2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review:

Load Flexibility with Heat Pumps

Field study of heat pump load shifting in rural cold climate regions

Presented by Chitra Nambiar

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Project No.: 1.4.1.19 Task 2

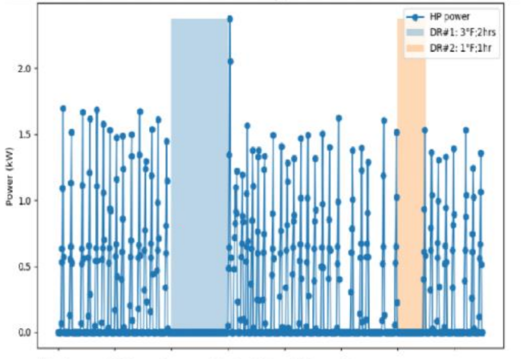
PNNL

Project Summary

OBJECTIVE, OUTCOME, & IMPACT

- Previous project performance studied the capabilities and impacts of load flexibility with DHPs in two climate zones FY22 & FY23 Portland, OR; FY23 & FY24 Cordova, AK) relying on the ANSI/CTA-2045 communication protocol.
- FY25 (Elim, AK) work will expand on these learnings, develop best practices for occupant centric winter DR programs in very cold climates based on heat pump system performance and occupant comfort.

Successful DR events examples- Heat pump energy data



Heat pump DR event power data for 3F and 1F events

PARTNERS

Partners: US HUD, Weatherization Assistance Program, Cordova Electric Cooperative, Copper Highway Heating, Native Village of Elim

KAWERAK, INC.

STATS

Performance Period: FY22-FY25

DOE Budget: $1.45M, Cost Share: $0k

Milestones:

FY22 Q3: Technical report for winter load shifting (Portland, OR)

FY23 Q4: Technical report on market analysis, experimental plan, and prelim results (Cordova, AK)

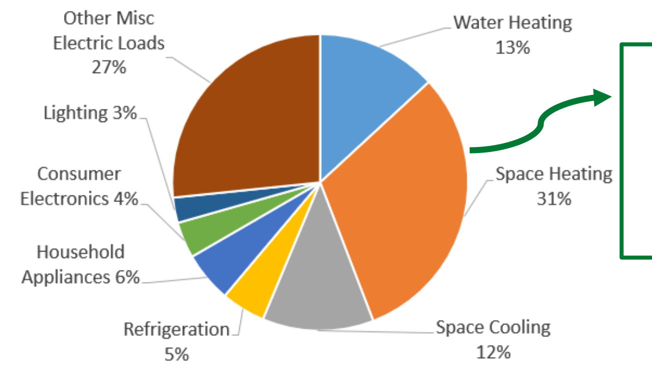
FY24 Q4: Final technical report/conference paper incorporating winter load shifting results (Cordova, AK)

FY25 Q4: Progress update on load shifting (Elim, AK)

Problem

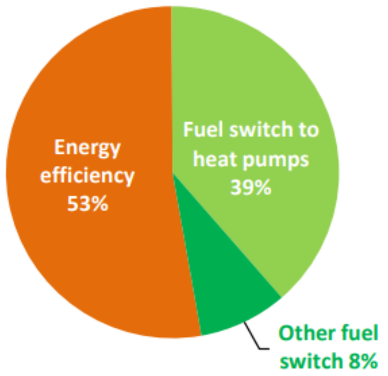
Space heating consumes the most energy of all residential end uses and has the highest potential for decarbonization. ***Heat pumps are energy-efficient and can be demand flexible to help address this problem***

Percent of 2024 Residential Energy Consumption by End Use



Space heating consumes the most energy of all residential end uses

Heat pumps projected as a key solution for decarbonization



- Heat pumps for cold climates is a promising solution for lowering emissions – *but need more testing in extreme cold climates*.
- Demand-flexible heat-pumps can stabilize the grid and improve energy resilience by using locally available renewable energy – *few studies exist on residential winter demand-flexibility with heat pumps*.
- Demand-response with heat-pumps may impact thermal comfort and interfere with daily routines – *DF/DR program administrators have limited resources to consider occupant impact in their planning*.

Data Source: RECS-EIA, WEO-IEA

Project Alignment

Developing best-practices for demand flexibility using residential heat pumps in rural U.S. locations aligns with DOE's Decarbonization Blueprint goals

National Buildings Blueprint for Decarbonization

By 2050, All primary electric resistance space and water heating is **replaced by heat pumps**, and 75% of all homes and businesses have automated control platforms that reduce energy waste and **enable flexibility**.

