Load Flexibility with Ductless Heat Pumps in Rural Cold Climates

Sam Rosenberg, Chitra Nambiar, Alex Vlachokostas, Pacific Northwest National Laboratory
Alexander Rees, U.S. Department of Energy Building Technologies Office

ABSTRACT

Decarbonization goals are widespread in the United States, and electrification and increased flexibility of residential end uses are necessary steps to take toward achieving these goals. Heat pumps are a promising option to replace heating systems dependent on fossil fuels. Furthermore, heat pumps are often enabled with communication capabilities that allow for grid-responsive, flexible controls. This paper discusses a project in rural Alaska focused on replacing fossil fuel heating systems with grid-enabled, cold climate heat pumps with the capability of shifting space conditioning load from peak times utilizing the American National Standards Institute/Consumer Technology Association CTA-2045 communication standard. This paper evaluates the heating season analysis of multiple field sites in Cordova, Alaska, with results discussing load flexibility capabilities across various strategies. Key results include peak-time hourly energy savings ranging from 12–35%, alongside a missed event signal communication loss reduction of 23%, and occupant opt-out rate of less than 20%. Market development efforts were marginally successful in initiating heat pump deployment through a local heating, ventilation, and air conditioning company, with upfront costs totaling around $5,000.

Introduction

The U.S. government has set goals to reduce greenhouse gas emissions 50% by 2030, achieve a carbon pollution-free electricity grid by 2035, and reach net-zero greenhouse gas emission by no later than 2050 (U.S. HHS 2022). These goals require massive changes to the end uses in residential buildings, including space conditioning.

To achieve total decarbonization of the United States energy supply, it is necessary to replace much of the fossil-fuel-based energy generation with electricity sourced from renewable sources. In parallel, it is necessary to decarbonize and electrify all building end uses to maximize the overall impact and effectiveness of grid decarbonization efforts. Furthermore, given the intermittent nature of renewable sources, building energy systems need to provide power flexibility to seamlessly adapt to the varying power availability from renewables.

A crucial step toward decarbonization and electrification of all end uses in buildings involves replacing heating powered by gas or oil with electric systems, namely heat pumps. As buildings transition to electric systems, it is important to address how to manage end-use loads effectively, considering occupant comfort and the strain on the electric grid. This can be achieved by reducing loads during peak times and using electricity when renewable energy is readily available. In the Pacific Northwest, the residential load shape of the grid is predominantly influenced by patterns of water heating and space conditioning energy usage (Douville et al. 2021). These peaks occur in the morning and evening due to occupant energy use behaviors. The key question then becomes: How can these peaks be leveled to ensure a balance between supply and demand for grid stability and renewable energy management?

In grid-interactive efficient buildings (Neukomm et al. 2019), where load-flexible controls are implemented, load shifting emerges as the primary method of achieving flexibility in 60% of applications. This is followed by shedding (19%), modulation (6%), and generation (16%) (Li et al. 2021).

This paper presents results from a field study from Cordova, Alaska, conducted by researchers from Pacific Northwest National Laboratory (PNNL). The study is aimed at testing the load flexibility potential and occupant acceptance of ductless mini-split heat pumps in replacement of the region's historical standard of fuel oil space conditioning systems. The main contributions of this paper are:

- ⇒ Examining load flexibility using mini-split heat pumps in rural cold climates, specifically in Cordova.
- ⇒ Demonstrating a case of heat pump market introduction in an area with no preexisting residential market.
- ⇒ Evaluating the reliability of American National Standards Institute/Consumer Technology Association CTA-2045 communication standard as a methodology to implement grid flexibility events.
- ⇒ Providing field deployment results of load flexibility strategies, including relative setpoint reduction and preheating followed by relative setpoint reduction.

Space Conditioning in Cold Climates

The Energy Information Administration (EIA) collects information regarding U.S. energy consumption and reports that across varying regions and demographics within the United States. Figure 1 shows yearly space conditioning energy usage across various fuel types for the U.S. residential sector (EIA 2015). This figure demonstrates that natural gas is the dominant fuel source for residential space conditioning, followed by electricity, fuel oil, and propane. Currently, electricity only makes up 16% of the residential space conditioning fuel mix nationally, and in cold/very cold climates, that number is halved at 8%. Additionally, homes in cold climates require more energy for space conditioning than national averages. Meeting the previously stated national decarbonization goals requires that this mix shifts heavily in favor of electricity, assuming that this electricity is generated from a mix reliant on renewable energy resources.

