Title
Characterizing electrical demand and load diversity of low-power water and space heating appliances in US homes

Authors
Less, Brennan
Sanchez, Lino
Walker, Iain

Publication Date
2026-08-02

Buildings & Industrial Energy Systems
Energy Technologies Area
Lawrence Berkeley National Laboratory

Characterizing electrical demand and load diversity of low-power water and space heating appliances in US homes

Less, Brennan[1], Sanchez, Lino[2], Walker, Iain[1]

[1]Lawrence Berkeley National Laboratory, [2] University of California - Berkeley

Energy Technologies Area
August 2026

https://doi.org/10.20357/B71021

This work was supported by the Assistant Secretary Office of Critical Minerals and Energy Innovation (CMEI) of the US Department of Energy under Contract No. DE-AC02-05CH11231.

Characterizing electrical demand and load diversity of low-power water and space heating appliances in US homes

Brennan Less, Lawrence Berkeley National Lab (LBNL)
Lino Sanchez, University of California - Berkeley
Iain Walker, LBNL

ABSTRACT

Home renovation and remodeling projects can involve costly and time consuming electrical infrastructure upgrades at the household level. From the grid perspective they also lead to costly replacement of local infrastructure, such as transformers, and can add stress to the grid at peak times. The emergence of innovative, power-efficient household appliances offers a way to minimize these problems. These appliances are designed for lower power consumption, simplifying installation through standard plug-in connections, reducing the need for new electric circuits/panels/service, and minimizing the peak power demand for the home. Key examples include low-power heat pump water heaters (HPWHs) and cold climate window heat pumps that operate on standard 120V outlets. To assess the real-world impact of these solutions, we compiled and analyzed power metering data from several US field studies. This data provides insights into the effects on peak power demand of selecting lower-power appliances. Our analysis focuses on several key metrics, including the maximum power demand of individual appliances, their operational runtime, continuous operation and load diversity. While individual low-power 120V space and water heating appliances offer significant peak demand reductions compared to 240V heat pump or resistance alternatives, their longer runtimes might increase the likelihood of operation during whole-dwelling peak events, albeit at lower power levels.

Introduction University of California - Berkeley

Renovation and remodeling projects in residential buildings frequently present significant financial and logistical hurdles related to electrical infrastructure. Upgrading or replacing major appliances can necessitate costly modifications to household wiring, circuit breaker panels, and the utility electrical service. From a utility perspective, cumulative load growth from home renovations can strain local distribution infrastructure, such as transformers, and contribute to stress on the broader grid, particularly during periods of peak power demand. The emergence of innovative, power-efficient household appliances offers a promising pathway to mitigate these challenges by fundamentally rethinking the relationship between appliance performance and electrical load.

For decades, the concept of "energy efficiency" has been a cornerstone of building performance, successfully reducing energy consumption and lowering utility bills for households. A focus on energy efficiency alone is no longer sufficient to address the modern challenges of managing electrical load growth and ensuring affordable home upgrades. To address these challenges, we introduce the concept of “power efficiency,” which focuses on power rather than energy requirements.

Recent work by Less, Walker, and Graessle (2026) provides a formal framework for this concept, defining power-efficient appliances based on: a significantly reduced rated power demand, simplified interconnection that allows for use of standard electrical receptacles, and the inclusion of advanced load control functionalities. This new focus on power efficiency is being cultivated by market transformation initiatives. Programs such as the Advanced Water Heating Initiative (AWHI)[1] and the U.S. Department of Energy's EASE-E Prize[2] have accelerated the development and commercialization of such technologies. Similarly, targeted challenges by the New York City Housing Authority (NYCHA), including the Clean Heat for All[3] program and the Induction Stove Challenge[4], are creating market certainty and prompting manufacturers to develop affordable, plug-in solutions for space heating and cooking (March et al. 2024).

As these market-shaping efforts accelerate product development, early field studies have begun to document the performance of first-generation power-efficient appliances. Recent investigations have explored the deployment and performance of 120V plug-in HPWHs in California and the Upper Midwest (Khanolkar et al. 2023; Slipstream 2024), the performance of heat pump clothes dryers[5] (Boudreaux et al., 2024; Graban et al., 2021; Martin et al., 2016; Pigg et al., 2021), installation and performance of battery-integrated 120V cooking ranges in tribal housing (Anderson et al. 2024), occupant satisfaction with window heat pumps in California's central valley (Beaini et al. 2024), and pilot deployment of cold climate units in NYCHA multi-family buildings (March et al. 2024). These foundational studies have primarily focused on energy consumption, deployment feasibility, and occupant satisfaction.

A critical gap remains in the detailed characterization of the power demand of these appliances, which is essential for understanding their impact on both household and grid infrastructure. This paper seeks to answer two primary research questions:

- How do the power demand characteristics of the sampled power-efficient appliances compare with conventional alternatives?
- What is the relationship between maximum power demand, runtime and the potential for coincidence with other household electrical loads?

This paper addresses two primary types of 120V plug-in power efficient appliances: HPWHs and cold climate window heat pumps. We assessed the power efficiency of these appliances by analyzing their operational characteristics, using several publicly available and proprietary field-metered data sets from across the United States. We also compared these 120V systems to conventional 240V systems using data for conventional appliances from Less and Walker (2026).

Description of the power efficient appliances and equipment

120V Plug-in HPWHs. Power-efficient water heating solutions are characterized by lower rated power, a lower rated voltage, and the capability to connect to existing 120V receptacle outlets. Utilizing existing receptacles allows these appliances to potentially alleviate breaker space limitations in electrical panels and reduce installation costs. Moreover, their significantly lower rated power offers the potential to reduce both electrical service sizes and grid power demand. Their power requirements are 500 to 1200 W compared to typical electric resistance storage water heaters of 4500 to 5500 W) and 240-volt hybrid HPWHs (which are typically 5000 W).

[1] https://www.advancedwaterheatinginitiative.org/
[2] https://www.energy.gov/cmei/articles/us-department-energy-announces-finalists-home-electrification-prize
[3] https://www.nypa.gov/news/press-releases/2021/20211220-decarbonize
[4] https://www.nyc.gov/site/nycha/about/press/pr-2023/pr-20230724.page
[5] We are unaware of any field measurements documenting performance of combined washer and dryer appliances.