This project meets **Decarbonization Blueprint** goals by:

- Conducting field testing and validating of communication protocols for implementing demand flexibility with heat pumps in remote locations.
- Testing demand savings potential of common demand response strategies using heat pumps.
- Establishing data collection and analysis methods to understand occupant experience of heat pump demand flexibility.
- Sharing lessons learned and best-practices to enable regional utilities to better utilize locally generated power and proactively manage increased electric demand.
- **Enabling market transformation efforts to increase uptake of heat pumps.**

Image Source: DOE National Blueprint

Research Impact

To maximize impact of DOE's decarbonization goals at the electric utility scale, this research addresses key gaps in heat pump performance and demand flexibility (DF) and demand response (DR) research

This field research can inform **better utilization of heat pumps** for:

- Regional DF/DR program implementation to improve local energy resilience
- Utility incentive program design for DF/DR-enabled technologies

By **addressing lack of relevant guidance** for:

- Equipment performance and
- Occupant comfort and acceptance of DF/DR with heat pumps in
  - Residential winter DF/DR
    - Reduce energy consumption during peak demand hours by
    - Adjusting temperature setpoint
  - Underrepresented location - extreme cold, rural and remote

Research contribution: quantify and **develop DF/DR best-practices** based on

- Local weather conditions
- Local building characteristics
- Local lifestyles, routines and practices

Approach

*Leveraging lessons learned from each research phase to inform various aspects of DF/DR implementation – **Phase 1: communication strategies; Phase 2: occupant comfort evaluation** methods; **Phase 3: program-level impact** using larger study sample*

Phase 1

Portland, Oregon (FY22-23) –
moderate marine climate regional electricity generation mostly renewable.
Sample size: 11 homes

- ✓ CTA-2045 for heat-pump DF
- ✓ Demand savings
- ✗ Occupant comfort
- ✗ Statistical validity

Phase 2

Cordova, Alaska (FY23-24) –
coastal fishing community locally produced hydroelectric power to offset fuel oil dependence
Sample size: 3/700 homes

- ✓ CTA-2045 for heat-pump DF in cold regions
- ✓ Demand savings
- ✓ Occupant comfort
- ✗ Statistical validity

Phase 3

Elim, Alaska (FY25-) –
small remote village
exploring sustainable solutions to reduce fuel oil dependance
Sample size: 15/70 homes

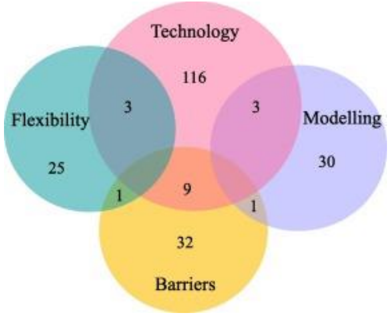
- ✓ DF/DR with heat-pump in extremely cold regions
- ✓ Demand savings
- ✓ Occupant comfort (subsistence-based lifestyle)
- ✓ Statistical validity – larger sample size

Approach

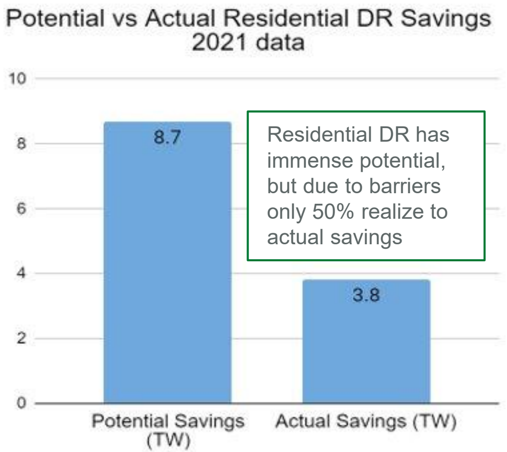
Overcome identified barriers to heat pump DF/DR for cold-climate regions by developing best practices

Background

- Current studies focus on heat pump and DF/DR technology; limited studies focus on heat pump flexibility and barriers to adoption
- Residential DF/DR has huge savings potential (EIA estimate 8.7 GW)
- However, barriers impact actual savings (only 50% of estimated savings were realized)
  - Studies have identified occupant comfort as major barrier for residential DF/DR participation (Parrish et.al)
- Few best-practices/resources are currently available for occupant-focused residential space conditioning DF/DR program design
- Due to these barriers, utility programs have trouble maintaining DF/DR participation needed to meet savings potential



