Data-Backed Backup Heat Behavior: Cost, Comfort, and Consequences of ER Heat in Cold Climate ASHP Installs

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ABSTRACT

Electric resistance (ER) heaters are commonly installed as backup, supplementary, or auxiliary heat in residential all-electric air source heat pump systems, especially in cold climate retrofits. Often treated as a safety net for comfort, ER in these systems is intended to operate rarely, if ever, and only in the coldest conditions. However, maximizing efficiency and minimizing costs require more than good intentions; the process requires good controls, thoughtful design, and high-quality installation. This paper presents a deep analysis of backup ER behavior in nearly three dozen low- to middle-income homes in Illinois. These homes completed electrification retrofits in late 2024 and were monitored using high-resolution time series submetering through early 2026. Upon analysis, these data reveal several ways unintended ER use can occur. We quantify what this ER use means for system performance, operational costs, and peak demand, which impact affordability and grid planning. The observed sites show that, while most sites used ER sparingly, unintended and avoidable backup ER use can erode the benefits of electrification in cold climates. These impacts are particularly important for low-income households in which cost control is critical. This paper concludes with specific recommendations for program implementers, heat pump installers, and manufacturers to ensure that ER systems support, and do not undermine, electrification and decarbonization goals.

Introduction

Air source heat pumps (ASHPs) are a highly efficient, electrified option to displace traditional residential heating systems. However, the ability of an ASHP to deliver its heating capacity degrades in very cold outdoor air temperatures (OATs). Designing and installing ASHPs in cold climates requires care to ensure the necessary heating loads are delivered year-round. To avoid comfort issues in low-ambient conditions, ASHPs are typically installed with an auxiliary heat source that will supplement or displace the ASHP should it fail to meet the heating load. For an all-electric heating system in a cold climate, ASHPs may be installed with electric resistance (ER) as their secondary heating system, ideally designed to run in tandem with the ASHP when needed. The ASHP is expected to always exceed the efficiency of ER, so the optimization function is simple: operate the ER as little as possible to maximize efficiency and minimize operating costs.

All-electric options are preferred in regions with comparatively high fossil fuel prices or where fixed monthly gas customer charges are costly. Those market conditions can make whole-home electrification (WHE) an attractive option even for low- to moderate-income (LMI) customers. WHE projects electrify natural-gas-fired end uses in the home (heating, cooking, water heating, clothes drying, etc.), unlocking operational savings by eliminating monthly gas utility fees and improving appliance efficiencies. While the potential for utility bill savings can be high, LMI electrification programs also demand increased scrutiny to verify that systems are designed, installed, and controlled optimally to ensure predicted savings are realized. With heating, ventilation, and air conditioning (HVAC) loads contributing the largest share of residential energy used in cold climate homes (EIA 2024), it is critical that all-electric ASHPs operate at maximum efficiency and with minimal need to call on auxiliary ER heating. ER heat is only up to 100% efficient, meaning that its operation reduces the overall efficiency of the heating system compared to the ASHP alone, which can exhibit over 200% heating efficiency even below 0°F OAT in the highest-performance models (PNNL 2025). Low HVAC efficiency can significantly increase electricity bills and must be avoided in LMI WHE programs.

ER heaters are not continuously variable capacity equipment, and at most, are discretely staged. Usually, the control algorithm triggering ER use and determining which stages to energize depends on a timer and/or a temperature threshold, though algorithms vary by product and may employ more complicated logic. Common ER stages include 3 kW, 5 kW, and 10 kW heaters, typically sized to ensure comfort in the coldest outdoor conditions. Wintertime peak electric demand can therefore skyrocket with ER use, particularly with higher kW-rated ER heaters and those with coarse or no staging. For example, an all-electric ASHP system with a 12,000 Btu/h (3.5 kW) heating capacity deficit to the heating load may increase instantaneous electric demand by 3 kW, 5 kW, or 10 kW, depending on the sizing of the ER heat. With a 3 kW unit, the system produces an additional 10,236 Btu/h, not quite meeting the entire hourly demand but improving comfort significantly compared to operating with the output capacity deficit of the ASHP alone. A 5 kW heater adds 17,061 Btu/h, addressing the entirety of the deficit, as does a 34,121 Btu/h 10 kW unit. If comfort may be temporarily compromised with slightly lower indoor air temperatures, the 3 kW heater is arguably sufficient to meet the load. Otherwise, the 5 kW and 10 kW units suffice but come at the cost of much higher instantaneous peak electric demand compared to the ASHP alone or the ASHP with a 3 kW heater.

Methodology

This study monitored the performance of all-electric ASHP systems in 34 residences across northern Illinois, including 20 single-family (SF) homes, 8 side-by-side quadplex units, and 6 apartment units in a larger multifamily (MF) property. Monitoring lasted from fall 2024 through spring 2026, capturing at least one heating season from each home. All monitored homes had recently electrified their natural gas end uses[1] as part of an income-qualified WHE program through their electric utility, ComEd. This included the installation of a new all-electric ASHP system to replace existing gas-fired forced air furnaces. Manual J load calculations were conducted by the installing contractors prior to ASHP selection for each site. All SF sites studied received cold climate, variable speed ASHPs between 3 and 3.5 tons of nameplate heating capacity. In every case, the ASHP was paired with an auxiliary ER heating system composed of two 5 kW stages for a total of 10 kW, equivalent to nearly 3 tons of auxiliary heating capable of running in tandem with the ASHP. Monitored MF units included similar ASHPs of 1 to 2.5 tons, paired with either 3 or 5 kW of auxiliary ER.

[1] All SF and the 8 MF quadplex homes electrified all gas end uses, while the 6 MF apartment units electrified only their HVAC systems.

