Customer Innovation

The Midwest 120V Heat Pump Water Heater Field Study

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Prepared For
Commonwealth Edison Company

Prepared By
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EXECUTIVE SUMMARY

Heat pump water heaters (HPWHs) are a promising technology for decarbonizing residential water heating. However, traditional HPWHs require a dedicated 240V circuit, reducing their cost-effectiveness as an electrification solution if major electrical upgrades are necessary. These cost concerns are especially salient for customers earning low incomes.

To address this, manufacturers released 120V HPWH models that plug into a standard wall outlet. These units often reduce the need for electrical upgrades but heat water more slowly. In the first phase of this project, the research team modeled feasibility of 120V HPWH units in the Midwest and interviewed key market actors. Market actors expressed concerns about whether 120V units can meet occupant needs in cold climate winters when groundwater temperatures are colder and heaters must work harder to meet occupant demand. For the second phase of the project, Focus on Energy, ComEd, Consumers Energy and Xcel Energy partnered to conduct a year-long field study of 120V HPWH performance at 27 sites across the Midwest to investigate their performance in light of these concerns, as well as to develop guidelines for site selection, installation practices and potential incentive programs.

Twenty-five of these sites switched from a natural gas unit, one from a propane unit and one from an electric unit. All sites had an occupancy of four people or fewer. We installed 19 shared circuit units and eight dedicated circuit units. The dedicated circuit units require more electrical work to install but have higher power draws and thus shorter runtimes (though they are less efficient).

This study demonstrates that 120V HPWHs are a cost-saving electrification retrofit technology compared to 240V units and can meet hot water demand even in colder climates for households with four people or fewer who consume an average amount of water (18 gallons per person or less). Installers and participants were generally satisfied with the switch, and there were few issues with hot water availability even at the coldest points in the year. Some participants reported shifting their consumption patterns to accommodate the unit’s runtimes, but this often did not impact overall satisfaction. Manufacturers have said that upon receiving the results of this report, they will reassess cold climate 120V HPWH distribution.

Installers reported that swapping out natural gas heaters for 120V HPWHs was equivalent in ease and feasibility to a like-for-like replacement. Yet most installers were not familiar with critical considerations for 120V HPWH installation (e.g., room volume requirements, outlet locations, backflow prevention valve necessity) at the start of the study, as these products are new to the market. We recommend that distributors stock 120V units so that they are available for water heater replacements and that ComEd and distributors work together to train contractors on unit operational characteristics

and best-installation scenarios. Installers should be provided with detailed site and equipment selection criteria to ensure these units are the best choice and are installed optimally. Section 12.0 contains these criteria.

We conducted installer interviews to gather insights into the installation process. One theme of the interviews was that upsized 120V HPWHs are much broader and heavier than their gas and electric resistance counterparts, necessitating two installers be present at most installations. Installers stressed that before the installation day, it is important to confirm that the installation space, and the pathway to that space, are large enough to accommodate the units. It is also important before installation to confirm that an outlet is within reach of the unit or to devise another electrical solution if it is not. Finally, it should be confirmed that there is sufficient air space in the room and that the room's air temperature does not dip below the manufacturer's recommended temperature; otherwise, ductwork or a louver will need to be implemented.

Fifteen of the 25 installation sites interviewed required minor electrical work to be done upon installation. The installer was able to do this work for 13 of those sites, while the installation companies subcontracted to a separate electrician for the other two. However, this amount of work should not be expected if sites are assessed ahead of time, as installers suggested.

While these results are promising, there are also lessons learned from the field study to ensure that participants do not experience hot water runouts that impact their daily routines. Most importantly, the field study revealed that runouts often follow a large consumption event.0F0F1 This is true for 240V or gas units, as well, but 120V units recover heat more slowly than their counterparts. Manufacturers have included an integrated mixing valve in many units and recommend upsizing the HPWHs to avoid runouts by increasing the available hot water from a full tank.1F1F2 Still, when hot water runs out with a 120V unit, it runs out for longer and could be a greater inconvenience.