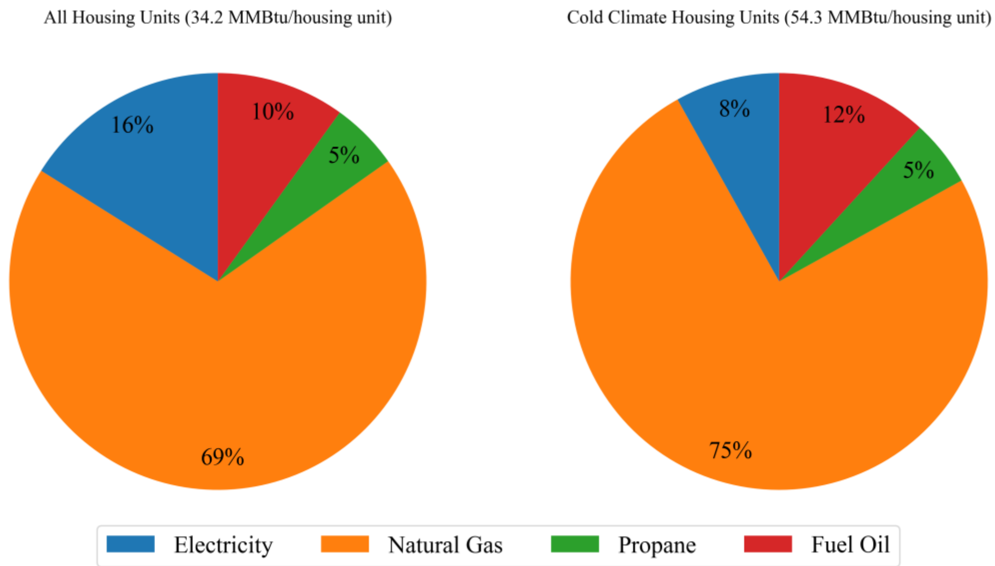

Figure 1: Yearly energy consumption per housing unit across various fuel types as used for space conditioning (EIA 2015).

Load Flexibility

Load flexibility is a well-established strategy that seeks to match the power consumption of electric appliances with the demand and supply of electricity in the grid. A utility or other electricity delivery institution can communicate external grid signals (in the form of price, percent power reduction, etc.) to end-use devices (heating/cooling systems, water heaters, lighting, etc.) to augment their power consumption.

Load shifting, a form of load flexibility, aims to specifically address peak times when loads are at their highest, and effectively manage this load across the grid through load-reduction techniques, such as temperature setpoint reduction for a set time period. The primary goal is to shift a portion of the load to a different time, ultimately achieving a balance between supply and demand. Load shedding, another form of flexibility, aims to reduce total energy consumption over a day, alongside peak-time energy reductions. This study focuses on demonstrating the load flexibility capabilities of CTA-2045-enabled heat pumps. In this paper we use load flexibility as a generalized term, inclusive of load shifting and load shedding, which aims to flatten peaks, reduce energy consumption, and generally manage grid load.

Energy used by the residential sector is drawn from the electric grid and is impacted by time, weather, public events, and household energy use behaviors. Electric utilities often attempt to understand and anticipate these factors, alongside historical energy usage patterns, to estimate grid-wide future usage patterns. By doing this, an electric utility can plan for the generation and transmission of energy to the grid to ensure a balance between energy supply and demand. As cost-effective and scalable energy storage systems have not yet infiltrated the market, nondispatchable energy resources, namely from renewables, are most effectively leveraged by manipulating end-use patterns to align with their generation patterns. Hence, load-matching strategies must be effectively implemented to achieve national, state, and local energy goals of increasing reliance on renewable energy resources, decarbonization, and resilience.

In Cordova, the adoption of widespread electric space conditioning systems in coordination with effective load flexibility strategies may allow the town to rely more on its 7.25

MW of hydroelectric generation plants, for example the Power Creek and Humpback Creek Hydroelectric plants, and shift some generation load from its diesel generation plant, the 10.8 MW Orca Plant (CEC 2023). Cordova has a few major load types: residential, commercial, and industrial. The industrial load is largely influenced by the semi-seasonal fish packing industry, making it highly unpredictable due to the variable quantities of fish caught each season.

This study discusses an application of load flexibility via the CTA-2045 communication standard with residential heat pump space conditioning systems and begins to examine the potential of CTA-2045-enabled heat pumps as a grid resource for the residential sector. CTA-2045 specifies a modular interface to facilitate communication with residential devices for energy management applications (EPRI 2014). The CTA-2045 standard communication protocol defines the method by which a third party may interact with a residential system. It is compatible with a variety of residential systems, such as water heaters, heat pumps, variable-speed pool pumps, electric vehicle supply equipment, and thermostats.

Although CTA-2045 facilitates the energy management of various residential loads, there has been limited literature on field studies that implemented the protocol with space conditioning technologies. Other technologies have been studied more widely. A field study from 2017–2020 in the Pacific Northwest demonstrated the aggregated load-shifting potential of residential heat pump water heaters using CTA-2045 (Hunt et al. 2021). A laboratory evaluation assessed the ability of variable-speed pool pumps, equipped with CTA-2045, to provide grid services (EPRI 2017a). Another evaluation assessed the ability of electric vehicles to supply equipment for grid services (EPRI 2017b). There have been laboratory studies on CTA-2045 in coordination with space conditioning systems, including using thermostats to assess the standard and determine the degree to which interoperability is achieved to control residential heating, ventilation, and air conditioning (HVAC) equipment (EPRI 2017c).