Each site received a sensor package to remotely collect continuous readings throughout the monitoring period, supplemented by spot measurements collected during in-person site visits. Continuous readings included temperature data collected using thermocouples and wireless temperature sensors. These sensors sampled supply and return air temperatures in ductwork once every second, and indoor air temperatures near thermostats once every 15 minutes. Current transformers were installed in the air handler and at the electrical panel to continuously measure current draw from the ASHP outdoor unit (ODU), ER auxiliary heater, and the blower fan motor all on a per-second basis. Combined with continuous power meter measurements for supply voltage at the panel, these readings are used to calculate the real input power for the ASHP, ER, and blower. Spot measurements include airflow in each operating mode, total external static pressure of the ductwork, pressure across the filter, thermostat setpoints, and general characteristics of the home. Other data sources include historical weather data requested from the nearest weather station for each hour of the monitoring period, and monthly utility billing information collected from each participant. All data sources were compiled to form a comprehensive understanding of the performance and behavior of the newly installed HVAC system.

System Sizing

Appropriate system sizing is a key component of a high-quality ASHP installation. Undersizing the ASHP can result in overuse of auxiliary ER heating, lowering heating efficiency and increasing costs for those periods. Oversizing the system can increase the amount of time for which the heating load is below the minimum heating capacity of a variable speed ASHP. This results in much shorter operating cycles in these periods, lowering heating efficiency (Schoenbauer, Genty, and Haynor 2024). Oversizing will also increase upfront costs to install higher capacity equipment. For example, two SF sites in this program showed an ASHP installation cost increase of $1,100 when specifying a 3.5-ton ASHP compared to a 3-ton ASHP of the same product line, installed by the same contractor one month apart.

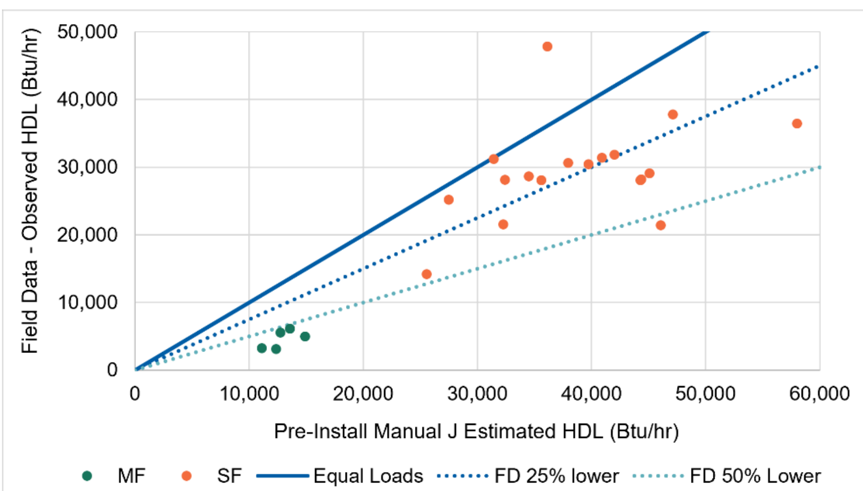

Figure 1. Relationship between Manual J estimates and field data (FD) for design heating load

Pre-installation, all-electric system sizing decisions are typically based on ensuring equipment meets or exceeds Manual J heating design load (HDL) estimates. However, comparing pre-install Manual J HDL estimates to observed heat load in design conditions reveals that Manual J usually overestimates the load. Thus, designing for capacity in excess of Manual J calculations exacerbates oversizing. Figure 1 charts the expected heating load at the 99th percentile heating design temperature (HDT) as estimated using ACCA Manual J at the time of system design as compared to measured load estimates from field data (FD) gathered from 5 MF and 18 SF homes for which Manual J estimates were available. The three lines represent Manual J estimates that are equal to field measured HDL (solid blue line), field data that is 25% lower than Manual J (dashed blue line), and field data that is 50% lower (dashed teal line).

Only one site in this study experienced a design load greater than its Manual J HDL estimate, 10 sites showed design loads within 25% below Manual J, 16 sites experienced design loads within 50% below Manual J, and the remaining six sites had measured design loads less than half the Manual J estimate. Notably, these six sites include all five MF apartments. Load calculations for these MF units were performed by floor plan, not uniquely to each unit. The load estimate therefore ignores factors like neighboring units, shading, and elevation, all of which will impact the true heating load of an apartment unit compared to a similar floorplan elsewhere in the building. As a result of high HDL estimates, the specified heating systems are likely larger than necessary. This study did not influence the sizing and product selection process of the sites monitored. Figure 2 charts the relationship between manufacturer-rated ASHP output at the HDT for the systems installed at these sites compared to the observed HDL. This figure includes some MF sites excluded from Figure 1 due to lack of Manual J data.

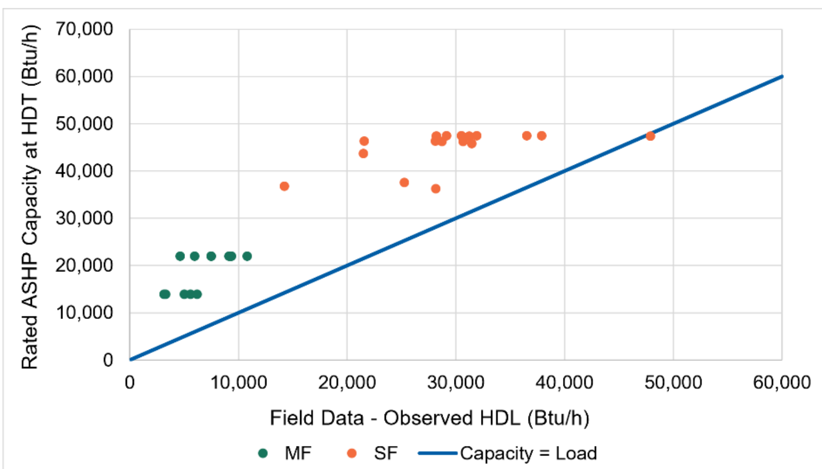

Figure 2. Relationship between manufacturer-rated ASHP capacity at the HDT and the observed HDL