Two proxies can be used to get an idea of a household's consumption: household size and the frequency of runouts with a household's old water heater (assuming that the old heater is not faulty or undersized). We recommend households that do not frequently deplete their current water tank switch to a shared or dedicated circuit 120V HPWH if they have three occupants or fewer. Households with an occupancy of four should switch to a dedicated circuit 120V HPWH because of these units' shorter recovery times. If installers verify that the household occupants take short (~5 minute)

[1] We define a large consumption event as a 3-hour period where greater than 50 gallons of hot water was consumed, but runout likelihood increases with additional gallons consumed in the prior three hours.
[2] Dedicated circuit units, with their shorter runtimes, could also potentially combat runouts, but more research is needed to this end.

showers, do not take baths and have low-flow showerheads in all showers, they can switch to a shared-circuit unit.

Groundwater temperature also influences the frequency of hot water runouts, especially at higher levels of consumption.2F2F3 This further underscores the importance of selecting only low- and medium-consumption households to switch to a 120V product. Figure 1, below, illustrates the combined effect of previous consumption and groundwater temperature. Large consumption events during the three hours prior to a draw show a higher percentage of water runouts overall, but all lines over 25 gallons slope downwards, with a higher percentage of runouts at lower groundwater temperatures.

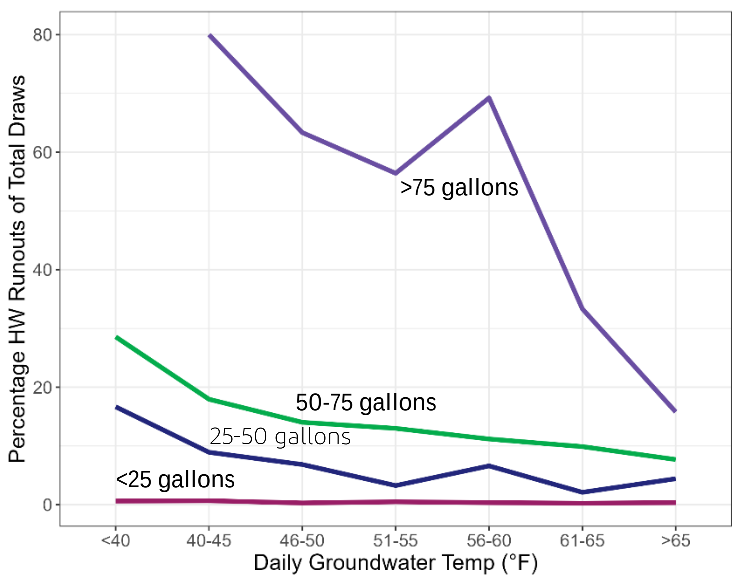

Figure 1. Percentage of HW Runouts vs. Groundwater Temperature, Grouped by Consumption over Three Hours Prior

The study measured a decrease in temperature of the room containing the HPWH following compressor operation. Measured room humidity also decreased slightly during the summer season. Participants saw dehumidification as a benefit, while the temperature findings oscillated between benefit and drawback depending on the season. Units should not be installed in a place where the resident spends a lot of time as the noise of the compressor can be annoying.

Units performed efficiently year-round, even in colder Midwestern climates. Units had an average coefficient of performance (COP) of 2.4. The average site used 87% less energy with a 120V HPWH than with its previous unit.

[3] Throughout this report, we will use the term "groundwater" to refer to the water piped into a residence, whether from a well, a body of water, or another source.

Units consumed more electricity per gallon of water delivered when groundwater temperatures were colder. Simultaneously, we found a negative correlation between COP and groundwater temperatures, with lower groundwater temperatures driving more efficient operation. We also found a positive correlation between COP and the temperature of the indoor air pulled into the heater, with warmer air resulting in more efficient operation. These latter two effects worked in opposite directions seasonally, leading to very little variation in COP throughout the year.