The latter often have a higher nameplate rated power than an equivalent electric resistance unit, because they contain both a compressor and the same electric resistance elements as a conventional tank, and in some models both can operate simultaneously. 240V lower-power options are beginning to come to market that have smaller or no resistance elements. Some marginally higher-powered 120V plug-in HPWHs are rated for installation on an individual (or “dedicated”) branch circuit, while the lowest power options are allowed on general purpose (or “shared”) circuits.

120V Plug-in cold climate window heat pumps. 120V plug-in heat pumps come in two configurations: one is floor-standing (usually on wheels), with ducts that connect to outside through a frame mounted in a window opening. The second is more like a classic plug-in air conditioner and fits in the window opening without any ducting required. Most plug-in heat pump solutions have inadequate performance in cold temperatures, making them unsuitable for cold climate applications. Recently, cold-climate plug-in heat pumps have been developed and are the focus of this study. To support adoption of these cold-climate plug-in heat pumps, the NYCHA created the Clean Heat for All (CH4A) prize. This prize incentivized and selected two manufacturers to produce cold-climate-capable window heat pumps, with NYCHA promising to bulk-purchase and install up to 30,000 units in its housing stock.

Data sources

The data sources for this work include both power-efficient and conventional appliances, summarized in Table 1 by the number of metered devices and voltage, and in Table 2 by the equipment type and rated voltage. Field-metered HPWH time series data were collected for 240V and 120V plug-in equipment from a combination of the DOE Heat Pump Database[6], a non-public data set for 120V HPWHs in the upper Midwest (Slipstream 2024), and from Less and Walker (2026). 120V plug-in cold climate window heat pump data were procured from a pilot study in two multi-family buildings by NYCHA's Clean Heat for All (CH4A) program. We sourced baseline data for conventional appliances from Less and Walker (2026), a study of sub-metered electricity use in 911 US dwellings. This study included data from two primary sources–Pecan Street Dataport and the Northwest Energy Efficiency Alliance (NEEA) End-Use Load Research project.

Table 1. Summary of data sources

Data Source	Voltage	Number of Systems	Source
Clean Heat for All (CH4A) Window HP	120	72	Proprietary dataset
NBI 2023 120V Plug-In HPWH	120	32	Khanolkar et al. 2023
Slipstream Residential Field 120V Plug-In HPWH 2020-2021	120	26	Slipstream 2024
E350 Residential HPWH Study	240	9	E350, 2018
MaxTech Residential HPWH Study 2023	240	2	Munk et al. 2023
Installed Performance of HPWHs in a Cold Climate	240	9	Cautley et al. 2021

[6] https://heatpumpdata.energy.gov/

Northwest End-Use Load Research Project	240	424	Less and Walker 2026
Pecan Street	240	620	Less and Walker 2026
SMUD Residential Field HPWH Study	240	10	None[7]

Table 2. Summary of system types

System Type	Voltage	Number of Systems
Space Heating		
Central Heat Pump[8] (Ducting Unknown)	240	413
Central Heat Pump (Ducted)	240	54
Central Heat Pump (Ductless)	240	42
Central Heating - Resistance	240	81
Room Heating - Heat Pump (Window)	120	72
Room Heating - Resistance	240	188
Water Heating		
Storage Water Heater - Heat Pump	120	58
Storage Water Heater - Heat Pump	240	50
Storage Water Heater - Resistance	240	254

Clean Heat for All (CH4A) Cold Climate Window Heat Pumps

As part of its Clean Heat for All program, the New York City Housing Authority (NYCHA) performed a pilot demonstration installing between 2 to 3 cold climate window heat pumps in each of 24 two-bedroom, 700 ft^2 ($65m^2$) apartments in two midrise multi-family buildings (12 apartments and 36 heat pumps per building) that were part of its housing portfolio (March et al. 2024). One unit was installed in each bedroom, plus one in the living room. A total of 72 window heat pumps were installed and metered. Metering data for this study was provided directly through a data sharing agreement with NYCHA and is not otherwise publicly available. Within each six-story building, the apartments were arrayed vertically and their conventional 2-pipe steam heating systems were disabled. Cold climate window heat pumps from two manufacturers were tested, with each building exclusively equipped with units from a single manufacturer. The window heat pumps had heating and cooling capacities of 9 kBtu/hr at 17°F and at 95°F (2.6 kW at -8°C and 35°C), respectively. Both manufacturer's units have nameplate rated power of 1380 VA (12A, 115V) (see Figure 1), and were installed using existing 15A, 120V receptacles where possible. Most circuits were dedicated and not shared with other miscellaneous loads. Each window heat pump unit was individually metered using 120V plug-through power meters, along with indoor temperatures and select other parameters.

[7] No research report is available for this study

[8] Anticipated mix of single- and dual-stage, as well as variable capacity equipment types. Specific equipment types are unknown. Presence of backup resistance heat is also unknown. "Central" here refers to whole-home systems. It does not refer to whole-building systems that serve multiple dwellings in a multi-family building.