Breakdown of current studies on heat pumps Gaur et.al. 2021



Data sources: EIA, 2021

Building sectors most impacted by this project
Residential: single-family, multi-family, and manufactured housing

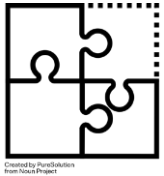
Approach

Barriers to conducting research and connected equipment programs in cold climates can be overcome through planning and collaboration

Barriers, challenges, and risks

- Project takes place in cold to extremely cold, remote locations
  - Winter OAT in Elim, AK can drop to -60˚ F
- Cellular communication is spotty, inhibiting data collection and event dispatch
- Extremely limited local technical/trades support
- Local tribal population has a unique lifestyle

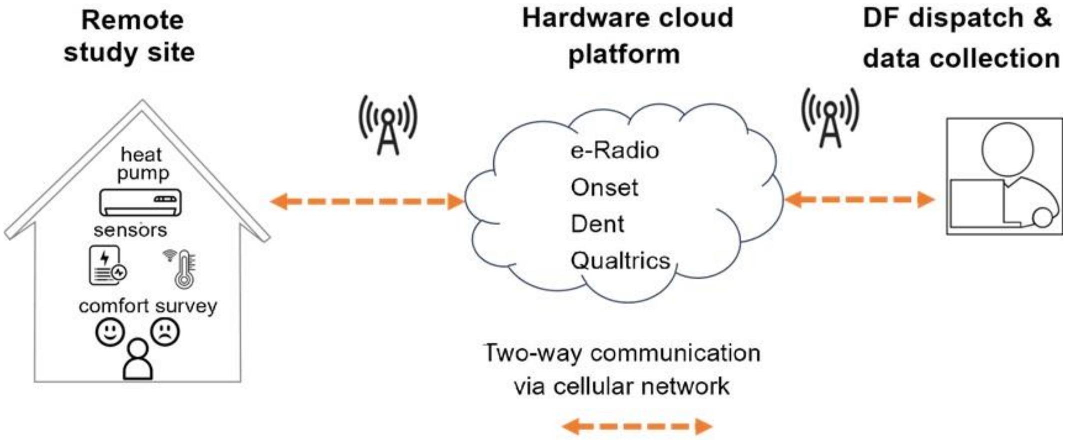
Mitigating these issues



- StarLink networking and on-board data storage for loggers
- Robust logger setup with backup sensors to reduce failure risk
- Work with tribe leaders, gain participant trust through transparency, informed consent, and information sharing.

Approach

Data collection and program delivery methods developed through this project enable automation, scalability, and reproducibility



Data collection includes:

- Physical environmental data
- Heat pump energy use data
- Supplementary heating source data
- Occupant interviews

Data Types:

- Indoor temperature and relative humidity
- Outdoor temperature and relative humidity
- Heat pump and supplementary heating energy use
- Heat pump thermostat data
- Occupant interviews and comfort survey

DF/DR signals:

- Synthetic – not through utility
- Temperature offset with and without preheat
- Duty cycle (if feasible)