The operational cost of 120V HPWHs is similar to that of the replaced gas units, with the HPWH yielding a study-wide average cost savings of around $7 per month. The range of monthly water heating energy cost change varied from being $9 more expensive to saving $18 for sites switching from natural gas fuel.3F3F4 The average total monthly 120V HPWH operating cost was $13.75 in ComEd territory. Since the study average 120V HPWH install cost was around $5,500, these units cannot pay for their increased installation cost with savings. However, units experienced operational cost savings at a natural gas price of $0.56 per therm or more, on average. Figure 2, below, shows the operational cost difference of participants' natural gas versus 120V units.

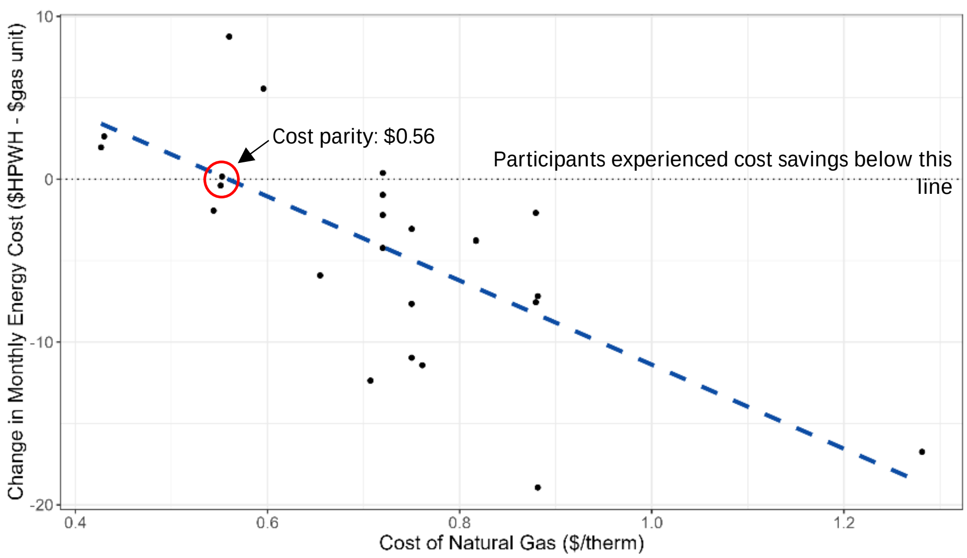

Figure 2. Change in Water Heater Energy Cost vs. Natural Gas Cost*

*Costs exclude lump taxes and service fees.

The results of this study indicate that 120V HPWHs are a feasible technology for fuel switching in ComEd electrification programs. The 120V HPWHs avoid electrical upgrades, including panel upgrades. They also deliver high efficiency and energy savings and maintain utility cost parity for most customers.

[4] This range in savings is due to differing gas and electricity rates in different territories, differing efficiencies of old and new units, and differing consumption patterns (people using more energy benefit more from the increased efficiency of the HPWH).

As with 240V HPWHs, the initial cost and the cost-effectiveness of 120V units remain major barriers. ComEd does not currently incentivize hybrid 240V HPWHs through its midstream program, and 120V units are not yet available in the Midwest. ComEd can leverage the midstream program to bring 120V units to Illinois; once these units are incentivized to offset their >$2000 incremental cost versus natural gas replacements and once manufacturers are aware that they can work in the Midwest, regional distributors are more likely to stock them. Most water heater replacements occur when a prior water heater fails, and the midstream program can incentivize deployment at this juncture, as well as in general.

If ComEd intends to incentivize 120V HPWHs in Illinois, the program should ensure that EESPs and distributors have access to educational materials and trainings on the best practices for installation. The installation recommendations in Section 12.0 should be incorporated into the program requirements through checklists.

This report presents and discusses the findings outlined above, detailing study design, unit performance, participant and installer experience, aggregate demand patterns and recommendations.