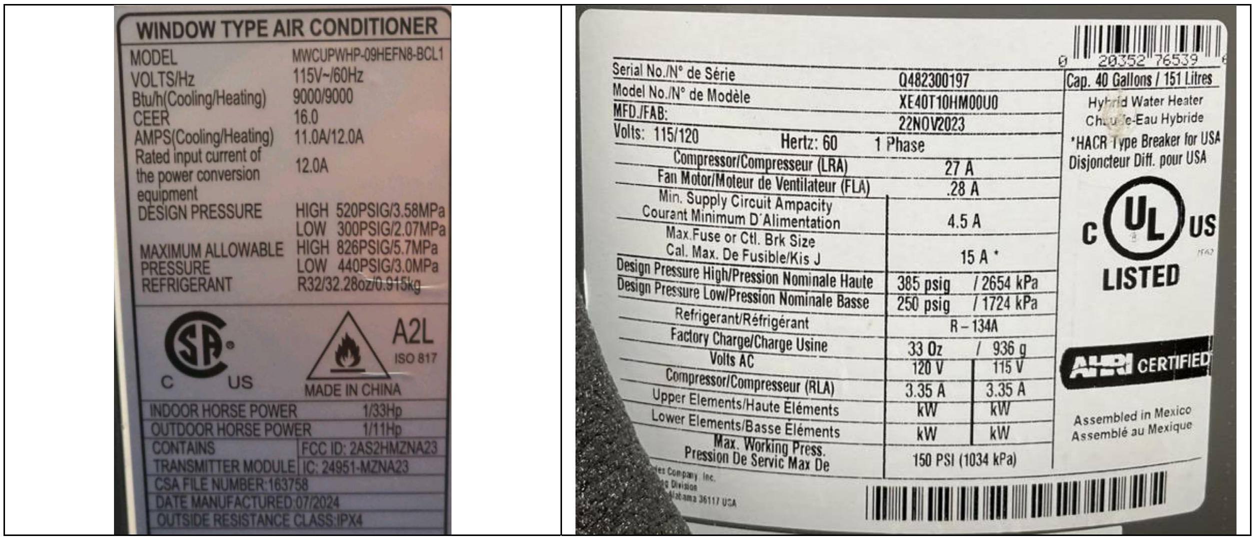

Figure 1. Example nameplates from installed window heat pump (left) and 120V plug-in HPWH (right)

NBI 120V Plug-In HPWHs in California

NBI reported on installation and metering of 23 120V plug-in HPWHs in California single-family households with 2-4 occupants (Khanolkar et al. 2023). The metering data for this study was retrieved from the DOE heat pumps database. We were not able to retrieve metadata for these homes and equipment, such as home floor area or details on the types of 120V HPWH. Correspondence with the authors confirmed that all installed units were “shared circuit” types, where the manufacturer does not require installation on an individual (“dedicated”) branch circuit. Shared circuit HPWH typically have lower nameplate rated power and lack any backup resistance heat elements. A few split system HPWH were installed, but the majority were integrated storage type HPWH. To be considered “shared” circuit units, rated power must be less than 900 W, but many of the installed units had lower rated power of around 540 W (4.5A, 120V) (see Figure 1), and were installed using existing 15A, 120V receptacles.

Slipstream 120V Plug-In HPWHs in Upper Midwest

Slipstream documented the installation, performance and user experience of 26 120V plug-in HPWHs in single-family homes in the Upper Midwest (8 homes each in Illinois and Michigan; 10 homes in Wisconsin) (Slipstream 2024). Most units were installed in basements. Metering data for this study was provided directly through a data sharing agreement with Slipstream and is not otherwise publicly available. This study evaluated two distinct types of 120V plug in HPWHs:18 shared circuit and 8 dedicated circuit units. A total of three distinct makes/models were installed from different manufacturers. The exact nameplate electrical ratings of the installed units are unknown, so we assumed the following nameplate power values: 540 W (4.5A, 120V) for shared circuit, and 1440 W (12A, 120V) for dedicated circuit units. These rated values were used for comparison against metered maximum power demand.

Methods

Metering data

Our analysis used 15-minute time series data for each appliance to determine maximum power, runtime fraction, continuous load fraction and demand factors. A primary challenge was reconciling the disparate time resolutions of the source data, which ranged from 15-seconds to 15-minutes. Direct comparison of peak power demand across these resolutions is misleading, as higher-frequency sampling provides more opportunities to capture transient spikes, while lower-frequency sampling smooths out variability in power demand. To create a basis for comparison, all time-series were down sampled to a uniform 15-minute interval. This was achieved by averaging all higher-resolution data points that fell within each 15-minute window. All measurements were standardized to real power in watts (W). CH4A provided metered data as accumulated energy (kWh), so average power was calculated for each 15-minute interval. Where sources provided apparent power (VA), it was converted to real power using the provided power factor. Real power was estimated using volts and current in data sets that did not otherwise report power directly. Gaps in the time series resulting from telemetry interruptions were maintained as missing values in the final dataset.

Appliance and Site Data

To compare load profiles across technologies, we linked the time series power data with two separate metadata files. The first file documented building site characteristics, including state, zip code, floor area and others. The second cataloged technical attributes for each unique piece of equipment, such as its type (e.g., central or window heat pump) and rated voltage (120V vs. 240V). Many fields were incomplete due to a lack of metadata provided as part of the data sources.

Power efficiency metrics

The following key metrics were derived from our compiled power efficient appliance data to facilitate a direct comparison with similar data sourced from conventional appliances by Less and Walker (2026). The primary assessment is the maximum power demand. To assess how 120V heat pump loads may combine with other household end-uses, we also evaluated runtime fraction, continuous load fraction and demand factors.

Maximum power demand. The peak instantaneous maximum power demand value provides a first-order assessment of equipment peak power demand, and facilitates comparisons between 120V and 240V equipment. In addition to comparing by system types, we also can compare measured peak power demand with equipment nameplate ratings. For each dwelling, we retrieved the maximum power value at its listed 15-minute interval timestamp, noting that for many units, this consisted of an aggregated maximum power demand derived from higher frequency data. For any system that does not have at least one cycle of 15 minutes or longer, this metric may underestimate maximum power demand. However, for heat pumps and HPWHs, runtimes of 15 minutes or greater are common.

Runtime fraction. We calculated the runtime fraction, a metric representing the percentage of time an appliance is operational. This metric is important for assessing the likelihood that an appliance's load will coincide with and compound other household loads, indicating its potential to contribute to dwelling peak power demand. The fraction was calculated by dividing the total time an appliance was 'on' by the total duration of its monitoring period. An appliance was considered 'on' during any 15-minute interval where its power draw exceeded a threshold of 100 W, a value established to distinguish active compressor operation from negligible standby power. This approach will systematically over estimate runtimes because there can be 15-minute intervals with very little actual operating time. In future work we will investigate the magnitude of this bias using the datasets that have shorter timescale data.

Continuous load fraction. We calculated the continuous load fraction to quantify the sustained nature of peak events. This metric is important for assessing household and grid impacts, as it distinguishes between brief, intermittent power spikes and prolonged high-demand events, which place greater strain on electrical infrastructure due to risk of overheating conductors. Loads identified as "continuous" in the National Electric Code (NEC) are often treated with a conservative 125% adjustment to account for potential overheating risks. The continuous load fraction was calculated as the ratio of maximum sustained power demand to the absolute peak power demand. We treated the maximum sustained power demand as the highest 3-hour average power (consistent with the NEC definition), identified across fixed 3-hour time intervals (e.g. 12:00 to 3:00, 3:00 to 6:00, 6:00 to 9:00, etc.) spanning the entire time series. This value was then divided by the highest single 15-minute interval power reading. The resulting value ranges from 0 to 1, where values approaching 1.0 indicate a sustained, continuous power demand, while lower values signify a more intermittent demand pattern.