Image source: Nambiar et.al 2024

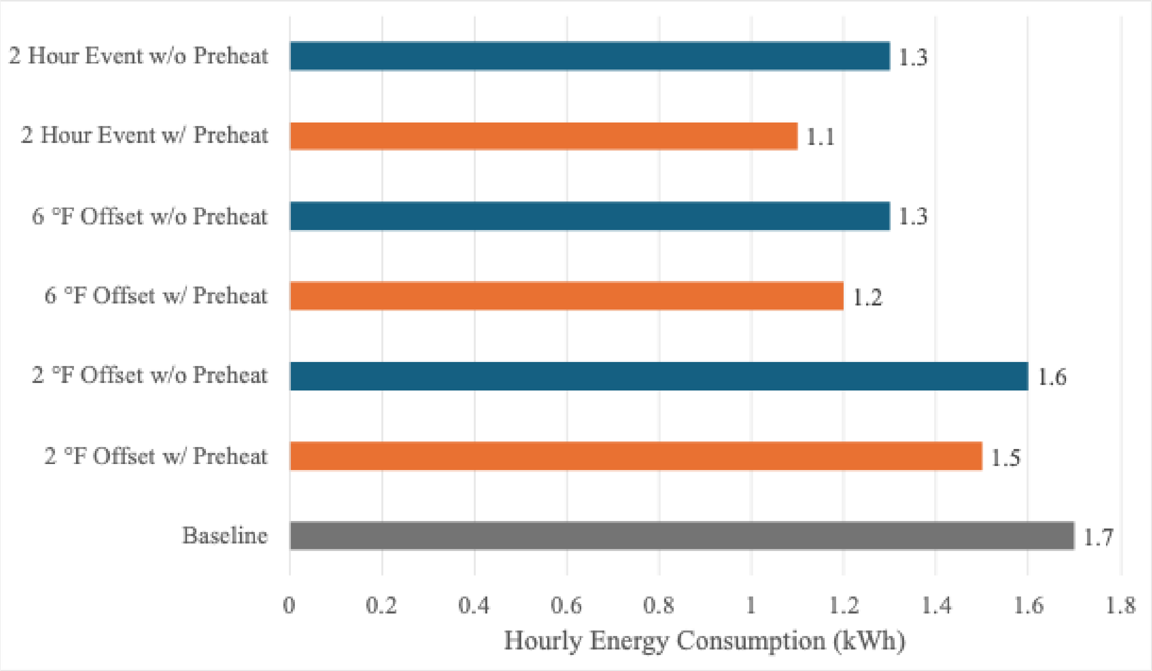
Progress and Key Findings

Phase 2 results for (1) energy impact across DF/DR event types, including varying durations, offsets, and preconditioning strategies

Phase 2 - Cordova, AK

Load Flexibility Event Aggregated Results

- 6–35% hourly energy consumption reduction during test hours
- Pre-heating increases peak load reduction across all tests
- Large setpoint reductions can be effective***

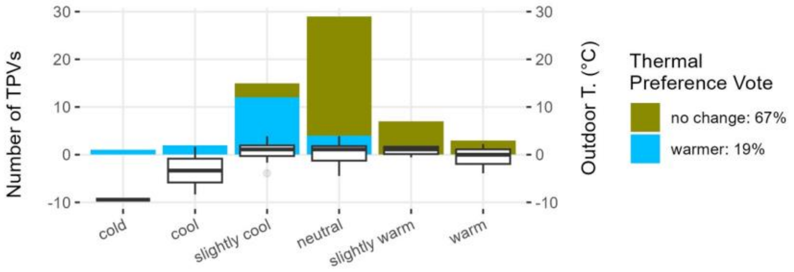


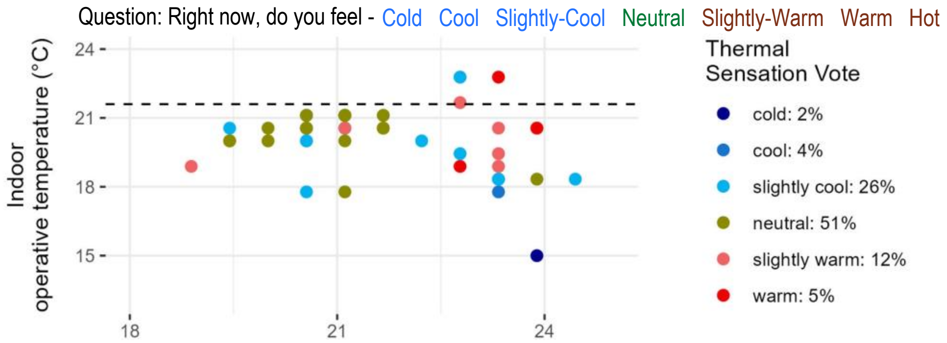
Progress and Key Findings

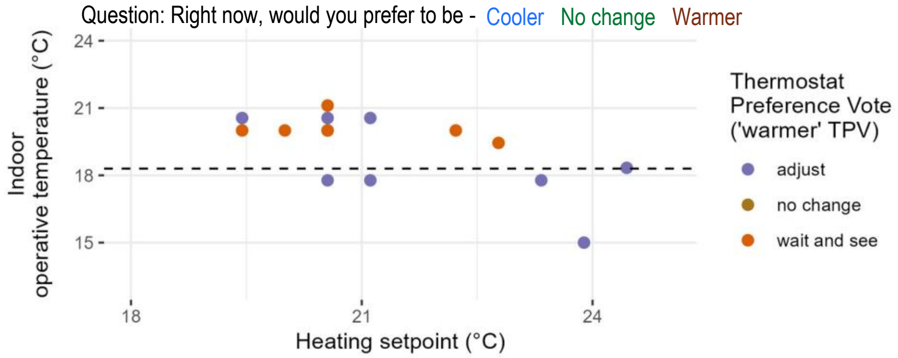
Phase 2 results for (2) comfort impact across DF/DR event types, including varying durations, offsets, and preconditioning strategies