The six apartment units in the single large MF property each received a 1–1.5-ton ASHP and a 3–5 kW ER ducted auxiliary heater. The eight side-by-side quadplex MF units all received 2.5-ton ASHPs and 5 kW of ER. SF sites were all detached homes, 18 of which installed 3.5-ton ASHPs and two installed 3-ton ASHPs. All SF sites included 10 kW of electric resistance. Generally, larger capacity ASHPs were paired with larger ER backups, regardless of the relationship between rated capacity and Manual J load estimates. Installers also selected ASHPs with higher capacity at the HDT than the calculated HDL at 20 of 23 sites for which we have Manual J estimates. Only one site has an ASHP with a manufacturer-rated heating output at the HDT that is below the observed design load. This is also the same lone MF site in Figure 1 with a Manual J design load that matches its observed design load. In this case, the selected 1-ton

ASHP is more likely to need the paired 5 kW ER to make up the difference between ASHP capacity and load in very cold ambient temperatures. In contrast, ASHP specifications and measured loads at HDT at all other sites appear sufficient to generally operate without any ER use. This assumes the ASHPs deliver their rated capacities and that occupant-driven load variation does not stray far from the average observed loads.

Observed Electric Resistance Use

Observed heating loads at design conditions at this study's homes were usually significantly lower than Manual J estimates and were also usually lower than the rated capacity of their ASHPs. Despite this, the studied SF installations used ER in colder OATs, with the use of auxiliary heat ramping up as ambient temperatures dropped below 15°F. Figure 3 displays ER use data for 20 SF sites and 13 MF sites. Of the 14 MF sites included in the study, one apartment unit displayed highly unusual use patterns in continuously monitored data and will be henceforth excluded for concerns of data quality, lowering the total to 33 sites. Each chart is colored by whether sites report significant ER use, defined as whether greater than 5% of their total load at each OAT bin was supplied by the auxiliary ER heater. The 5% threshold has been selected to exclude ER use attributed to brief anomalous events, such as short periods of ASHP downtime and temporary changes to control settings, which will not cause noticeable impacts to customer electric bills. The height of each stacked bar represents the total number of sites with data available in each OAT bin. Some sites did not experience the coldest temperatures during the monitoring period or were subject to data loss.

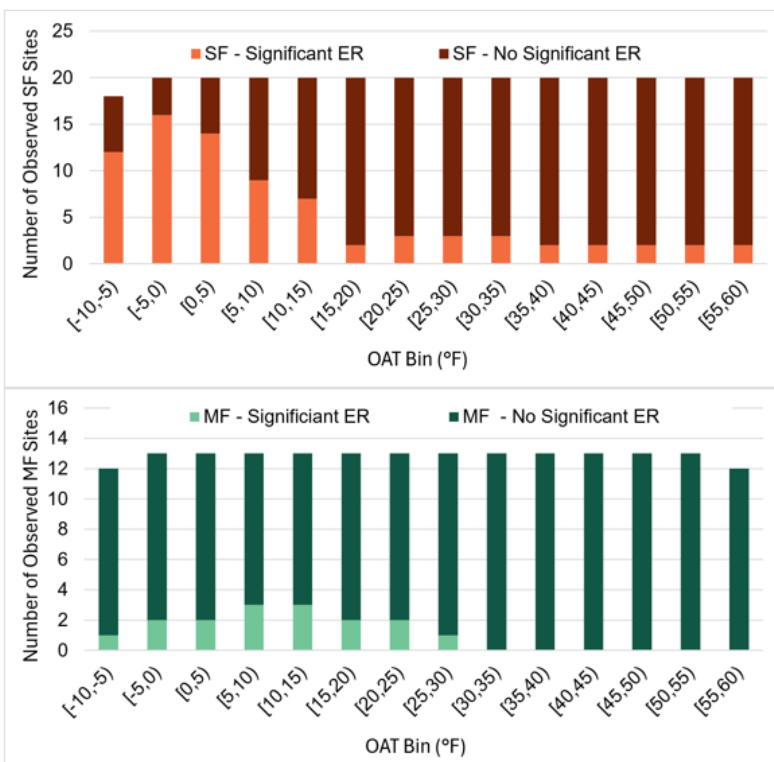

Figure 3. Number of sites showing significant ER load as a subset of all sites reporting data between -10°F and 60°F ambient temperatures, shown for SF (top) and MF (bottom)

Below 5°F, most SF sites used ER to deliver more than 5% of their heating load. The load contributed by auxiliary heating averaged 12% between 0°F and 5°F and 22% below -5°F across all SF sites. Three SF sites had no significant ER use observed, while two sites had ER use even in mild ambient temperatures above 50°F. The percentage of load supplied by ER at the study's SF sites has no strong correlation to the extent to which a site's ASHP was oversized, where oversizing is estimated by the ratio of manufacturer-rated ASHP capacity at the HDT to the observed HDL. This suggests that ER use may not have been reduced by simply increasing the ASHP size installed at these sites. In contrast, the monitored MF sites exhibited much less ER usage and show no strong pattern of ER use increasing in low temperature conditions. Only three MF sites had significant ER use observed during the monitoring period.

Sites with little to no ER use observed may not require auxiliary heating at all. Of the 33 total sites (13 MF, 20 SF), 26 sites (12 MF, 14 SF) supplied below 5% of their total heating load with ER over the observed period. Fourteen of these sites (10 MF, 4 SF) showed less than five hours of ER runtime over the course of the study, and seven sites (5 MF, 2 SF) showed no ER runtime at all. Designing systems without auxiliary ER heaters can help avoid the need for panel upgrades. The installation of 3 to 10 kW ER heaters that can run in tandem with the ASHP and potentially coincident with other large electric loads demands electric capacity in excess of the existing service in many homes. However, ASHPs installed in cold climates without ER could increase the risk of comfort issues during system failures, setback recovery periods, and cold snaps. Each of these issues were observed in at least one participating site in this study and will be discussed next.