Demand factor. We calculated the demand factor to quantify load diversity and coincidence within a dwelling. This metric is important for improving electrical system sizing, as it contrasts the actual observed peak power demand with a theoretical maximum. It is calculated as the ratio of the maximum observed coincident power demand to a theoretical maximum. The numerator—maximum observed coincident power demand—was the highest measured power draw from all appliances operating simultaneously. The theoretical maximum is the sum of nameplate ratings, calculated by adding the manufacturer-rated power (voltage × amperage) of each appliance. In this analysis, demand factors were calculated only for window heat pumps in the CH4A dataset, because multiple metered devices were installed in the same dwelling unit. All other data sources included metering of only one device per dwelling and did not include whole dwelling power demand metering, which did not facilitate demand factor calculation.

Results

Heat pump water heaters

It is evident from the maximum power demand plotted in Figure 2 that 120V heat pumps have lower maximum power demand than their 240V heat pump counterparts. Most 120V units peak at <1 kW, while almost all 240V units peak at >4 kW. These values align roughly with the nameplate rating estimates for these types of equipment. 120V HPWHs connected to a dedicated circuit saw a mean maximum power demand of 1491 W, which was substantially higher than shared circuit 120V HPWHs, with mean maximum demand of 513 W. Maximum power demand for 240V HPWHs and electric resistance water heaters were similar, with mean maximums of 4380 and 4540 W, respectively. Median maximum demand was roughly 200 W higher for 240V HPWHs.

The continuous load fractions are shown in Figure 3, and they exhibit an opposite relationship with maximum power, where higher maximum power 240V HPWHs have low continuous load fractions, averaging between 40-50%, and commonly ranging from 20-80%. The lower-powered 120V HPWHs have consistently high continuous load fractions between 80 and 100%, suggesting their compressors sometimes operate for three or more hours without stopping. The wide range for 240V HPWHs likely results from interrelated operation of the compressor and the backup resistance heating elements. A continuous fraction of 100% would require that the backup resistance elements operated at full power for at least 3-hours, which was rare.

The runtime fractions calculated for 120V and 240V HPWHs shown in Figure 4 are quite similar and not obviously distinguishable. Almost all devices in both voltage categories have runtimes less than 40% of the metered intervals, with the majority of devices operating from 15-30% of the metered time period. The lack of distinction between the 120V and 240V water heaters in terms of runtime suggests that most 240V HPWHs operated on their compressors for most of the metered time period, and only occasionally operated their backup resistance heaters to recover from large hot water draws. For 240V HPWHs, we estimated runtimes for the backup resistance and the compressor separately, and we found that the majority of total runtime (mean of 85%; median 97%) was the compressor. Relative to total runtime, compressor values ranged from 53-100%, which suggests that many units effectively never operated their resistance, while others relied on it up to half of the runtime. This rare, occasional backup operation drives maximum power up and continuous load fractions down (relative to 120V HPWHs), but it appears to have minimal impact on equipment runtime. Notably, we do not know the HPWH equipment settings, which can be set to lock-out backup resistance, lock out the compressor, or allow hybrid operation of both.

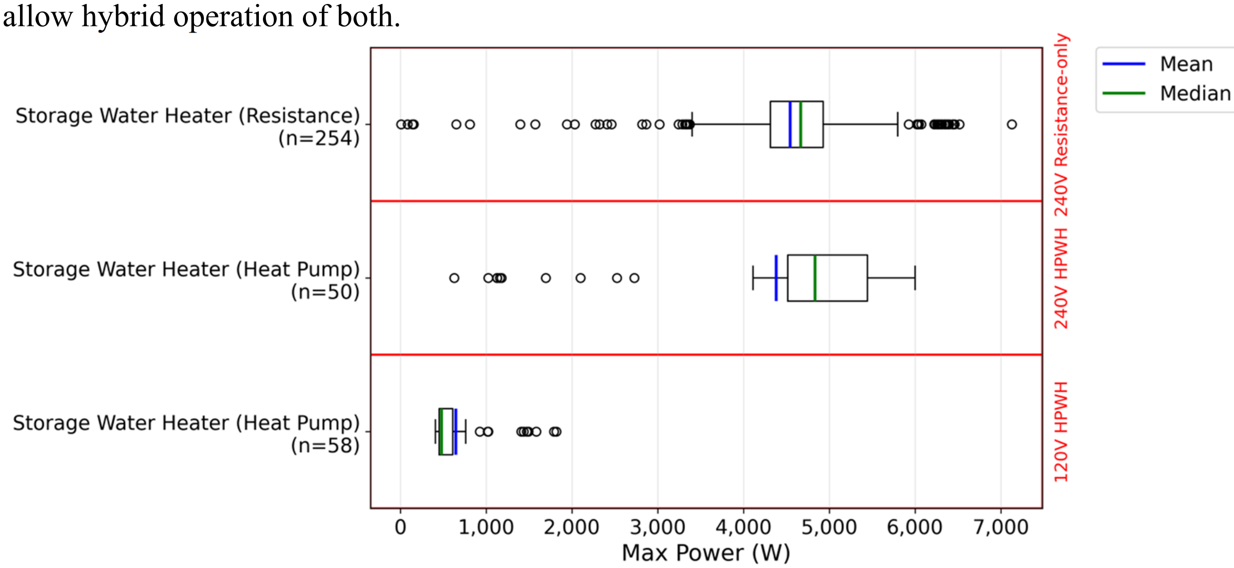

Figure 2. Maximum power demand for water heating equipment. The mean is represented by a vertical blue line and the median by a vertical green line.