Field Deployment

Overview of Study Sites

The field deployment took place in Cordova, Alaska, a city with approximately 2,600 residents. The coldest months are December and January, with average daily temperatures around 30°F, while the warmest months are July and August, averaging around 56°F. Typically, the lowest daily temperatures range from 10°F to 20°F. These relatively moderate low temperatures enable existing heat pump technologies to operate at high performance levels and are well within their expected operating conditions. These temperature patterns make Cordova an excellent test bed for studying heat pump load flexibility in a cold climate, as the weather is moderate enough to ensure reliable operation with commercially available products while still retaining the characteristics of a cold climate. The study was conducted in three homes with areas ranging from 1,000–2,000 square feet. Figure 2 shows an example floor plan and equipment installation. A Mitsubishi ductless heat pump system was installed in all three homes, usurping an existing fuel oil heating system as the primary source of space conditioning. The fuel oil system was left in place for emergency usage but turned off for most of the study period, with exceptions being on days when indoor temperatures were not maintained by the heat pump system. The number of mini-splits in each home varied from one to three based on the home size. One of the homes had completed energy-efficiency upgrades within the past five years, including improved air sealing and replacement of single-pane windows with double-pane.

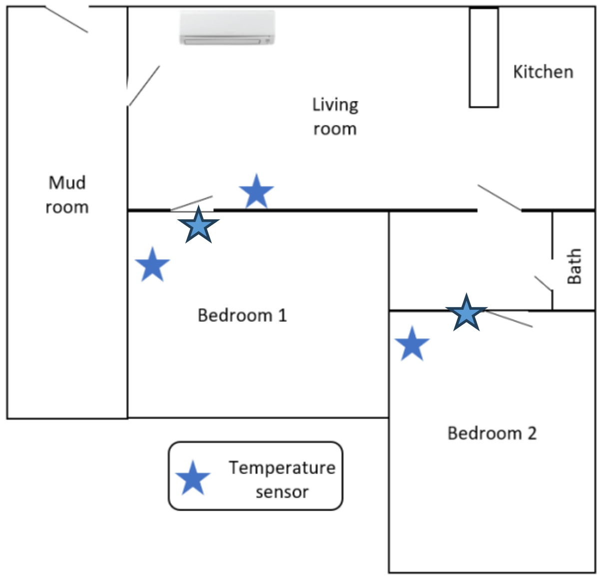

Figure 2. Example of equipment and sensor layout.

Hardware Equipment

The field site deployment was carried out by a contracted electrician and a PNNL researcher. The overall setup for the equipment is shown in Figure . At the core of the communication architecture lies a Cradlepoint cellular modem. This modem facilitates the transmission of heat pump setpoint data through WiFi via the CTA-2045 module, temperature and relative humidity (RH) data through the HOBO gateway, and power data from the DENT power logger via an Ethernet cable. Subsequently, all the gathered data are transmitted to the nearest cell tower and then directed to the respective server of each third-party company. The research team accessed the data remotely via the individual product Architectural Program Interface (APIs). Table 1 provides an overview of the hardware devices used for the data collection and their specification. A description of each device is provided below.

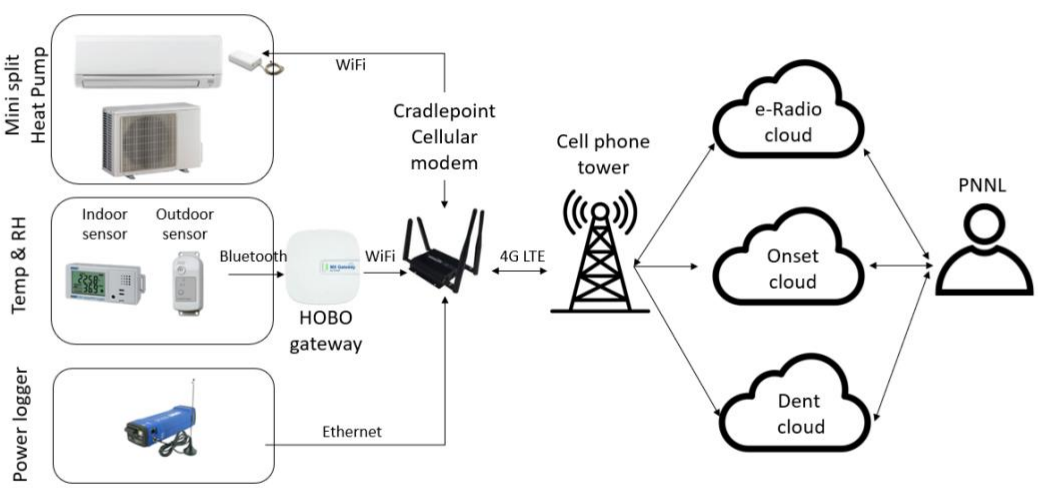

Figure 3. Overview of hardware setup and communication procedure for the field deployment.

Table 1. Hardware devices and their specifications

Measurement Device	Parameters	Accuracy	Resolution	Sampling Location(s)
e-Radio CTA-2045	CTA-2045 load-shaping commands, power (est. W), operating state, temperature setpoints	Defined by Mitsubishi HP HVAC	1 minute	At each indoor unit
HOBO MX1101	Temperature, RH	± 0.2°C (0.36°F), ± 2% RH	1 minute	Each room with space conditioning, central location
HOBO MX2301	Temperature, RH	± 0.2°C (0.36°F), ± 2.5% RH	1 minute	Outdoors
DENT ELITEpro	Whole-house power, heat pump power, additional electric heating power	<1% (<0.2% Typical) kW	1 minute	Electrical panel

CTA-2045-equipped Ductless Heat Pump

A CTA-2045-enabled universal communications module, provided by e-Radio (e-Radio 2023), was installed on each indoor unit using the Mitsubishi PAC-WHS01UP-E USNAP interface, which allows an electric utility company and/or aggregator to send control commands to and collect data from the Mitsubishi units.

