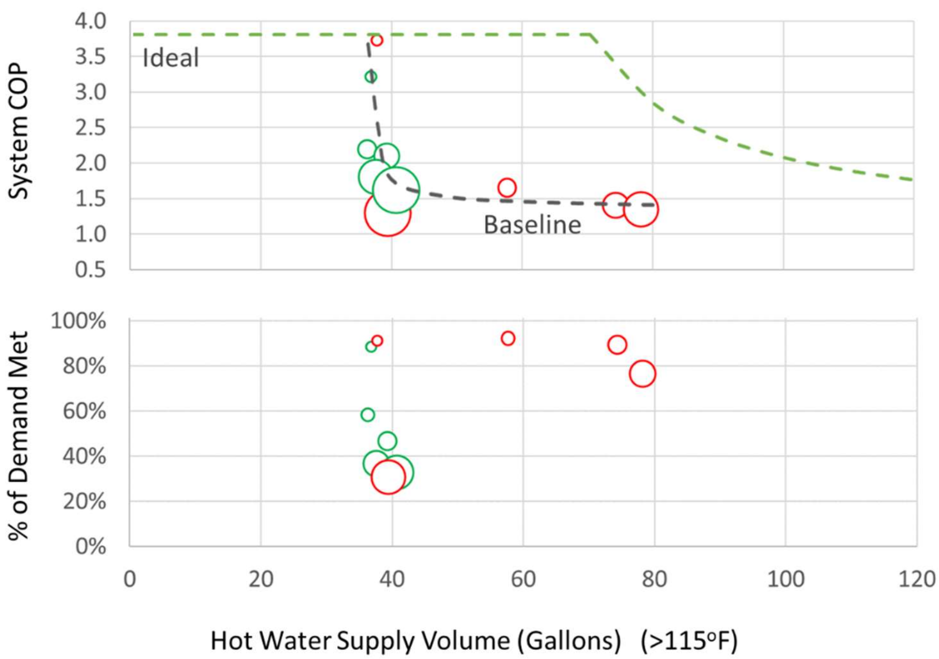

Figure 5 Performance map for baseline (HPWH only).
Bubble size indicates the level of hot water demand. Bubbles with green outline are for HPWH in efficiency mode and bubbles with red outline are for HPWH in hybrid mode.

As shown in Figure 5, for tests with demand higher than the lowest level (40 gallons in 3 hours, represented by the smallest bubble), COP of the baseline system was below 2.5, well below the HPWH's uniform energy factor (UEF) of 3.8. It should be noted UEF is based on hot water demand reflecting typical usage patterns in single family homes. The maximum amount of hot water supplied by the system with temperature higher than the 115°F threshold was 78 gallons. The highest percentage of demand met was 92%, achieved by using hybrid mode to serve 60 gallons of draws in 3 hours. When the HPWH was in efficiency mode (bubbles with green outline), the demand met was markedly worse. Based on these observations, we conclude that the baseline design could not provide satisfactory hot water supply for the five draw conditions. Baseline performance trend is represented by a black dashed line for easy comparison to test results of other design options.

The study also developed "ideal" performance, shown by the green dashed line, to illustrate the potential performance of the small HPWH system under evaluation. The ideal performance was developed with the following assumptions:

- For hot water demands not exceeding the system's useful storage capacity, the system meets demand without activating electric resistance heating. Assuming 70% of the physical storage volume is useful, this equates to a useful storage of 70 gallons. Recovery of the HPWH and primary storage to their setpoints relies solely on heat pump operation, with the system's COP presumed to match the HPWH's uniform energy factor of 3.8.
- When hot water demand exceeds the system's useful storage capacity, electric resistance heating is activated for the 3-hour draw period to fulfill the excess demand. Following this period, heat pump operation is utilized to return the HPWH and primary storage to their respective setpoints. The system's COP is derived from the combined use of heat pump and electric resistance heating.

While the baseline provides the minimum level of performance to be achieved by the small HPWH system, the ideal performance provides a design target for the small HPWH system.

Low HPWH flow restriction (FRL1 and FRL2)

Figure 6 presents performance results for the system with no and low HPWH flow restriction. The HPWH was in efficient mode.