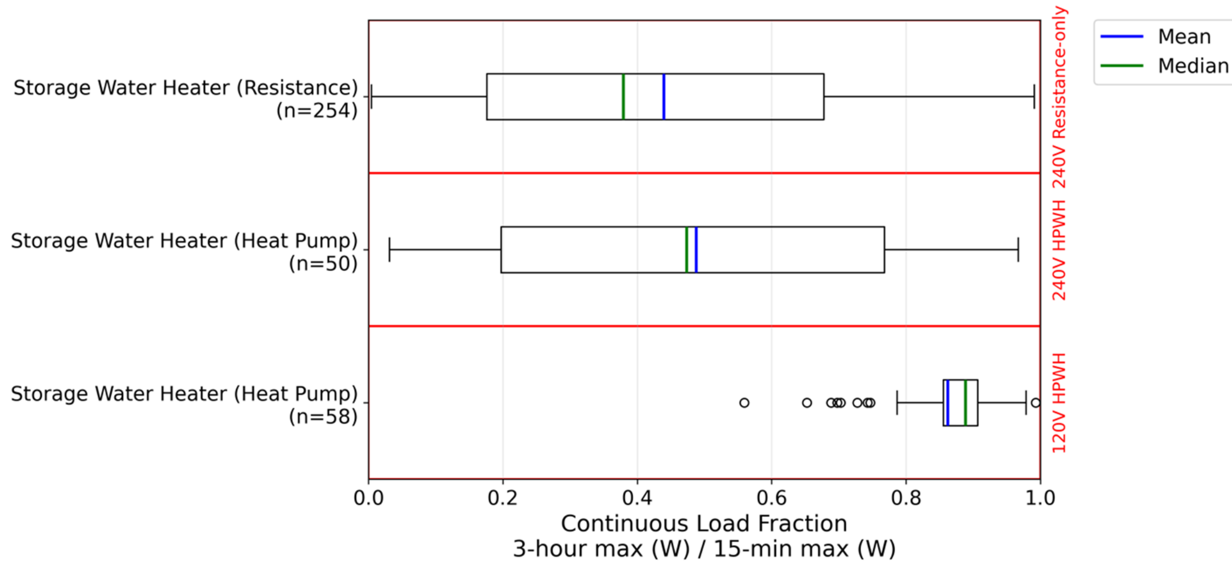

Figure 3. Continuous load fraction for water heating equipment.

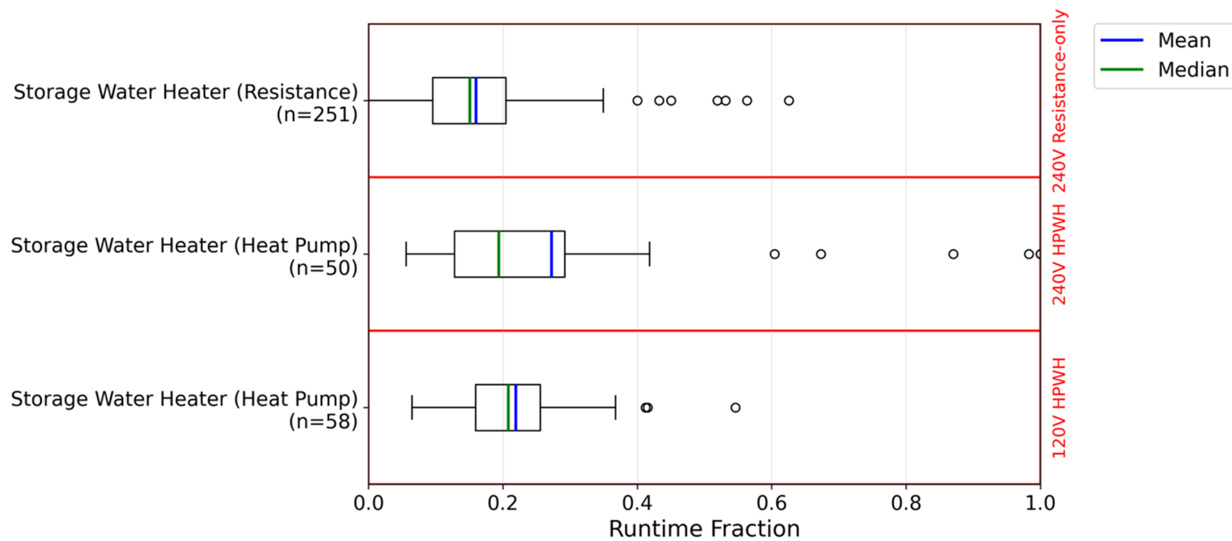

Figure 4. Runtime fraction for water heating equipment.

Window heat pumps

Cold climate window heat pump maximum power demand, both for individual heat pump units and aggregated by the 3 units in each apartment, are plotted in Figure 5, along with comparisons to conventional 240V space heating equipment from Less and Walker (2026). Almost all HVAC heat pump equipment had maximum power demand <5,000W. Central heating (resistance) exhibited much higher demand, commonly in the range of 5-15 kW and extending up to 24 kW.

While individual window heat pumps have lower maximum power demand, when all the individual heat pumps serving an apartment were combined, their combined maximum power demand was largely indistinguishable from other HVAC systems serving whole dwellings from Less and Walker. This suggests that the demand for 120V plug-in cold climate window heat pumps may in fact not be any less than that for more conventional HVAC heat pump systems for a whole dwelling, if that dwelling requires multiple window heat pumps. Given this lack of distinction on a whole dwelling level, the power efficient aspect of the 120V HVAC heat pumps relies on their use of existing receptacles and their use of 120V power, or their application in smaller dwellings where only a single unit is needed. This requires less breaker space in a dwelling unit electrical panel. Installation costs are also reduced because they do not need any ducting and/or running refrigerant lines through walls when connecting outdoor to indoor units. The power efficiency of these devices may also be more apparent for applications using individual units - either to heat smaller spaces or in locations with lower heating loads.

Window heat pumps were individually rated at 1,380W, and each apartment in our CH4A data set had three heat pumps, meaning their theoretical maximum coincident demand was 4,140W. Observed coincident demand was substantially less, indicating a demand factor of less than one. The demand factors were calculated dividing the coincident demand of the units in each apartment by the sum of the estimated nameplate power of the units in each apartment. The results in Figure 6 show that demand factors are usually substantially less than one for groups of window heat pumps in apartment dwelling units, with a typical demand factor of 40-60% for small groups of window heat pumps serving the same apartment.