Temperature and RH Data Loggers

Onset HOBO temperature and RH sensors (Onset 2023) are often used for environmental monitoring in indoor and outdoor settings, providing data on temperature and RH levels. The external sensor provides highly accurate temperature (-25.6°F to 158°F) and RH (0% to 95%) readings. These readings are reported at 1-minute intervals (Table). The sensors use Bluetooth technology to wirelessly communicate with a gateway. The gateway connects to a Cradlepoint cellular modem that relays the data to the Onset cloud platform via 4G LTE (Figure 3).

DENT Instrument Loggers

Current transducer (CT) loggers are devices commonly used in the field of energy monitoring and management. CTs primarily monitor and record the power consumption of electrical appliances, in this case, the heat pump. The sensors report data on how much electrical power the heat pump is drawing over time. CTs wrap around the electrical wires carrying the power supply to the heat pump and work on the principle of electromagnetic induction, measuring the current passing through the wire without directly interrupting the circuit. CTs are noncontact sensors, meaning they do not physically connect to the wire but instead detect the magnetic field produced by the current flow. CTs are equipped with data logging capabilities. They collect data on the current passing through the heat pump's power line at 1-minute intervals (Table). The DENT power logger (DENT 2023) is connected via Ethernet to the Cradlepoint cellular modem. The data are sent to the DENT cloud via a cell connection and accessed on the DENT cloud through an API (Figure).

Software Architecture

The implementation of the load signaling and data collection were handled using commercially available cloud services. This allowed for improved reliability, reproducibility, and scalability of the methods developed in this deployment.

Cloud Services

Amazon EC2 instances were used to operate the network of communications that takes place within this project. For demand response implementation, a continually running Amazon EC2 instance ran Python scripts on a schedule, which executed each demand response event through the e-Radio API per the parameters set in the event schedule. Amazon S3 was used for storing data that were collected as a part of this project. Cloud services helped to automate the seamless execution, storage, and remote access of multiple APIs, thereby facilitating studies in remote locations like Cordova that may have been challenging otherwise.

e-Radio API

e-Radio provided a Restful API which enabled seamless access to the Mitsubishi unit via the CTA-2045 module. Leveraging the e-Radio API, an electric utility and/or aggregator has the capability to send POST API calls, allowing for thermostat setpoint adjustments on the Mitsubishi units. In the present implementation there were two different API calls:

Relative setpoint reduction: In this implementation a command was sent to the mini-split heat pump unit to decrease its thermostat setpoint by a fixed value relative to the current setpoint, accompanied by a specified duration.
Preheating: A command was sent to increase the thermostat setpoint to a specific setpoint during preheating. Another command was required to end the preheating and establish a new setpoint.

Occupant Comfort

In addition to examining the load flexibility potential of the heat pumps, this study also collected data to gain insight into the impact of heat pump and load flexibility strategies on occupant comfort. Occupant comfort data included indoor and outdoor temperature and RH using HOBO sensors (see Table for details) and comfort surveys that collected subjective responses of study participants to their thermal environment. The comfort surveys were administered via Qualtrics and fielded throughout the study period via text messages. Additionally, interviews were conducted with the study participants to gain deeper insight into participant experience with the new heat pumps and load flexibility events. Detailed findings of comfort evaluations are discussed in an accompanying paper at this conference (Nambiar et al. 2024).

Market Barriers and Remote HVAC Installation

In general, heat pump deployment is more difficult in remote areas, and these impacts are amplified if the HVAC workforce in the region is already overburdened. That was the case in Cordova, where the workforce consisted of a single HVAC company with three employees. An initial step of this project was to assist the local HVAC company with obtaining training and materials to begin installing heat pumps as a residential HVAC solution. After completing training and acquiring new tools, the HVAC company then had to develop or update distribution networks, come up with shipping and delivery plans, and acquire the heat pumps. This proved more difficult than expected, largely due to the remote nature of Cordova. Shipping times exceeded 3 months, and costs were significantly higher than expected (30% increase over costs in Portland, Oregon). Additionally, the HVAC company had trouble keeping up with staffing needs during the installation window and was unsuccessful in hiring new qualified technicians. These barriers, although amplified due to the remote nature of the test location, are seen in various forms across the U.S. HVAC market. The new technologies require training, tools, and staff that were not necessary with historical HVAC technologies.

Load Flexibility Experiment Design

To test the load flexibility potential and occupant comfort impact of heat pumps, different types of experiments were conducted. These experiments were conducted from November 2023 to March 2024, during which time the outdoor temperature in Cordova ranged from 35°F to 0°F. The experiments include events with no preheating, experiments with preheating, and experiments with preheating done one hour in advance of the event. Figure is a schematic of the three experiment types.