Occupant Comfort Acceptability Ranges

- Indoor temperature range:
  - 67–71˚ F (19.4 to 22˚ C)
- Thermostat heating setpoint range:
  - 66–71˚ F (19 to 23 ˚ C)
- Optimum indoor temperature range for DF
  - 65–71˚ F (18 to 22 ˚ C)

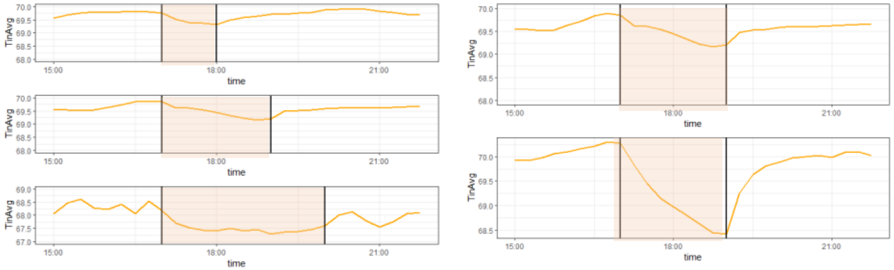




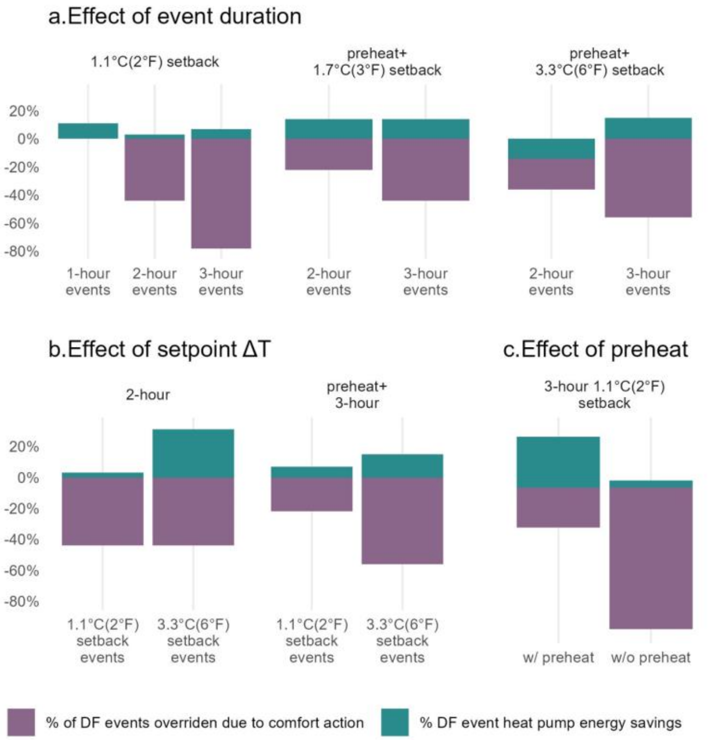


Progress and Key Findings

Phase 2 results for (3) comparison of outcomes of DF/DR event types of varying durations, offsets, and preconditioning strategies



- DF event energy savings increase when setback temperature change is larger
- DF event energy savings larger for events with less comfort action
- Longer durations – increase likelihood of comfort action, hence reduced participation and lower energy savings
- Larger setbacks are tolerated if event duration does not exceed 2 hours



Progress and Impact

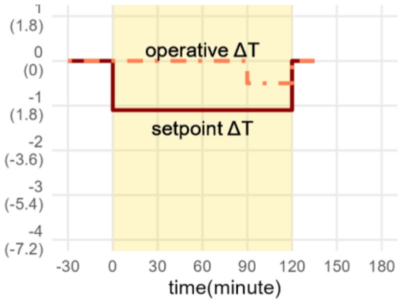
In situ support

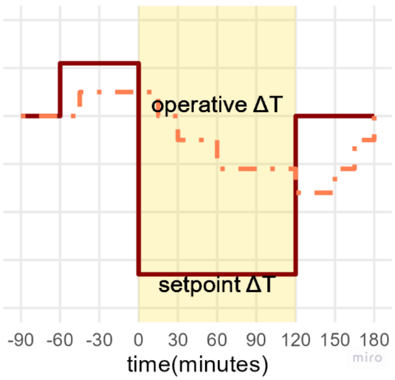
- Providing input to technical reference manual (TRM) heat pump/DF measures and working groups
  - Northwest Regional Technical Forum
  - Texas Heat Pump Working Group
  - Midwest Air Source Heat Pump Collaborative
  - Arkansas Heat Pump Working Group
- Assisted in developing a new heat pump incentive offering in Cordova Electric Cooperative territory