Continuous load fractions are reported for space heating equipment in Figure 7, and there are two distinct groupings. As with the low power 120V HPWHs, the plug-in window heat pumps individually appear to have high continuous load fractions (80-95%), which are also well aligned with the estimates from Less and Walker for central heat pumps with unknown ducting configuration (80-100%). The other central heat pump categories in Figure 7 have much lower continuous load fractions (typically <50%), which Less and Walker hypothesized was due to those systems being variable capacity rather than single stage equipment. Both the Central and room resistance heating categories also showed lower continuous load fractions, potentially because they were able to satisfy heating load more rapidly under very cold weather conditions, when conventional heat pumps are known to have reduced heat output.

Runtime estimates are shown in Figure 8. Extended runtimes are evident for both individual units and for apartments. Run times for individual units averaged around 40% of the monitoring period and commonly ranged between 20 and 60%. When aggregated into groups of window heat pumps, runtime estimates increased, averaging around 70%, typically ranging between 50 and 85%. However, from a peak demand perspective, this increase in the aggregate needs to be tempered by the fact that not all units operate together. Any one unit operating contributes to the runtime - but the associated power may only be for a single unit - not all units combined.

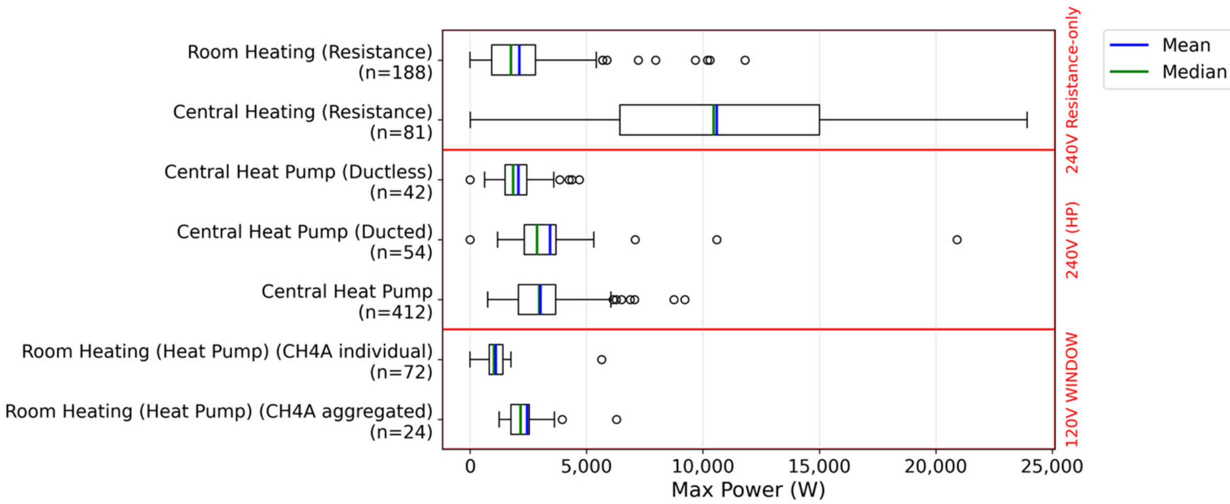

Figure 5. Maximum power for space heating equipment. Note that the “Room Heating (Heat Pump)” entries are cold climate 120v plug-in window heat pumps. They are presented individually (i.e., one appliance) and aggregated in each apartment (i.e., groups of three appliances).

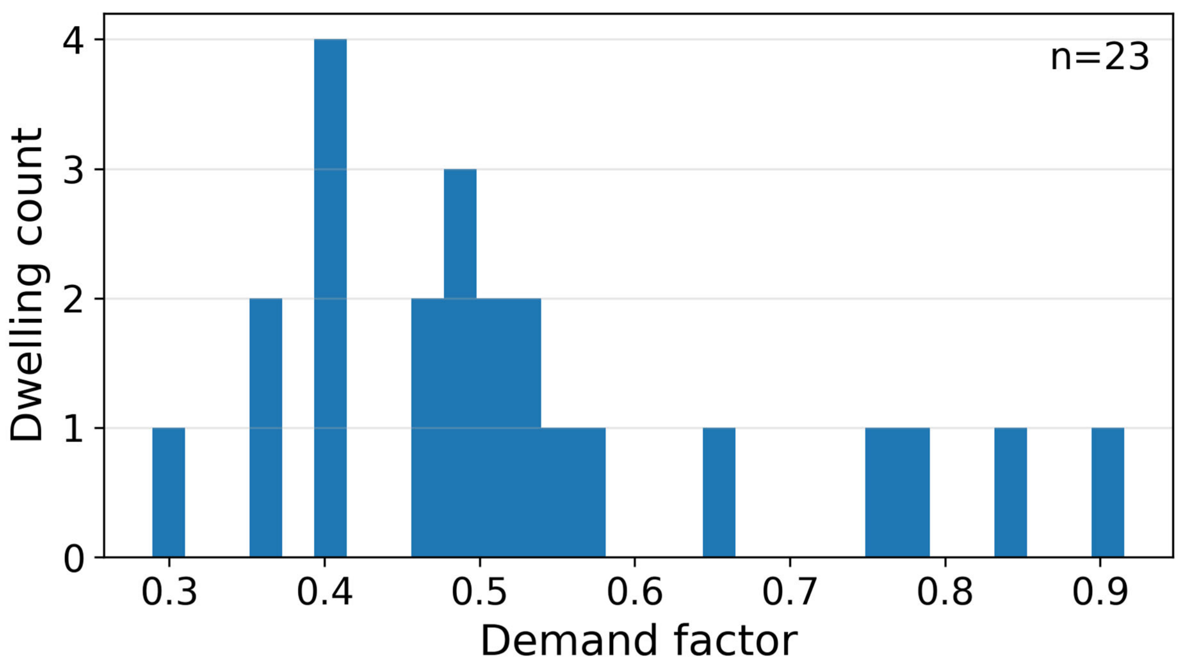

Figure 6. Demand factors for cold climate window heat pumps. Normalizes aggregated demand by the sum of the estimated nameplate power of the units in each apartment.