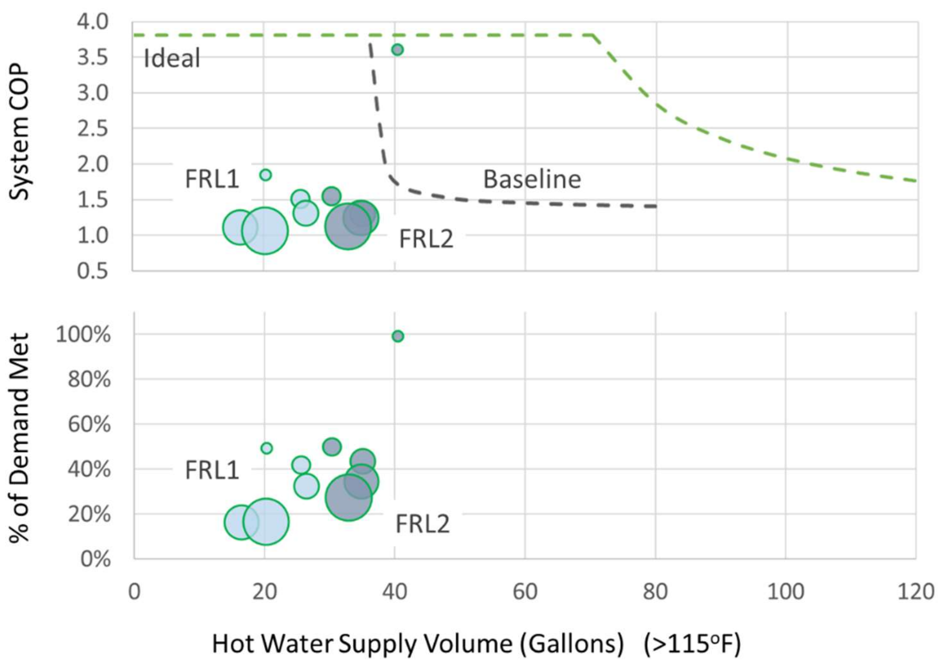

Figure 6 Performance map for system configurations with no and low HPWH flow restrictions. Bubble size indicates the level of hot water demand. Bubbles with green outline are for HPWH in efficiency mode and bubbles with red outline are for HPWH in hybrid mode. HPWH setpoint and transfer pump control deadband at normal levels

Compared to the baseline, the system provided lower efficiency and significantly lower amount of hot water supply with satisfactory temperature, except for the test scenario of low HPWH flow restriction with the lowest demand. The percentage of load met was very low for most of the test scenarios. Because of these poor performance results, the study decided not to perform additional tests involving other system configuration options with no or low HPWH flow restriction.

Medium HPWH flow restriction (FRL3)

Figure 7 presents the performance map for system configurations with medium HPWH flow restriction. This figure includes three groups of design options:

1. Bubbles with solid orange color: HPWH in efficient or hybrid mode, HPWH and primary storage setpoint at the normal level, and no recirculation.
2. Bubbles filled with orange dots: HPWH and primary storage setpoint at the high level (HPWH in hybrid mode and no recirculation).
3. Bubbles filled with orange stripes: with recirculation (HPWH in hybrid mode, HPWH and primary storage setpoint at the normal level).