ER Use in Setback Recovery

An HVAC setback is a scheduled period where the space temperature target (setpoint) is temporarily lowered. With a traditional heating system like a gas furnace, setbacks reduce heating energy use by lowering the heating load in those periods with lower setpoints. Setbacks are usually scheduled when a building is unoccupied or overnight when occupants may not notice or may prefer cooler temperatures. Once a setback period ends, the HVAC system must produce enough heat to raise the indoor temperature back to the regular setpoint, referred to as setback recovery. Fossil fuel systems are usually sized large enough to recover quickly and use less energy when setbacks are used. An all-electric ASHP's efficiency can also benefit from lower loads during setback periods but an ASHP may be unable to quickly recover at the end of the setback, especially if it coincides with low ambient temperatures where the ASHP has reduced capacity. To avoid comfort issues, systems with ER backup often rely on the ER to accelerate setback recovery. However, the efficiency penalty of ER use in recovery can counteract the benefits of lower heating loads during the setback period and increase peak demand.

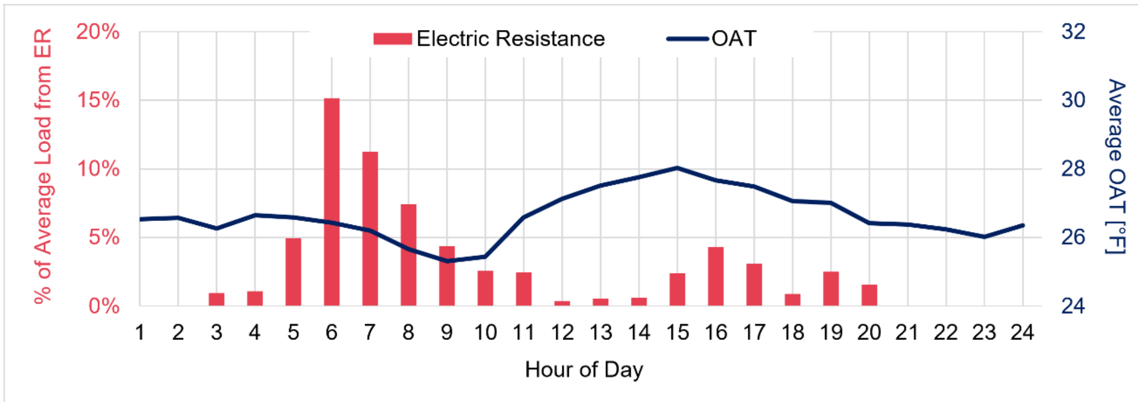

Figure 4. Data from site SF024 showing average share of hourly load supplied by electric resistance and average hourly OAT from all hours below 40°F, shown by hour of day

SF024 is one of four sites with a strong relationship between setback recovery and ER use. This site had a comparatively high reliance on ER that increased below 15°F outdoors. Thirty-three percent of the heating load was supplied by ER in the coldest conditions at this site. Here, ER use regularly occurred around 6 a.m. and 4 p.m. The heating load saw a defined uptick at these times that was matched by a higher likelihood of ER use. Figure 4 displays the percentage of load supplied by ER (red bars) as compared to the OAT (navy blue line) when averaged for each hour of the day for all hourly data below 40°F, the warmest temperature at which SF024 uses ER. ER use is quite tightly distributed around 6 a.m. and 4 p.m., particularly in the morning, despite no clear indication that it is much colder at those times. Figure 5 displays the median air temperature measured near the thermostat at this site for each hour of the week, using all hours below 50°F. This confirms the existence of an overnight setback. Thermostat programming is not uniform throughout the week at this site, however, as seen by the unique indoor air temperature pattern observed on Sundays.

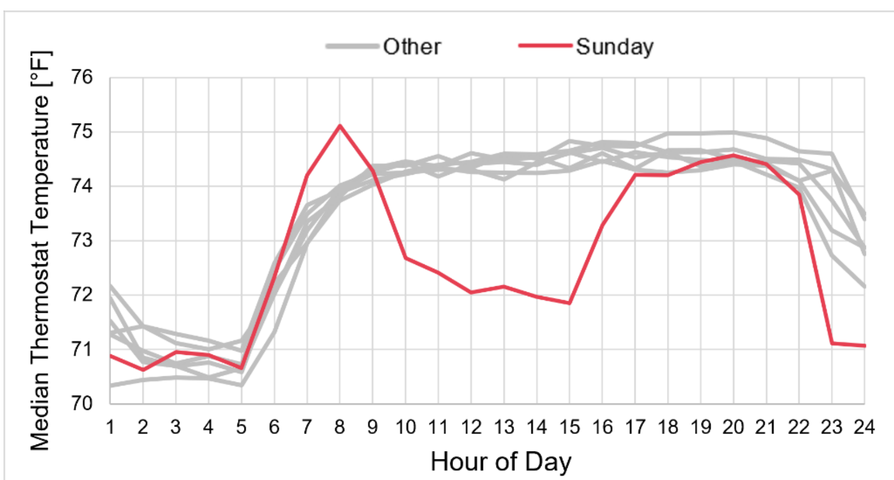

Figure 5. Data from site SF024 showing median temperatures measured near the thermostat, displayed by hour of day across each day of the week

The large uptick in ER use early in the day shown in Figure 4 corresponds with the setback recovery period observed on every day of the week in Figure 5. The secondary, shorter peak in Figure 4 is likely due to the second recovery period around 4 p.m., observed only on Sundays. The nighttime thermostat setpoint is around 71°F, while daytime setpoints are uniformly around 74–75°F. The setback period around midday on Sundays approaches 72°F. Homes with ER use that increases at specific times of day are likely to use a setback schedule similar to that employed at this site.