Table 1: Findings and Recommendations

Category	Findings	Recommendations
Program Design	• As a technology specifically designed for electrification retrofits, 120V HPWHs easily replace natural gas units when space is not constrained and an outlet is present. Midwest basements often meet these requirements, presenting utilities with low-friction opportunities to install HPWHs in these residences. • The optimal type of unit to install depends on whether a shared circuit outlet, dedicated circuit outlet or existing 240V line is present. In the absence of a 120V outlet and an unconstrained panel, a 240V hybrid unit may be equal in cost to install because an electrician will be required in both situations. Form factor innovations such as top versus side piping and unit dimensions should also be considered, especially as more manufacturers and models enter the market. • Installers require additional education and training on required air volumes and electrical work for 120V HPWH installations in residences. • 120V HPWH and gas units are at around operational cost parity with slight average monthly savings after HPWH installation. The average monthly operational cost savings in the study was $7. A natural gas volumetric price of $0.56 per therm resulted in net operational cost savings. • At program scale, we estimate that the full installation of a 120V HPWH full will cost over $4,000. These units do not pay back their upfront cost in savings across their lifetime for natural gas customers, but they do have a lower first cost than 240V units due to reduced electrical upgrade requirements. For propane customers, these units have a simple payback of fewer than 10 years.	• Utilities should incorporate 120V HPWHs into electrification programs as a cost-saving measure compared to 240V units when switching from natural gas and propane water heaters with a nearby outlet. However, for natural gas customers, these units would require large incentives to pay back and would likely not be cost effective from a total resource cost perspective. Future research could confirm effective messaging and incentive levels to motivate customers to install 120V HPWHs. • The 120V units are not recommended to replace electric resistance water heaters, which have a circuit present that can accommodate a 240V unit. • Utilities should leverage midstream programs and distributor relationships to ensure installers have access to 120V units at the time of old unit replacement. The available units through programs should cover as many form factors as possible to address a variety of installation spaces. • Utilities should consider recruiting candidates for 120V HPWH retrofits through weatherization programs as these programs can gather the necessary information on-sites' panel constraints and outlet locations. To facilitate referrals to a 120V HPWH retrofit program, utilities should consider adding additional data gathering requirements to these programs. • Utilities should prepare educational materials based on the installation recommendations in this section for contractors to distribute and review with their customers. • Utilities should only recommend 120V HPWHs to customers whose hot water consumption patterns would

Category	Findings	Recommendations
		not be constrained by a 120V HPWH's longer recovery time, even if program cost-effectiveness compels the program administrator to choose otherwise.
Energy Use and Efficiency	• There was no measured COP variation by season. COP values are slightly negatively correlated with groundwater temperatures. When groundwater is cooler, heat transfers more efficiently from the heat pump's refrigerant to the water, even though more heat in total is required to heat cold water to reach the setpoint. There is a positive relationship between COP and the temperature of the indoor air being pulled into the heater, with warmer air resulting in less standby energy loss and more efficient HPHW operation. These two effects counteract each other seasonally. • Units performed efficiently even in the cold groundwater and air temperatures of the Midwest, but they consumed much more energy in the winter than in other months. Most sites had an average daily COP between 2 and 3, with an average overall COP of 2.4 and a range between 0.7 and 3.2. The average site used 87% less energy with a 120V HPWH than with its previous unit. Dedicated circuit units had an average COP lower than the shared circuit units, at 2.0 versus 2.6, due to their more powerful and less efficient power draw.	• Installers should confirm that the room containing the water heater does not regularly dip below the manufacturer's recommended indoor temperature during the winter. If winter temperatures drop below recommended indoor temperatures, ducting into the conditioned portion of the house will be required for successful installation of a HPWH. • Installers should confirm that the room hosting the HPWH is in line with the manufacturer air volume specifications. If not, the installer should be trained and ready to duct the unit. The unit can also be louvered into an adjacent room, so long as the compressor's impact on temperature would not be a nuisance.