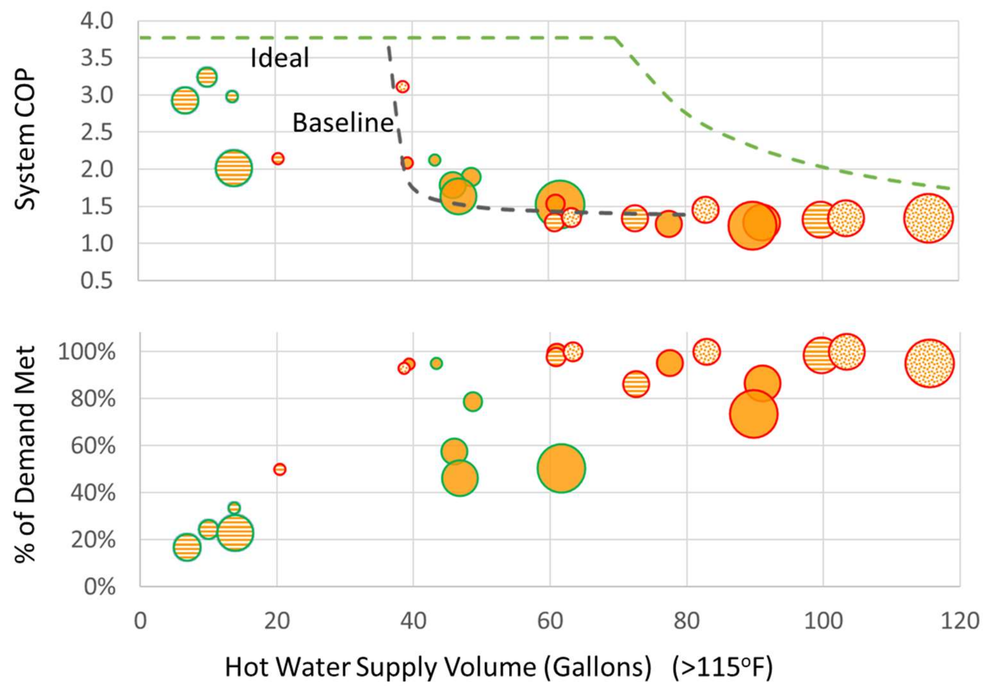

Figure 7 Performance map for system configurations with a medium HPWH flow restriction. Bubble size indicates the level of hot water demand. Bubbles with green outline are for HPWH in efficiency mode and bubbles with red outline are for HPWH in hybrid mode.

Compared to no or low HPWH flow restrictions, medium HPWH flow restriction significantly improved system performance in both efficiency and hot water supply capacity. Analysis of detailed measurement results revealed that the improvement was due to the increased use of primary storage when flow into the HPWH was more restricted, leading to less load for the HPWH and therefore less electric resistance heating. By using a 5°F higher setpoint for both the HPWH and primary storage (group 2 tests), significantly more demand was able to be met while system COP remained relatively the same. The system was almost able to meet even the highest demand for test (120 gallons in 3 hours). With the recirculation flow turned on (group 3 tests), the system was able to meet hot water demand with the HPWH in hybrid mode.

Recirculation did not reduce system COP, which was already relatively low without recirculation.

Figure 7 shows that the system design with HPWH in efficiency mode was unable to meet demand and did not provide high-efficiency operation. In contrast, system designs with the HPWH in hybrid mode were able to meet large hot water demand (up to 100 gallons in 3 hours), as well as supporting recirculation operation.

Most of the bubbles in Figure 7 are aligned with the baseline performance trend line, indicating the designs options did not achieve higher efficiency than the baseline. However, these design options achieved significantly higher hot water supply capacity than the baseline. Some design options were able to meet 100% of the demand for 100 gallons of draws in three hours.

As indicated previously, water pressure variations caused by the water reclaim boost pump led to deviations in hot water draw volumes from targeting values. For example, the actual draw volume of the 100-gallon test for group 2 test (bubbles with orange dots) was 103 gallons, the system met 100% of the demand and provided 103 gallons of hot water above 115°F. This issue is noted to avoid confusion in interpreting the performance map.

High HPWH flow restriction (FRL4)

Figure 8 presents the performance map for testing using high HPWH flow restriction.