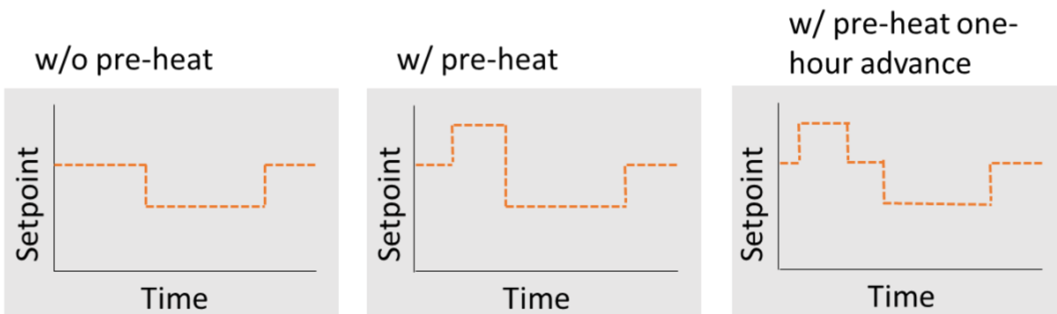

Figure 4. Experiment types.

Approximately 55 events were conducted in each home. Events of each type were repeated at least three times across the study period to capture results across different outdoor and indoor conditions. The preheat experiments involved preheating the units by 2°F for 1 hour prior to the event. The results from these experiments are then compared against baseline conditions (nonevent days).

Study Results

The main findings from the load flexibility experiments are summarized below. All plots show hourly average energy consumption across the sites for a test type, only for the hours of an event occurrence. Preheating, an effective strategy that is validated in commercial buildings, was also implemented for most test types. The success of preheating is dependent on the building's thermal mass, including wall insulation, window R-value, and indoor materials. Events with and without preheating are compared for the various relevant strategies presented in this section. Additionally, occupant opt-outs deteriorated the energy performance analysis of some events. Results are shown without events that experienced occupant opt-out. Temperature and opt-out results are discussed in an adjacent paper in these conference proceedings (Nambiar et al. 2024).

1. **Baseline.** A baseline energy load was calculated for each site, as well as the aggregate of all sites. During baseline days, the average daily energy consumption of the heat pump system was 39 kWh and the average hourly event-time energy consumption was 1.7 kWh.
2. **Duration-based load flexibility.** In this section, results are shown for tests of different event durations. This is the load flexibility strategy most commonly seen in practice. The setpoint was fixed while the duration of the load flexibility event was varied by 1 and 2 hours. Figure 5 shows that 1-hour events without preheating result in a 12% hourly energy reduction over the baseline, consuming 1.5 kWh per event hour. A longer event of 2 hours yielded a 24% hourly energy reduction compared to the baseline, consuming 1.3 kWh per event hour. Three-hour events were also conducted, but results are excluded from this analysis due to their small sample size, driven by occupant opt-out.

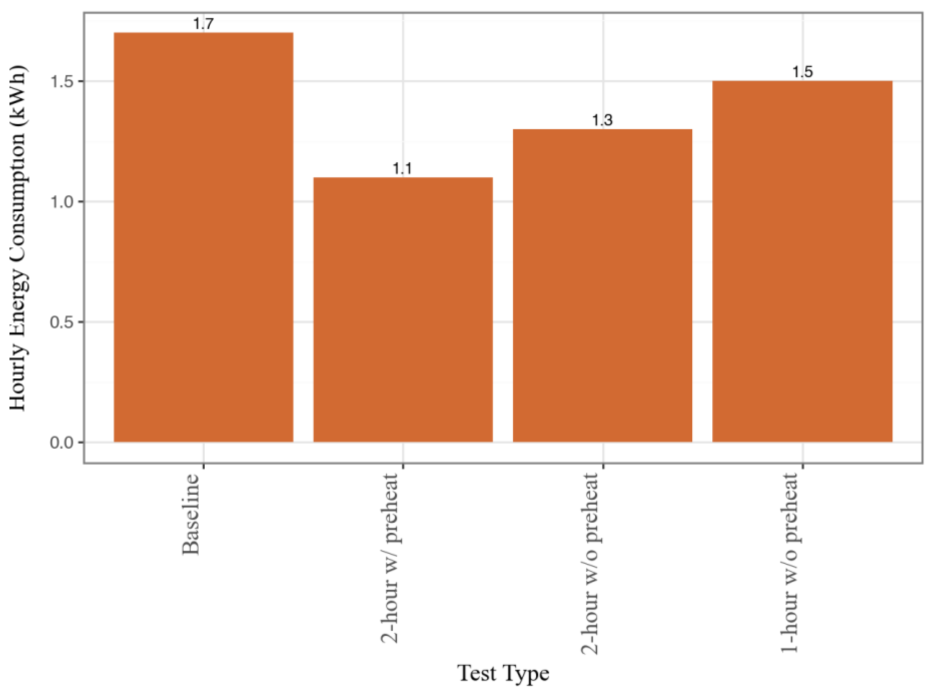

Figure 5. Setpoint reduction for varying duration and a fixed setpoint setback during load flexibility events.

Figure 5 also shows the difference between a 2-hour event with preheating and one without preheating. The 2-hour events with preheating consumed 15% less energy per hour than the 2-hour events without preheating, and 35% less energy than the baseline, consuming only 1.1 kWh per event hour. One-hour events with preheating were also conducted, but occupant opt-out and data loss reduced the sample size for analysis and results were omitted.