Water Consumption and Runouts	• Most sites did not have issues with hot water runouts, even during the winter. The average site registered a hot water runout on one out of every 20 days. Eight out of 24 survey respondents reported that they occasionally ran out of hot water during the overall course of the study.	• To avoid hot water runouts, installers should **not** install 120V units at locations where:
		  ○ The occupancy/potential occupancy of the home is more than four people. If there are four occupants, do either or both of the following:
		    ▪ Install a dedicated circuit unit and

Category	Findings	Recommendations
	The remainder reported never running out. No participants reported frequently running out. • The participant with the lowest satisfaction also reported the most hot water runouts, had the highest water consumption and had reported frequently running out of water with their prior fully functional water heater. They frequently took long, back-to-back showers. • Consuming a large amount of water across a few hours greatly increases the risk of running out of hot water in the following hours. Higher water consumers experienced a higher number of hot water runouts. While this may be true for 240V or gas units, as well, 120V units heat water more slowly than their counterparts, which can be an inconvenience when the consumer's consumption habits are clustered around the same time of day and cannot be changed. • A higher percentage of hot water runouts occur when groundwater temperatures are colder because recovery times for the HPWHs are lengthened. Three participants noticed a seasonal variation in their 120V HPWH's operation with more hot water runouts in winter months. • Dedicated circuit units were not upsized and provided similar hot water reliability with smaller tanks. Upsizing these units could be a way to increase reliability in higher consumption households, but more research is needed to prove this. • Survey responses indicated increased awareness among participants about personal hot water consumption patterns. Many participants stated that they learned to separate large consumption events to avoid runouts. It is noteworthy that about the same number of people	▪ Ensure that the household takes short (~5 min) showers, does not take baths and has low-flow showerheads in all showers. o The household's existing water heater often fails to provide hot water (more than once a week), and that water heater is not obviously faulty or undersized. o The household frequently uses a lot of water in a small interval (i.e., multiple people taking long showers consecutively). • Recommend and offer to install low-flow fixtures, particularly showerheads, if they are not present. • Installers should suggest customers raise the tank temperature if they are experiencing runouts. • Installers should install a mixing valve if a unit does not have an integrated mixing valve. • Installers should install backflow prevention valves with the water heater. Due to slower reheat times, 120V HPWH operation is more sensitive to poor installation conditions such as backflow. One participant experienced backflow that was detected by the study's monitoring devices. This likely influenced their hot water recovery times.

Category	Findings	Recommendations
	commented that they had increased their water use with their new heater because they no longer had to worry about their smaller and older gas heaters breaking.	
Overall Satisfaction	• Participants were quite satisfied with their 120V HPWH units. Out of 25 respondents, 23 rated their satisfaction at a 4/5 or 5/5, with that same number of people saying they were likely or extremely likely to recommend the HPWH unit to a friend. A few participants said that they would make sure the unit was a good fit for their friend's consumption habits before recommending it. • User satisfaction increased as the study progressed. One possible explanation is that participants became more familiar with the HPWH's controls and operations. A second explanation is that user satisfaction was lowest during the winter months (at the beginning of the study) because participants were experiencing increased water runouts due to cold air and groundwater temperatures. • More than half of the participants either did not notice cooling, humidity or noise impacts from their HPWH or did not classify those impacts as drawbacks. However, one participant who regularly spent time near the unit was dissatisfied with the noise and cooling impacts.	• The ideal customer for a 120V unit is a household with four or fewer occupants who consume an average amount of water (18 gallons or less per person per day), who currently have a propane or natural gas heater and who have an electrical setup that accommodates the unit. • Installers should educate customers on the HPWH's controls and encourage them to download the manufacturer's controller app, if applicable. Many apps offer control over the water setpoint, have a vacation mode and provide customers with an estimate of available hot water left in the tank at any given time. Participants in our study found these features helpful, especially those who changed their consumption habits to avoid occasional water runouts. • Installers should not install the 120V unit within a room where the occupant spends a large amount of time. Units make some noise and cool the surrounding area.
Unit Availability	• Manufacturers have been awaiting the results of this study before evaluating whether to make units available to Midwest distributors.	• Manufacturers should make these units available to Midwest distributors, provided that clear guidance is provided on appropriate installation scenarios. Distributors should provide the installation recommendations below to installers to educate them on the use case for these units.