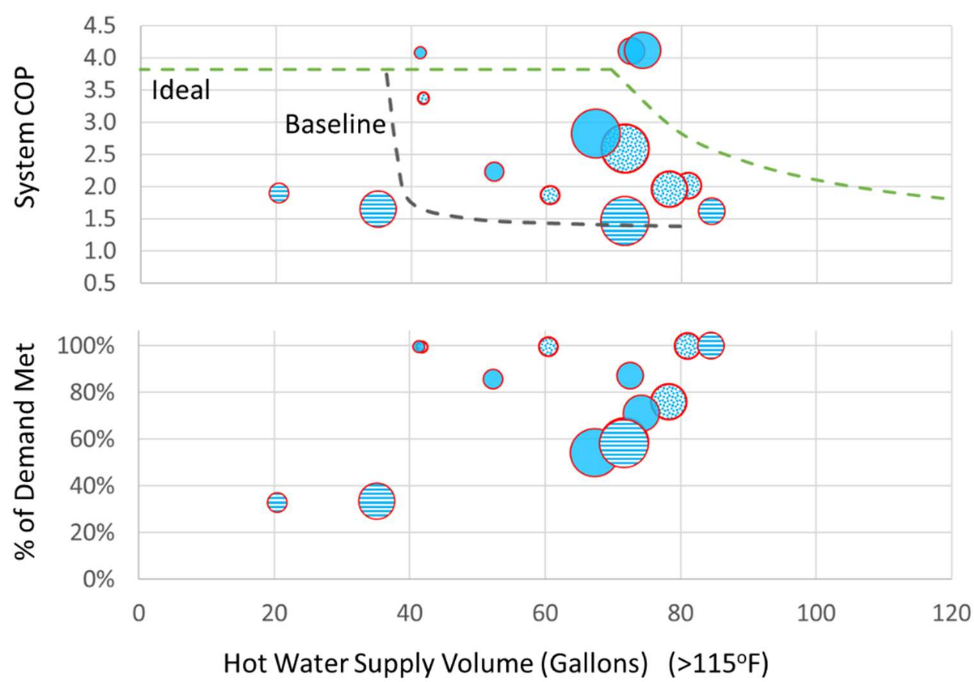

Figure 8 Performance map for system configurations with a high HPWH flow restriction. Bubble size indicates the level of hot water demand. Bubbles with blue dots are for tests using the high HPWH and primary storage setpoints.

High HPWH flow restriction led to a notable improvement in COP. High HPWH flow restriction achieved two effects: forced most of the draws to go through the primary storage and allowed the cold water to be slowly pumped into the HPWH from the primary storage. With these two effects, the HPWH experienced a slow and steady load, which allowed the HPWH to have relatively efficient operation. At the same time, the primary storage was used to buffer large demands. In some cases, the slow and steady load for the HPWH did not trigger electric resistance heating and the system achieved a COP of more than 4.0. Previous tests showed that system configurations with the HPWH in efficient mode had poor performance in satisfying hot water demand. Therefore, the study did not use efficient mode for this set of tests.

When the HPWH setpoint and transfer pump control deadband were set to the normal option, the system was unable to meet high demand without recirculation and was only able to meet the 80-gallon draw test with recirculation. By using the high option for both the HPWH setpoint and transfer pump control deadband, which increased HPWH and primary storage tanks by 5°F, the system was able to meet 100% of the demand for up to 80 gallons of draw in 3 hours. The current phase of the study did not test using high HPWH and transfer pump control deadband setting to serve system operation with recirculation.

Feasible system configurations

Figure 9 presents a performance map for tests that met more than 95% the demand. These tests present design solutions that are feasible to provide satisfactory hot water services.

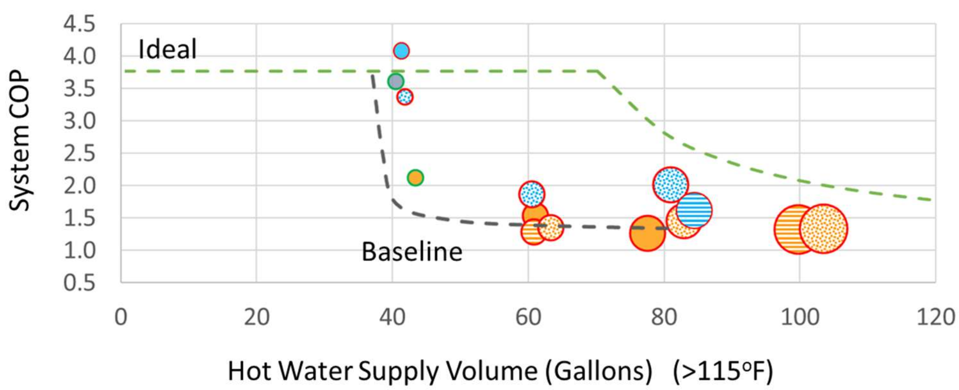

Figure 9 Performance results for tests meeting more than 95% of the demand.
Bubble size indicates the level of hot water demand. Bubbles with green outline are for HPWH in efficiency mode and bubbles with red outline are for HPWH in hybrid mode. Bubbles filled with stripes are for tests with recirculation. Bubbles filled with dots are for the settings to increase stored energy.