ER Use During ASHP Failure

Several sites were impacted by periods of ASHP failure, during which the ER served as the sole heat source for the home. As system controls are designed to seamlessly use ER heat when the ASHP capacity is insufficient, residents were typically unaware of any ASHP failure until they received abnormally high electric bills (if they connected the bills to HVAC issues at all) or the research team notified them of unusual usage patterns in collected data. Specific reasons for system downtime weren't always reported by the installers and residents, but some failures are known to result from refrigerant leaks from faulty fittings that required emergency repair and replacement during cold weather periods. Observed failures lasted from a few days to nearly an entire month. The greater the time between fault and repair, the longer the system operates at minimal efficiency. This can cause a sharp increase in utility bills, especially in cold weather. Site SF022 is one of the more severe cases, using entirely ER heat between the initial ASHP failure on 10/23/25 and the date of repair on 11/18/25. During this time, 2,362 kWh were supplied from the ER heater. The event spanned ambient temperatures of 25–70°F, where ASHP heating efficiency is expected to be at its highest.

Energy Usage Impacts

Over-reliance on ER can significantly impact HVAC energy use. The extent to which energy is impacted depends on the duration of the issue and the efficiency gap over that period. Longer duration, moderate temperature events can have a greater total energy impact because the difference in efficiency between the ASHP and ER is larger. The climate of northern Illinois tends to experience more load in milder winter conditions, between 25–45°F, when the comparative efficiency of an ASHP is two to three times that of the ER heater. The heating efficiency of the ASHP and ER heater can be expressed as a coefficient of performance (COP), defined as the unit-neutral ratio of the space heating energy delivered by the system to the electrical energy used to supply that heat. Figure 6 displays COP averaged across all sites for hours occurring in each OAT bin from -10°F to 60°F. These are separated into hourly COP averages using hours during which only the ASHP operated (teal line), the auxiliary ER operated in tandem with the ASHP for any portion of the hour (maroon line), and total hours across all sites (dark green line). Also shown on the secondary y-axis is the average percentage of delivered heating load supplied by the ER for context. ER use in milder temperatures includes fewer observed data points, and instances of ASHP with ER operation above 35°F typically use ER for just a small portion of the load. COPs with and without ER use vary the most at warmer temperatures, with average hourly COPs dropping up to 48% when ER is used between 55–60°F as compared to when only the ASHP is used.

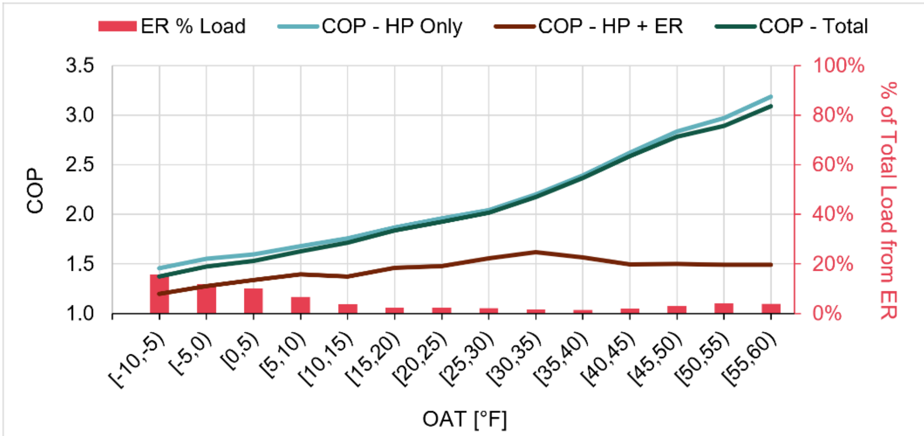

Figure 6. System COP data and share of load from ER vs. binned OAT from all sites

These comparative heating efficiencies emphasize the performance penalties experienced at sites with ASHP failures and at those that call on auxiliary heat for setback recovery. The COP across all hours is very similar to the ASHP-only curve given the general lack of ER use across most sites in the dataset (up to 16% of load on average at the coldest OATs). The COP profiles in Figure 6 converge as temperatures drop, ER is used more often at more sites, and the efficiency of the ASHPs degrades. The penalty for ER use at colder temperatures is therefore less severe compared to that of warmer temperatures. A 16–18% efficiency reduction occurs when operating ER below 5°F.

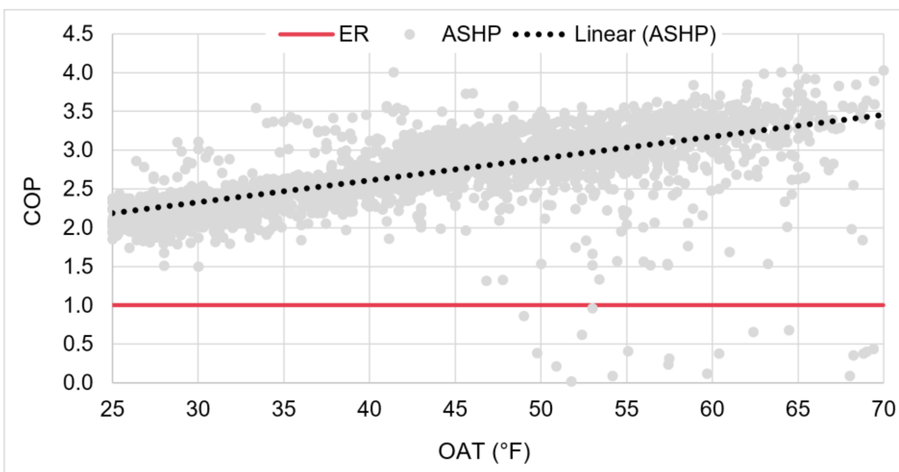

Figure 7. SF022 COP data between 25°F and 70°F

Energy Impacts During ASHP Failure

The ASHP at SF022 was disabled from 10/23/25 to 11/18/25. During this period, the 10 kW ER unit supplied the entirety of the load across an OAT range of 25–70°F. Figure 7 shows the ASHP COP measured at this site for this temperature range when it was operating normally, as compared to the maximum efficiency of the ER heater. At 25°F, the ASHP is 2.2 times as efficient as the ER system, up to 3.5 times when heating at 70°F. The ER system required 2,362 kWh to supply the heating load during this period of downtime. When applying this difference in performance to those same loads on an hourly basis, the ASHP is estimated to have had the potential to reduce this input energy by 63%, requiring only 866 kWh for the same load. The system failure remained for nearly a month, in part due to the ER system avoiding occupant discomfort that would otherwise indicate an issue. The penalty for this delayed response during mild weather nearly tripled the energy used to heat the home.