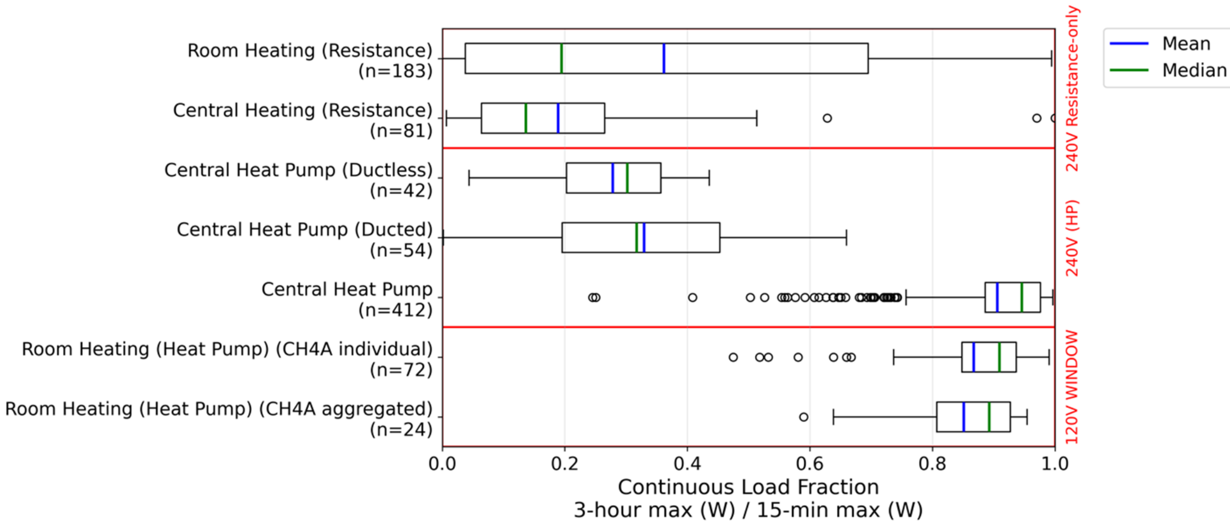

Figure 7. Continuous load fraction for space heating equipment. Note that the "Room Heating (Heat Pump)" entries are cold climate 120v plug-in window heat pumps. They are presented individually (i.e., one appliance) and aggregated in each apartment (i.e., groups of three appliances).

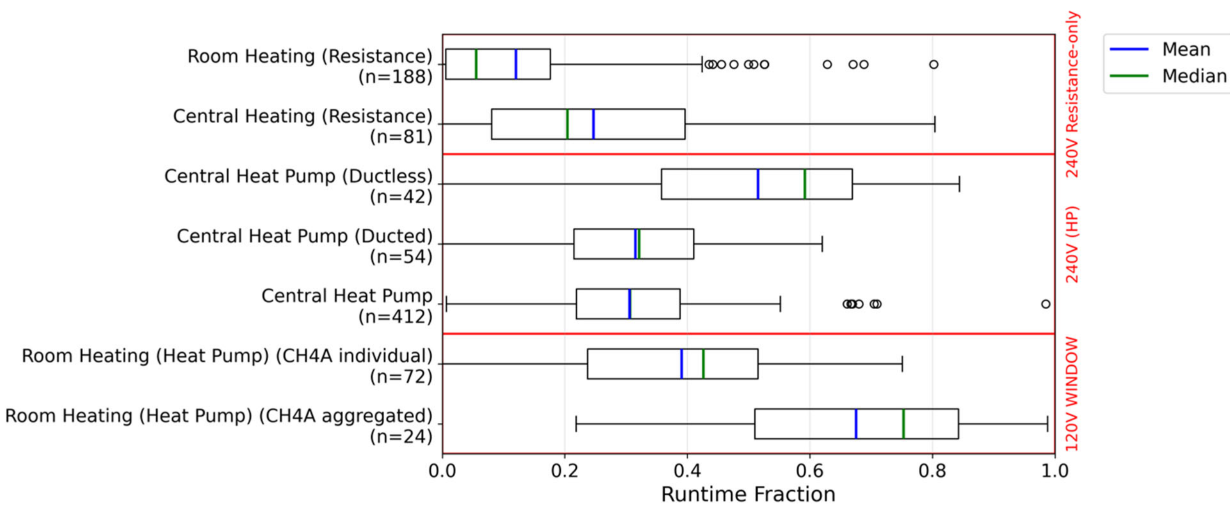

Figure 8. Runtime fraction for space heating equipment. Note that the "Room Heating (Heat Pump)" entries are cold climate 120v plug-in window heat pumps. They are presented individually (i.e., one appliance) and aggregated in each apartment (i.e., groups of three appliances).

Conclusion

This comparative analysis of low-power space and water heating appliances reveals distinct performance outcomes for water heating and space heating applications. Our findings show that 120V HPWHs provide a reduction in peak power demand for water heating relative to 240V HPWH and electric resistance alternatives, typically about 4000W. This confirms their effectiveness as an electrical load-reduction solution. The results for cold-climate window heat pumps in New York multi-family buildings are fundamentally different, because they aggregate together the operation of several units within each dwelling. While individual window units have low maximum power demand, their aggregated peak demand per apartment is comparable to conventional whole dwelling central HVAC heat pump systems and is about 7500W less than resistance heating. The crucial benefit for both technologies is their ability to operate on standard 120V plug-in circuits, which has potential to significantly lower installation costs, simplify adoption, and make these efficiency upgrades more accessible for DIY installation.

One goal of this study was to explore the relationship between maximum power demand, continuous operation and runtime. Lower maximum power demand for 120V plug-in technologies was clearly associated with continuous operation at or near the maximum. This was the case for both space and water heating technologies. Runtime estimates were quite similar for 240V and 120V HPWHs, and both types were marginally higher than electric resistance options. 120V plug-in window heat pumps had the longest runtimes when grouped together to serve entire apartments; runtimes for individual units were similar to 240V ductless heat pumps. All other space heating equipment showed substantially lower runtime estimates. These dynamics create a critical trade-off: the low-power appliances may be more likely to be operating during a dwelling's peak demand event, but their individual contribution to that peak is likely smaller. Future research should focus on whole-dwelling analysis to quantify the net-impact of this trade-off between higher coincidence and lower demand, for both households and the grid.