3. **Offset-based load flexibility.** In this set of experiments, the event duration is held fixed and the setpoint is varied. This set of experiments shows the effect of the setpoint adjustment on the energy savings during the load flexibility events. Figure 6 shows that events (excluding events with occupant opt-out) with a 2°F setpoint reduction yield a 12% hourly energy reduction compared to baseline during the event. Additionally, events (also excluding events with occupant opt-out) with a 6°F setpoint reduction yield a 24% hourly energy reduction during the event. Including occupant opt-out in this sample resulted in increases in hourly energy consumption of 12% for 2°F setpoint reductions and 24% for 6°F setpoint reductions.

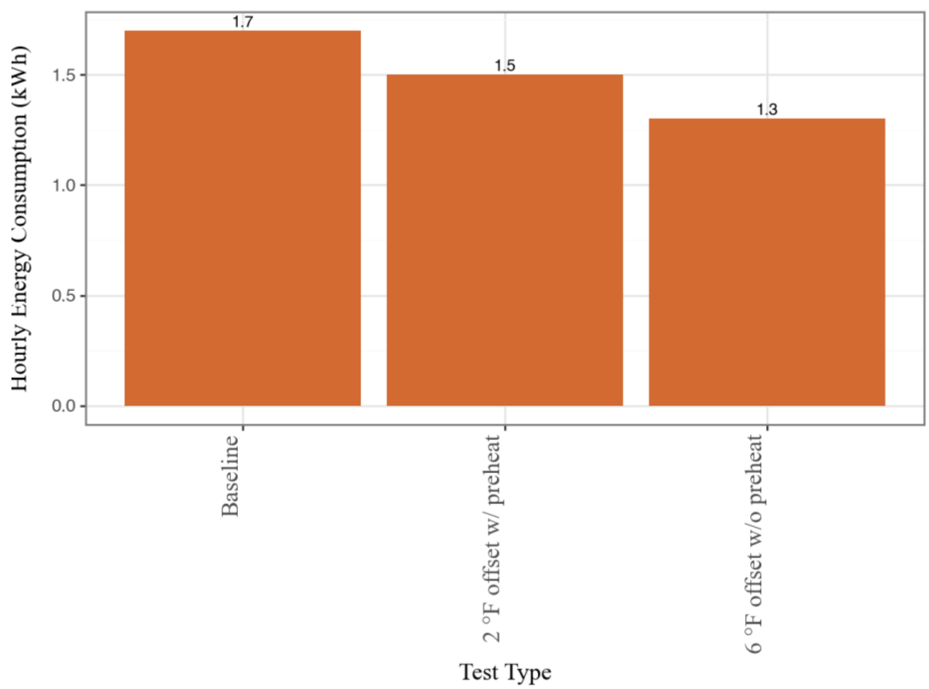

Figure 6. Setpoint reduction for a fixed duration and a varying setpoint setback during load flexibility events.

Occupant Comfort

The overall thermostat override rate for the events across the study period was 19%. In addition to thermostat overrides, participants resorted to their typical adaptive behaviors, for example relying on supplemental heating or firing up their wood stoves to maintain comfort on some event days. In post-study interviews, study participants noted that they did not perceive any noticeable changes to differentiate between event and nonevent days and that the load flexibility events did not interfere with their normal household routines. The participants expressed needing no change to their thermal environment when indoor temperatures were maintained between 65°F and 71°F.[1]

CTA-2045 Communication Reliability

Sending signals to the heat pump indoor units via the CTA-2045-enabled Utility Message Channel has been both fast and reliable. One identified benefit of the CTA-2045 communication standard is that signals have a relatively low data requirement and can be sent over LTE, WiFi, or FM radio, allowing for reliable communication even if one of the avenues is not accessible. The cellular modems used in this study have been functioning reasonably well, but in the month of January 2024, the cellular modem at Site 1 experienced 22 hours of downtime, or around 3% of hours. During these hours, WiFi-reliant communication methods would have failed to communicate effectively. In contrast, the e-Radio Universal Communication Module (UCM) at Site 1 had a 0.7% downtime rate, resulting in 0 missed communications. This is an example of the improved reliability that is enabled by this communication method's flexibility. In total, communication loss was 23% lower with the e-Radio UCM than the cellular-enabled WiFi network.

Study Limitations

This research project was not without its share of issues, setbacks, and limitations. These issues included difficulty increasing the sample size due to workforce shortages, technology and communication issues, and unexpected equipment and participant behaviors.

At the beginning of this project, the goal was to initialize uptake of heat pumps in Cordova's residential HVAC market by assisting the only local HVAC company with training and acquisition of tools and then funding the installation of their first three residential heat pump installations. The expectation was that the HVAC company would continue installing heat pumps in residences during the following summer, and the research team would be able to access a larger population for study recruitment. Unfortunately, due to local economic and other challenges, all homeowners who had stated their intent to install a heat pump system over that summer revised their plans, and no additional units were installed. As of May 2024, very few heat pumps have been installed in town outside of this study, although interest is rising as the 2024 summer season approaches.