The following observations are made from this performance map:

- All scenarios are for medium and high HPWH flow restrictions, except one scenario of using low HPWH restriction to serve the lowest demand (40 gallons in 3 hours).
- For serving more than the lowest demand, the HPWH needs to be in hybrid mode (bubbles with red outline).
- With high HPWH flow restriction (blue bubbles), the system achieved the highest COP when serving high demand. With medium HPWH flow restriction (orange bubbles), the system achieved the highest hot water supply capacity.

Conclusions

The study systematically examined the performance of design options for a small HPWH system based on a 50-gallon HPWH and a 50-gallon storage tank. Using a novel laboratory testing procedure, the study assessed both energy efficiency and hot water supply capacity of the different design options to identify feasible design solutions and provide data to develop design guidelines. Laboratory testing results show that successful designs include three key features: flows into the HPWH are highly restricted, the HPWH is set in a hybrid mode that promptly activates resistance heating to provide stable hot water supply temperature, and both HPWH and primary storage use a relatively high setpoint.

HPWH flow restriction setting has the largest impact on system performance. Without adequately limiting water flow rate for the HPWH, it will quickly run out of hot water during high-demand periods, leading to high levels of electric resistance heating. At the same time, the primary storage will be under-utilized and unable to boost system supply capacity. Effective use of the primary storage is achieved when medium-to-high levels of flow restriction are applied to the HPWH. High levels of HPWH flow restriction can reduce the load for the HPWH during peak demand, reducing electric resistance heating and improving efficiency. However, this setting also reduces HPWH utilization and leads to a lower hot water supply capacity than medium HPWH flow restriction.

Heat pump operation alone cannot produce enough hot water to meet large demand. It is critical for the system to activate electric resistance heating quickly, when needed, to ensure reliable hot water supply. The HPWH's hybrid mode activated resistance heating before its upper tank temperature was significantly reduced and, therefore, was able to produce hot water quickly enough to meet relatively large demand. In contrast, efficient mode activated resistance heating only after the HPWH was significantly depleted. This not only caused the HPWH to not be able to produce hot water quickly enough to meet demand; in some cases, it also led to more electric residence heating than hybrid mode to recover the HPWH to the setpoint. Efficient mode can be a good option when the HPWH is used as an individual unit to serve one dwelling unit but it is not appropriate when the HPWH is used in a small system to serve several dwelling units.

The system's hot water supply capacity was substantially improved by increasing the setpoint of the HPWH and primary storage by 5°F. The elevated setpoints increased delivery temperature and, therefore, the amount of delivered hot water exceeding the 115°F threshold.

Performance of all feasible design options identified by the study is significantly lower than the ideal performance. The highest system COP for meeting demands higher than the lowest level was under 2.1. The project team plans to conduct more laboratory tests to explore additional design options to achieve better performance in terms of both energy efficiency and hot water supply capacity using the laboratory test procedure and performance analysis method developed by this study.

References

NMHC (National Multifamily Housing Council). 2024. " Characteristics of Apartment Stock". www.nmhc.org/research-insight/quick-facts-figures/quick-facts-apartment-stock/characteristics-of-apartment-stock/.

Banks, A; Grist, C; Heller, J; Lim, H. Sustainability 2022 "Field Measurement of Central CO2 Heat Pump Water Heater for Multifamily Retrofit." www.doi.org/10.3390/su14138048

Dryden, A, Andy B., Emily H., Greg P., Meghan D., Nehemiah S., & Sean A. 2023. "Getting to All-Electric Multifamily Zero Net Energy Construction". California Energy Commission. Publication Number: CEC-500-2023-006-D.

Rothgeb, S., Hoeschele, M., & Weitzel, E. Davis, California 2017 "Building America Case Study: Multifamily Central Heat Pump Water Heaters". www.nrel.gov/docs/fy17osti/66429.pdf.

Zhang, Y., Higa R., and Kim, C. 2020 "Balancing Heating Capacity and Storage Volume in Heat Pump Water Heater Systems", ACEEE 2024 Summer Study on Energy Efficiency in Buildings