Energy Impacts During Setback Recovery

Site SF024 had a regular overnight setback, dropping the indoor air temperature from around 74.5°F in the day to 71°F between 9 p.m. and 5 a.m. A secondary setback period was observed on Sundays, dropping to a setpoint of 72°F between 8 a.m. and 3 p.m. Each setback period was followed by a few hours of recovery as the home must be heated to 74.5°F, causing an increase in ER use during these hours. The overall impact of these setbacks on heating energy use is the net change in consumption when factoring in energy saved by the load reduced during the setback period and the increase in energy consumption as the heating system operates less efficiently in the recovery period. The primary factors driving sensible heating load in cold ambient conditions are conductive heat losses across the building envelope and outside air infiltration into conditioned space. Above-grade conductive losses and infiltration accounted for 93% of the Manual J HDL calculated at SF024. The extent to which these factors impact heating load linearly correlates to the temperature difference between the indoor and outdoor air, or delta-T. To model the heating load for hours during the setback period, the delta-T for each hour is adjusted to what it would have been had the indoor air temperature stayed at 74.5°F. For each setback hour, the heating load at the new delta-T is estimated using the average load observed at a similar delta-T from all hours outside of setback and recovery periods. Figure 8 displays this heating load relationship, averaging across delta-T binned in 2°F increments across 2,670 hourly observations.

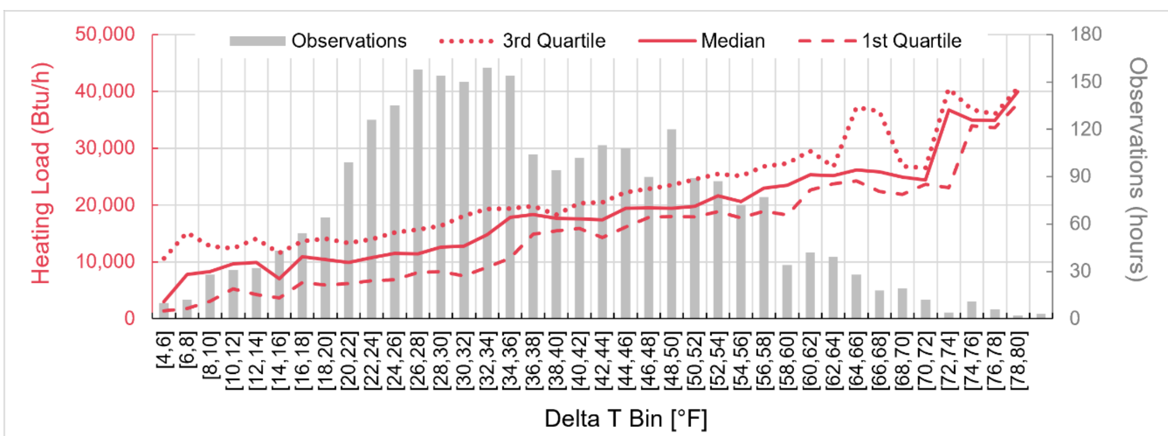

Figure 8. SF024 hourly heating loads vs binned delta-T outside of setback and recovery periods, including the number of observations used for each bin

The new delta-T during setback and recovery hours is determined using an indoor air temperature of 74.5°F, selected from average thermostat temperatures in non-setback periods, resulting in a 7% increase in delta-T on average. The load for these modeled hours is estimated using the data presented in Figure 8, matching each hour to an average load by its binned delta-T after the adjustment. As the delta-T increases without a setback, the modeled load is larger overnight and around midday on Sundays, resulting in an increase in energy consumed by the heating system at these times. The opposite is true of the recovery period that follows, during which the observed spike in heating load no longer exists in the modeled scenario, resulting in energy savings in these hours. This is coupled with an assumed improvement in system COP, modeled using the average COP at similar OATs observed in hours outside of setback and recovery periods. The resulting energy savings are presented in Table 1.

Table 1. Summary of observed heating electricity consumption compared to modeled usage without a setback

Period	Hours	Observed kWh (with setback)	Modeled kWh (without setback)	kWh Difference	% Difference
Setback Time	959	2,051	2,656	605	29%
Recovery Time	578	2,305	1,353	-952	-41%
Other Heating	2,685	5,875	5,875	0	0%
Total Heating	4,222	10,231	9,884	-347	-3%

The modeled results show a 29% increase in energy consumed during the setback period, followed by a 41% decrease in energy during the recovery period should a setback not have been used. The net impact through the one-year monitoring period spanning 4,222 heating hours is a slight reduction in overall energy use of 3%, saving 347 kWh compared to the observed system behavior with the setbacks. Repeating this process for the first and third quartile load estimates shown in Figure 8 results in an 11% decrease and 4% increase compared to the observed kWh usage, respectively. Based on these results, any energy savings yielded from the setback at SF024 are likely negated by greater energy consumption in recovery, although the net impact is expected to only slightly increase overall energy use across a year based on median load estimates.

Residents may employ setbacks due to comfort preferences and perceived energy savings benefits stemming from an understanding of more traditional HVAC system operation, including gas furnaces. For residents using comfort-driven setbacks, the conclusion is neutral: they may cool down their homes with a relatively small impact to their energy use and bills. Cost- or efficiency-driven residents, especially those lowering setpoints at the expense of comfort, should be instructed that setbacks are unlikely to save energy due to the inherent differences in all-electric ASHP operation compared to traditional heating systems. All else held equal, sites with longer setback periods and similar setpoints will likely see more positive results as they spend more time at lower load conditions with the same period of recovery. Sites with deeper setbacks will observe steeper spikes in load during recovery, thereby experiencing similarly negative outcomes as are estimated for SF024.