Technological and communication issues also affected the study. Most of these issues impacted data loggers and were linked to wireless communication systems, exaggerated in contrast to other studies by the remote nature of the study location. The temperature/RH sensors relied on Bluetooth to communicate data back to a central communication unit, and this Bluetooth connection proved unreliable. In some cases, sensors missed days, weeks, or months of data. These sensors were generally replaced, but some remained inaccessible due to poor connectivity. The power logger also experienced data loss. The download process of the chosen power logger is administered over TCP/IP (Transmission Control Protocol/Internet Protocol) connections and occasionally resulted in data logging being turned off upon disconnection from the logger. It was impossible to check for this error because one must reconnect to the logger to

[1] The comfort impact of the load flexibility events is discussed in detail in an accompanying paper in this conference proceeding (Nambiar et al. 2024).

check the logging state, and the error is possible during the termination of this connection. Over 2 months of power data were lost due to this issue, mainly at Sites 2 and 3.

Finally, unexpected equipment and participant behaviors were also present in this experiment. Although the CTA-2045 implementation was generally very reliable and resilient, one indoor unit at one site experienced a consistent and currently unexplained issue. During exit interviews, the occupants of this site stated that they noticed unexplained operations from this unit, including randomly entering standby mode, turning on and off unexpectedly, and changing operation mode. From observation of the event data, during longer events (2h and 3h), one unit at Site 3 would report an “occupant opt-out” signal at the exact same time of day, down to the second. Additionally, the setpoint would revert to the exact setpoint held before the event. Due to the methodical nature of the timing and setpoint change, alongside participant interview information, we believe these opt-out events to be caused by some sort of technological failure. It is currently unclear whether this failure stems from the HVAC equipment, the communication system, loss of connection to the communication system, or otherwise, but investigation is ongoing.

Summaries and Next Steps

Overall, this research project was a successful first endeavor to study load flexibility in a rural, grid-constrained, cold climate region. Results of this research show successful peak-time energy reduction across various strategies in multiple homes. Alongside energy performance, this research project shed light on the improved communication reliability delivered by the CTA-2045 communication standard and the e-Radio UCM, as well as successes and difficulties in developing the heat pump market in an underdeveloped region. Finally, this study showed the importance of occupant comfort considerations in developing reliable and occupant-centric load flexibility strategies.

Peak Load Mitigation Capabilities

One of the objectives of this research was to characterize the potential increased electricity consumption from widespread heat pump installation and determine the peak load reduction potential of grid-enabled residential heat pumps in rural cold climate communities. Extrapolating to an assumed residential building stock of 950 homes in Cordova, it could be expected that the full adoption of heat pumps would increase the average daily electricity consumption of Cordova homes by around 37,050 kWh per day (1,544 kWh per hour). During the late afternoon hours used for testing, a peak consumption of 1,615 kWh per hour was identified. This research has shown that, in the best case of a 2-hour event with varying setpoint reduction amounts, an aggregate energy reduction of 0.6 kWh per home per event hour can be reasonably expected. This extrapolates to 1,045 kWh per hour during these events, a 570 kWh per hour savings over no intervention. These savings may seem minimal to a larger utility with power-purchasing capabilities, but in a rural, isolated grid case like this one, these peak-time savings may result in the utility’s ability to manage the load without having to add nonrenewable generation resources to the mix.

Communication with CTA-2045

Throughout this study, communication via the e-Radio CTA-2045 UCM has proven to be more reliable than cellular-based WiFi communication strategies. Many other pathways for end-use control are delivered via a WiFi network, which in remote areas or when attempting to isolate the system from homeowner WiFi, is often delivered via a cellular network. This is incredibly impactful in remote or internet-constrained regions, especially for grid managers who may be implementing a load flexibility program in those regions. Simply put, without communication, control is impossible. By relying on various methods of communication to send information from a grid management program to an end-use device and receive a response, events can be more reliably implemented. This is especially important during extreme events, where the grid manager must be able to expect that the end-use control signal being sent will be received and result in the expected outcome.

Market Development

This project included a market development phase, where the local HVAC company received a manufacturer-provided training opportunity, specialized tools, and localized information to effectively deliver on customer expectations.

The training course required one of the two HVAC technicians at the local company to travel from Cordova to Tacoma, Washington. The training spanned two days, and in total the technician was unavailable to the company for four days. The cost of this training was roughly $3,200 per technician, including travel, lodging, per diem, and the training itself. In larger companies or territories with more HVAC technicians, the time and cost of this training may not be a notable issue. However, in this case, and other cases where the HVAC market is underdeveloped, these time requirements may disrupt normal operations significantly. To mitigate these effects, training programs may consider targeting underdeveloped markets and bringing the training to them, allowing more technicians to receive appropriate training at a reduced cost and time requirement.

The set of tools required to transition from fossil fuel-based HVAC work to heat pump installation and maintenance work included specialized power tools, refrigerant tools, and electrical tools. The total cost of this tool set was roughly $2,000.

Before the provision of these trainings and tools, the HVAC company expressed little to no interest in developing heat pump installation capabilities. By providing the training and tools at no cost to the HVAC company, this project was able to convince the company to not only participate in the project but also to offer heat pumps as an option to all customers considering a new HVAC system. This type of market development is relatively low cost for a large program, but it enables a city, area, or region with an underdeveloped heat pump market to take the first steps toward widespread adoption.