This work is limited in that it did not assess the service delivered, such as thermal comfort or hot water adequacy. To resolve the net impact of the observed operational trade-off and account for service delivery, future research must pair appliance sub-metering with whole-dwelling monitoring. This approach is essential to definitively quantify the effect of these appliances on aggregate household and grid peak demand. In addition, we compared space heating solutions largely derived from single-family dwellings with new metering data from multi-family apartment buildings. Evaluations in similar housing types will facilitate more valid comparisons. Window heat pump results are for applications where several units are used in each apartment and will not be representative of applications for single appliances heating smaller spaces or in milder climates.

While this analysis focuses on heat pump power characteristics, the total energy impacts of power-efficient appliances for whole households and regional electric grids remain an area for future work. There could also be implications for operating costs under time-of-use rates (or rates that include a peak demand charge), because the lower power alternatives use different amounts of power over different time periods. This study serves as a foundational step in characterizing these new technologies, providing essential data on their real-world operational load profiles to inform their role in future home modernization efforts.

Acknowledgements

This work was funded by the U.S. Department of Energy Office of Critical Minerals and Energy Innovation, Building Technologies Office under Lawrence Berkeley National Laboratory contract no. DE-AC02-05CH11231. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or the Regents of the University of California. This work would not be possible without metering data contributed from several sources, including the Pecan Street Dataport, NEEA End-use Load Research study, Slipstream, New York City Housing Authority's Clean Heat for All, and the many contributors to the DOE's heat pump data website.

During the preparation of this work the author(s) used Gemini 2.5 Pro in order to selectively help improve the clarity and reduce the length of previously written individual

sentences and paragraphs. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

References

Amruta Khanolkar, Mischa Egolf, & Noah Gabriel. (2023). Plug-In Heat Pump Water Heater Field Study Findings & Market Commercialization Recommendations: Lessons learned on the performance of 120-volt HPWHs from California-wide installations. New Buildings Institute. https://newbuildings.org/wp-content/uploads/2023/07/PlugInHeatPumpWaterHeaterFieldStudyFindingsAndMarketCommercializationRecommendations_NBI202308.pdf

Anderson, D., Phillip, C., Robinson, R., & Pfotenhauer, G. (2024). 120V Induction Stoves with Battery Backup (Final Report ET23SWE0064). CalNEXT. https://calnext.com/wp-content/uploads/2025/01/ET23SWE0064_120V-Induction-Stoves-with-Battery-Backup_Final-Report.pdf

Beaini, S., Quinn, S., Tam, A., Daher, M., Showunmi, D., Langsdorf, A., Romanin, V., Sander, J., Higbee, E., & Phillip, C. (2024, August). Field deployment of Window Heat Pumps in Multi-Family and Single-Family Low-Medium Income Homes. ACEEE Summer Study On Energy Efficiency in Buildings 2024. https://aceee2024.conferencespot.org/event-data/pdf/catalyst_activity_48501/catalyst_activity_paper_20240722163144234_21fee6c0_d8df_48f6_b308_bb81ed054c45

Boudreaux, P., Hall, C., Gluesenkamp, K. R., Karman, S., Willocks, J., Patel, V., & Gehl, A. (2024). Fast-airflow tumble clothes dryer with small thermoelectric heat pump: Experimental evaluation. Thermal Science and Engineering Progress, 55, 102960. https://doi.org/10.1016/j.tsep.2024.102960

Cautley, D., Gries, K., Cacko, D., & Margolies, J. (2021). Installed Performance of Heat Pump Water Heaters in a Cold Climate. Slipstream. https://heatpumpdata.energy.gov/system/files/files/cchp-2025-02/heat-pump-water-heaters-cold-climates_0.pdf

E350. (2018). CO2 & Integrated Heat Pump Water Heater Performance Report. Fortis BC. https://heatpumpdata.energy.gov/system/files/files/cchp-2024-02/CO2%20%26%20Integrated%20Heat%20Pump%20Water%20Heater%20Performance%20Report%20FINAL.pdf

Erik March, Jake Marin, James Mannarino, Maelyn Southers, & Sinan Chen. (2024). Super-Efficient Room Conditioners as a Multifamily Market Mover. ACEEE Summer Study on Energy Efficiency in Buildings. https://www.aceee.org/sites/default/files/proceedings/ssb24/assets/attachments/20240722160802234_36119e7d-75eb-48b9-ac5f-b4c191450e36.pdf

Graban, A., Groll, E., Braun, J., & Ziviani, D. (2021). Review of Heat Pump Tumble Clothes Dryer Energy Efficiency. International Refrigeration and Air Conditioning Conference (IRACC). https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3221&context=iracc

Less, Brennan D., Iain S. Walker, and Quinn Graessle. 2026. *Defining Power Efficient Residential Electric Appliances and Equipment*. LBNL Report. Lawrence Berkeley National Laboratory. https://escholarship.org/uc/item/5jk9g7w3.

Less, Brennan D., and Iain S. Walker. 2026. "Characterizing Peak Electricity Demand for U.S. Households: An Assessment of End-Use Loads and Demand Factors." *Applied Energy* 410 (May): 127422. https://doi.org/10.1016/j.apenergy.2026.127422.

Martin, E., Sutherland, K., & Parker, D. (2016, August). Measured Performance of Heat Pump Clothes Dryers. ACEEE Summer Study on Energy Efficiency in Buildings. https://www.aceee.org/files/proceedings/2016/data/papers/1_160.pdf

Munk, J., Hunt, W., Gehl, A., Rendall, J., & Metzger, C. (2023). Field Performance of R- 1234yf Heat Pump Water Heaters (PNNL-34257). PNNL. https://heatpumpdata.energy.gov/system/files/files/cchp-2025-02/PNNL-34257.pdf

Pigg, S., Lord, M., Schoenbauer, B., & Bensch, I. (2021). Field and market assessment of heat pump clothes dryers (Conservation Applied Research and Development (CARD) FINAL Report Contract 139379). Slipstream. https://slipstreaminc.org/sites/default/files/documents/research/heat-pump-clothes-dryers.pdf

Slipstream. (2024). The Midwest 120V Heat Pump Water Heater Field Study: Final Report. Slipstream. https://slipstreaminc.org/sites/default/files/2025-03/120V%20HPWH%20-%20Field%20Study%20-%20Final%20Report.pdf