Operating Cost Impacts

Operating cost impacts are estimated by applying monthly historical rate information to measured HVAC electricity use. All sites observed in this study share an electric utility and became eligible for special space heating rates once they installed new all-electric ASHP systems. SF and MF homes are considered separate rate classes and are therefore charged different effective electric rates. SF rates range from 13.18–16.39 ¢/kWh and MF rates range from 13.80–17.02 ¢/kWh through the observation period, adjusted for inflation to 2026 dollars.

Electric rates used for this analysis are inclusive of all volumetric components, including tax, and do not include fees that do not change with kWh usage, such as monthly customer charges and demand-based components. Rate structures do not vary with time of use or time of day.

Figure 9 summarizes estimated per-site costs from ASHP and ER electricity use and total costs per MMBtu of heat delivered during the observation period. Also shown are the number of hours of heating data collected at each site used for each cost estimate, plotted on a secondary y-axis. Sites were not instrumented for the same duration of time, and some sites have very limited data due to shorter collection periods in heating season, measurement errors, or equipment failures. Monthly average costs are displayed for comparison between sites with different amounts of heating data.

Heating costs are highly variable, more so at SF and larger MF units. MF sites included four smaller apartment units in a large apartment complex, each with 1–1.5-ton ASHPs (MF007 through MF011), and seven larger quadplex units with 2.5-ton ASHPs (MF013 through MF021). The total heating costs for the small apartment units were similar across the four sites, at $50–$63 per observed month. Heating costs for the seven quadplex units varied from $30 per month at site MF016 to $96 per month at site MF015, despite the systems and homes themselves being nearly identical. MF016 showed no ER use, while about 8% of the operational cost at MF015 was from operating the ER heater. The cost difference between these sites is primarily driven by load, with the average Btu/h load at MF015 being 70% higher than at MF016.

Figure 9. Summary of overall heating cost estimates for each observed site, expressed in average monthly dollars attributed to ASHP and ER use (top) and dollars per million Btu delivered (bottom)

Normalizing by heating load shows that ASHP performance primarily drives total system costs outside of load. Sites with high heat delivery costs showed lower average ASHP COPs, reflected in higher ASHP-only $/MMBtu values displayed in Figure 9. The impact of ASHP efficiency overshadows any influence of the minimal ER use on the overall cost of heat delivered at most sites, save for those with the largest load and cost contributions from ER (MF010, SF010, SF015, SF022, SF058, and SF117). As normalized costs span all observed heating hours, variance between sites can be partially attributed to the impacts of site-to-site differences in weather and observation periods on ASHP performance. Eighteen of 20 SF installations were conducted by the same contractor, with the remaining two installations performed by the same installer on the eight quadplex units. The six apartment complex units also shared an installer, for a total of three contractors across all sites. As each contractor followed the same design and installation procedure for every installation, likely sources of variation between sites with similar installed equipment may include shared factors like the varying accuracy of Manual J load estimations used for system design decisions, and site-specific factors like occupant behavior (e.g., nonoptimal thermostat scheduling) and system issues or downtime.

Table 3. Summary of cost impacts from cases with ASHP downtime and setback recovery outcomes

Site	Issue	Additional kWh	Additional Cost
SF022	ASHP Failure	1,497	$236
SF024	Setback	-605	-$87
SF024	Recovery	952	$139
SF024	Setback + Recovery	347	$52

Table 3 summarizes the resulting cost impacts when applying the appropriate electricity rates to the months during which sites SF022 and SF024 were impacted by downtime and setpoint recovery penalties. The need for 1,497 kWh of electric resistance consumption compared to ASHP operation in relatively mild OATs results in an additional $236 in electric bills for the 27-day event. The modeled scenario estimates that heating setbacks at SF024 increase costs by around $52 per year. Repeating this process for first and third quartile load estimates from Figure 8 results in a cost decrease of $158 and a cost increase of $61 per year, respectively.

Peak HVAC Demand

Utility peak demand estimates are typically performed across 15-, 30-, or 60-minute averaging periods and will include contributions from other coincident electric end uses existing on the same meter as the HVAC system. For this analysis, peak demand is defined as the highest hourly HVAC kW observed at each site through the heating season. These are unlikely to coincide with grid-wide peaks that are expected to occur in summertime in this region, though this may change as more buildings electrify. Since ER heaters operate in relatively large kW stages (typically stages of 3 or 5 kW), their use can significantly impact the peak electric demand when running in tandem with the ASHP. MF007 was equipped with a 3 kW ER heater, while all other MF sites received a 5 kW unit. All SF sites included a 10 kW ER heater. Sites with minimal or no need for ER use can exhibit as little as half the peak demand of those that are more heavily reliant on auxiliary heating. Figure 10 charts the hourly peak loads observed across all sites.

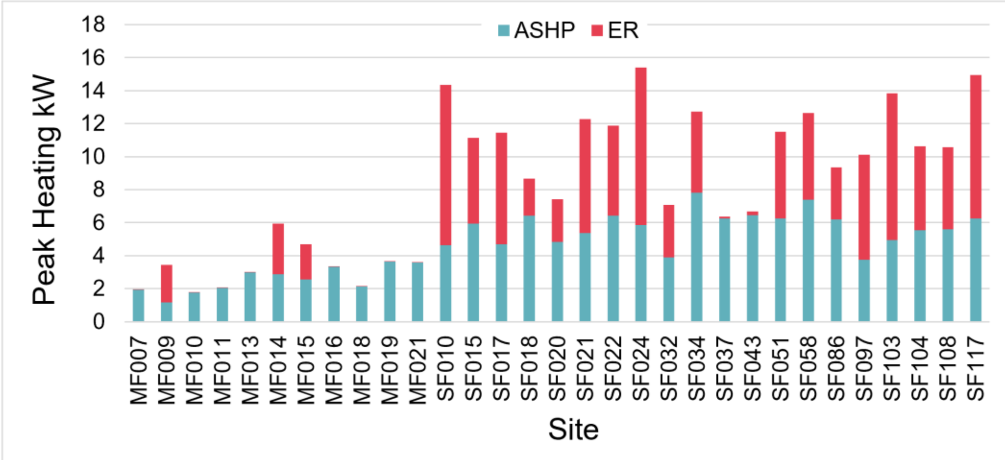

Figure 10. Share of overall peak heating kW observed at each site attributed to ER and ASHP

All peak hours included some ASHP operation. As the auxiliary ER heat is designed to run in tandem with the ASHP, it is unlikely that the overall system peak heating kW will include only ER operation. The exception to this would be an ER sized larger than the HDL operating during a cold weather ASHP lockout or failure, which was not observed in this study. Despite the extended ASHP failure, SF020 did not exhibit an ER-only peak as the ER use while the ASHP was operational was large enough that the ER with ASHP demand is greater than the maximum demand from ER alone.