Comfort Evaluation

Thermal comfort impacts of load flexibility strategies are a key factor impacting occupant opt-outs; hence comprehensive evaluation of thermal comfort was an important focus area of this study. Key lessons learned include:

- Whole-building energy efficiency and weatherization are an important first step to residential load flexibility program enrollment to ensure their reliability and persistent participation.
- Thermal comfort is a key factor influencing success and reliability of load flexibility events. Strategies that allow participants autonomy over control of their thermal environment can enable trust, leading to long-term commitments and persistent participation.
- Load flexibility strategies that consider participants' thermal comfort boundaries have potential to be more reliable as they triggered lower levels of overrides and other energy-intensive responses in these studies.

Next Steps

Continuing from the 2023–2024 heating season research in Cordova, this research will extend to other rural cold climate cities and villages in Alaska. The research plan for these new samples will incorporate learnings from the previous study to refine and improve methodologies and will more extensively investigate the occupant comfort impact of various strategies. Homes in the new samples will be audited for envelope performance to improve understanding of preheating and setpoint manipulation opportunities and performance across various bins of building characteristics. Additionally, improved sensor packages have been identified to mitigate data loss experienced in the previous sample, allowing for a more effective analysis of the impact of various events and strategies.

References

ANSI/CTA, 2045-B. 2022. "Modular Communications Interface for Energy Management." Arlington, VA: Consumer Technology Association. https://shop.cta.tech/products/https-cdn-cta-tech-cta-media-media-ansi-cta-2045-b-final-2022-pdf

Cordova Electric Cooperative (CEC). 2023. https://www.cordovaelectric.com/

Dayem, K. 2018. Standardized Communications for Demand Response An Overview of the CTA-2045 Standard and Early Field Demonstrations. 2018 prepared for the National Rural Electric Cooperative https://www.cooperative.com/programs-services/bts/Documents/Reports/Standardized-Communications-for-Demand-Response-Report-June-2018.pdf

Dent Instruments, ELITEpro SC Portable Power Data Logger, available online: https://www.dentinstruments.com/shop/power-meter/elitepro-xc-portable-power-data-logger

Douville, T. C., and D. Bhatnagar. 2021. Exploring the Grid Value of Offshore Wind Energy in Oregon. *Energies*, *14*(15), 4435. https://doi.org/10.3390/en14154435

e-Radio USA Inc. 2023. http://e-radioinc.com/

Electric Power Research Institute (EPRI). 2014. Introduction to the ANSI/CEA-2045 Standard. Technical Update 3002004020.

———. 2017a. Performance Test Results: CTA-2045 Variable Speed Pool Pumps: Testing Conducted at the National Renewable Energy Laboratory. EPRI, Palo Alto, CA.

———. 2017b. Performance Test Results: CTA-2045 Electric Vehicle Supply Equipment: Testing Conducted at the National Renewable Energy Laboratory. EPRI, Palo Alto, CA.

———. 2017c. Performance Test Results: CTA-2045 HVAC Thermostat: Testing Conducted at the National Renewable Energy Laboratory. EPRI, Palo Alto, CA.

Fact Sheet: New Innovation Agenda Will Electrify Homes, Businesses, and Transportation to Lower Energy Bills and Achieve Climate Goals, accessed 6/27/2023, available online https://www.whitehouse.gov/ostp/news-updates/2022/12/14/fact-sheet-new-innovation-agenda-will-electrify-homes-businesses-and-transportation-to-lower-energy-bills-and-achieve-climate-goals/

Hunt, W., E. Mayhorn, T. Ashley, and C. Metzger. 2021. Factors Influencing Electrical Load Shape of Heat Pump Water Heaters, ASHRAE Journal 63 (2):24-29.

Li, H., Z. Wang, T. Hong, and M. A. Piette. 2021. Energy flexibility of residential buildings: A systematic review of characterization and quantification methods and applications, Advances in Applied Energy 3 10005, https://doi.org/10.1016/j.adapen.2021.100054

Nambiar C., S.I. Rosenberg, and T. Peffer. 2024. "Enhancing Participation in Residential Demand Response: Insights from Case Studies Conducted in Alaska and California." In 2024 ACEEE Summer Study on Energy Efficiency in Buildings. PNNL-SA-195671.

Neukomm, M., V. Nubbe, and R. Fares. 2019. "Grid-Interactive Efficient Buildings Technical Report Series: Overview of Research Challenges and Gaps." NREL/TP-5500-75470; DOE/GO-102019-5227. National Renewable Energy Lab. (NREL), Golden, CO (United States). https://doi.org/10.2172/1577966

ONSET BRANDS, HOBO Temperature/Relative Humidity Data Logger, available online: https://www.onsetcomp.com/products/data-loggers/mx1101

U.S. Department of Health and Human Services. 2022. HHS launches pledge initiative to mobilize health care sector to reduce emissions. https://www.hhs.gov/about/news/2022/04/22/hhs-launches-pledge-initiative-mobilize-health-care-sector-reduce-emissions.html

U.S. Energy Information Administration. (2015). *Residential Energy Consumption Survey (RECS)*. https://www.eia.gov/consumption/residential/data/2015/