Products

- Conference (paper and presentation):
  - 2024 ACEEE Summer Study (2)
  - 2022 ASHRAE Buildings XV
- Journal Publication (under review, available in pre-print, SSRN) http://dx.doi.org/10.2139/ssrn.4952712
- Presentations/webinars:
  - 43rd Peak Load Management Alliance Conference
  - Better Buildings Residential Network Webinar
  - PG&E Webinar
  - ASHRAE Buildings XV
  - Better Buildings Resource Network

Lessons Learned and Next Steps for FY25





FY 24 Highlights:

- Address research questions that cannot be answered in “controlled environment” or simulated studies
- Key Focus: Establish reproducible methods
  - Test CTA-2045 capabilities in extreme-cold weather (remote DF/DR)
  - Test automated data collection process
  - Establish novel comfort evaluation method for typical DF/DR strategies

FY 24 Limitations:

- Small sample size – limits generalizability of findings
- Testing limited to Mitsubishi ductless heat pumps
- Wide variation in envelope efficiency between homes – thermal lag impacts

FY 25 Goals:

- Assist the Native Village of Elim in reaching their Integrated Resource Plan goals
- **Key Focus**: Expand and validate findings
  - DR using communication strategies other than CTA-2045, GREE heat pumps
  - Impact of weatherization on DF/DR comfort and energy savings
- Occupant-focused best practices for winter DF/DR in extreme cold climates

Thank you

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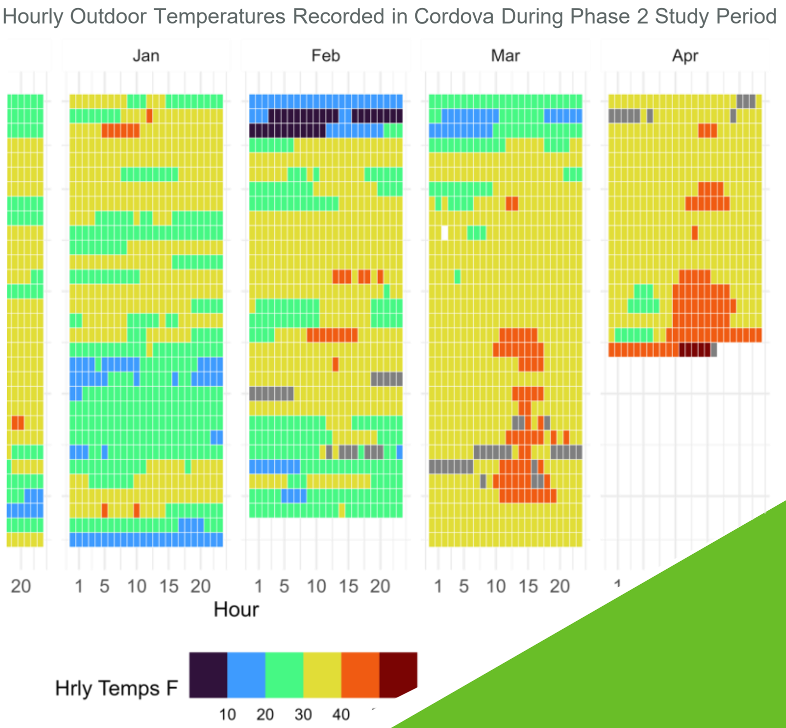

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Reference Slides

Project Execution

	FY2023				FY2024				FY2025			
Planned budget	$304,500				$255,500				$313,000			
Spent budget	$287,000				$261,000				-			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Draft Report - Winter Load Shifting capabilities of ccHP in Cordova, AK (Part 1)												
Final Report - Winter Load Shifting capabilities of ccHP in Cordova, AK (Part 1)												
Draft Report - Winter Load Shifting capabilities of ccHP in Cordova, AK (Part 2)												
Final Report - Winter Load Shifting capabilities of ccHP in Cordova, AK (Part 2)												
Current/Future Work												
Participant selection framework for larger sample load shifting study in Elim, AK												
Draft Report - Mid-Study update on larger sample load shifting study with ccHP in Elim, AK												

Team

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