Eighteen sites did not use their installed ER to its full installed capacity (energizing all heating elements), including all MF sites. Seven sites required less ER heat in peak conditions than could be supplied with the next smallest size (e.g., 3 kW compared to 5 kW, and 5 kW compared to 10 kW), and the remaining ten did not require ER use at all during the peak hour. ER contributions to hourly peaks may not be in increments of standard ER element sizes and observed hourly peaks will typically underestimate instantaneous peak demand. For example, SF037 has a small ER peak contribution of just 0.1 kW as the ER element energized briefly during the peak demand hour. Peak hours across sites were often clustered around similar weather events. Nine sites showed peak heating hours between 1/19/2025 and 1/24/2025, during which they experienced OATs between -5°F and 12°F. Similar peak periods were shared between three sites on 12/14/2025 (-1°F–2°F OAT). Two sites experienced peak hours in warmer weather, between 44°F and 56°F. SF024 reached its peak hourly heating kW at 5 a.m. on 1/20/2025. This peak was likely caused by setback recovery given its time of day, combined with brisk morning temperatures around 0°F. The magnitude and timing of peak HVAC loads for these sites is significant for electric service and panel capacity upgrade requirements, which cost between $10,000 and $11,000 for sites in this project. Peak loads may also become significant should time-varying electric rates like hourly pricing or time-of-use rates apply. In that case, minimizing peak HVAC loads or being able to control when they occur may be a cost-saving opportunity.

Conclusions

The most economical way for all-electric ASHPs to operate is to minimize the use of ER heating. ER is intended to operate rarely, if ever, and is typically considered a comfort safety net should the ASHP struggle to supply sufficient heat in low ambient conditions. Designing an all-electric HVAC system that minimizes ER use requires a quality ASHP installation sized to supply most (or all) of the annual heating load and controlled to avoid very rapid setback recoveries.

All sites in this project had high-performance cold climate ASHPs sized for heating, which enabled relatively low ER use overall. The industry standard for design load estimation relies on ACCA Manual J, which tends to overestimate the true HDL as observed in field data. ACCA Manual S may also be used to inform system sizing decisions after load estimation, but this was not documented as part of the system selection process for any site. The gap between estimated and true load was larger in the study's MF units, particularly when Manual J calculations were performed per unique floor plan, not apartment, thereby excluding impacts of shared walls, shading, and other factors related to the position of each unit in the building. Electrification programs should recommend installers assess those nuances as they relate to expected system loads.

Manual J load estimates appear to have been used as a lower bound for ASHP capacity in product selection, rather than an upper bound. The installers observed in this study selected from two unique ASHP sizes for MF apartments, one size for MF quadplex units, and two sizes for SF homes, despite each housing category representing a broad distribution of design load estimates. This limited product selection results in a high variability in the relationship between design load and capacity across the observed sites. Electrification programs should encourage installers to select equipment exceeding Manual J estimates as little as possible and ensure projects are not constrained to select from one or two compatible ASHP sizes. Right-sizing ASHP installations is associated with lower upfront equipment costs (as evidenced by a $1,100 additional cost for a 3.5-ton vs a 3-ton unit of the same product line) and higher operational efficiency by minimizing cycling in mild weather (Schoenbauer, Genty, and Haynor 2024).

In this study, ER was used sparingly at most sites, with 26 of the 33 total sites receiving less than 5% of their total observed load from ER. Eighteen sites never used ER to its maximum installed capacity, only ever needing lower-capacity stages for the observed period. This suggests that smaller ER systems could have been used. While they offer less capacity in case of an ASHP failure, smaller ER systems have lower potential peak demand, may help avoid expensive panel upgrades, and could also help customers identify ASHP failures faster than if their ERs were oversized.

Case studies on two of the sites with comparatively high ER use revealed that ASHP failures and scheduled thermostat setbacks can cause ER overuse. Failures in all-electric ASHP systems can be difficult for occupants to notice, particularly if the ER heater is large enough to meet the heating load during failures. Identifying, diagnosing, and correcting ASHP failures can be a slow process, resulting in extended periods of inefficient operation as the system relies entirely on ER. The penalty for this delay can be severe, as much as tripling customer bills if the failure occurs in a milder weather period. While electrification programs should aim to avoid failures entirely, they should also consider options to improve response times if issues arise. ASHP failures during cold weather periods could trigger sudden and noticeable changes in customer electricity use patterns, especially if ER is used sparingly during normal operation. ASHP failures have potential to be identified through advanced metering data, should this be available.

Thermostat setbacks save energy during the setback period but can negate those savings with inefficient operation in the recovery period that follows. The ASHP is much more likely to employ ER to meet a sudden spike in heating load when the setback period ends if the setback is large or the weather is cold. This can result in a net neutral to negative impact of setbacks. Annual costs were estimated to increase by 4% for the site in this case study. Despite only a slight increase in energy and cost, setbacks can result in much larger peak electric loads through additional ER use. Programs installing ASHPs with ER should inform customers that setbacks may result in increased energy use and costs, contrary to their former heating system. Customers adjusting setpoints for comfort may do so knowing that the impact to cost is likely close to neutral. However, those who employ setbacks to save energy, particularly customers who compromise on comfort to do so, should be informed that this is not necessary with their new ASHP.

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