Better Buildings® U.S. DEPARTMENT OF ENERGY

Better Buildings Residential Network
Peer Exchange Call Series

Demand Response Programs and Their Impact on Peak Load Energy Usage and Comfort

April 25, 2024

Agenda and Ground Rules

- Moderator
  - **Jonathan Cohen,** Better Buildings Residential Network, U.S. DOE Residential Buildings Integration Program (RBI)
- Agenda Review and Ground Rules
- Residential Network Overview and Upcoming Call Schedule
- Opening Poll
- Featured Speakers
  - **Bethany Sparn,** National Renewable Energy Laboratory (NREL)
  - **Chitra Nambiar,** Pacific Northwest National Laboratory (PNNL)
  - **Gabriel Kjos**, Portland General Electric
- Open Discussion
- Closing Poll and Announcements

Ground Rules:

1. **Sales of services and commercial messages are not appropriate** during Peer Exchange Calls.
2. Calls are a safe place for discussion; **please do not attribute information to individuals** on the call.

The views expressed by speakers are their own, and do not reflect those of the Dept. of Energy.

Join the Network

Member Benefits:

- Recognition in media, social media and publications
- Speaking opportunities
- Updates on latest trends
- Voluntary member initiatives
- One-on-One brainstorming conversations

Commitment:

- Members only need to provide *one number*: their organization's number of residential energy upgrades per year, or equivalent.

Upcoming Calls (2nd & 4th Thursdays):

- *5/9: The Latest on Zero Energy Windows, Thin Triples, and Advanced Window Technologies*
- *5/23: Decarbonizing Low Income Homes – The DOE Affordable Home Energy Shot*

Peer Exchange Call summaries are posted on the Better Buildings website a few weeks after the call

Bethany Sparn

NREL

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Transforming ENERGY

Residential HVAC Demand Response: Impact on Peak Power and Comfort

Bethany Sparn
Senior Research Engineer
April 25, 2024
Better Buildings Residential Network Webinar

Presentation Outline

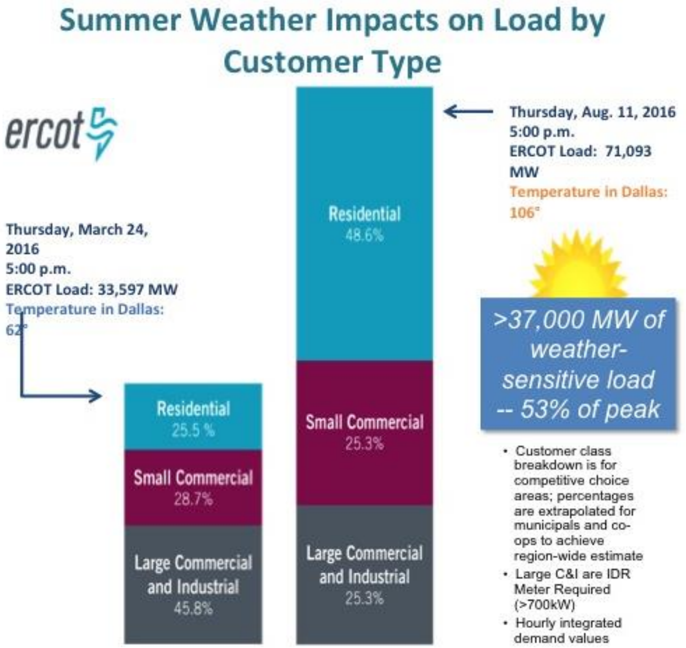
Residential HVAC DR implementation:

- Old method: Relay control of compressor via utility control
- Current method: Set point control via smart thermostat
- Future method: Direct control of variable speed heat pumps can reduce speed/power with less cycling.
- What about **comfort**??

Demand Response for Residential HVAC

Residential Air Conditioners have been controlled to provide Demand Response for many years.

- It is one of the largest loads in the home and generally coincides with highest peak on the grid.
- In fact, residential air conditioning often drives summer peak.
- Efficient envelopes and thermal mass in buildings may allow them to coast through demand response events, especially with some preconditioning.



Source: www.sierraclub.org/texas/blog/2018/09/it-s-time-increase-texas-energy-efficiency-goal

Demand Response via Direct Load Control

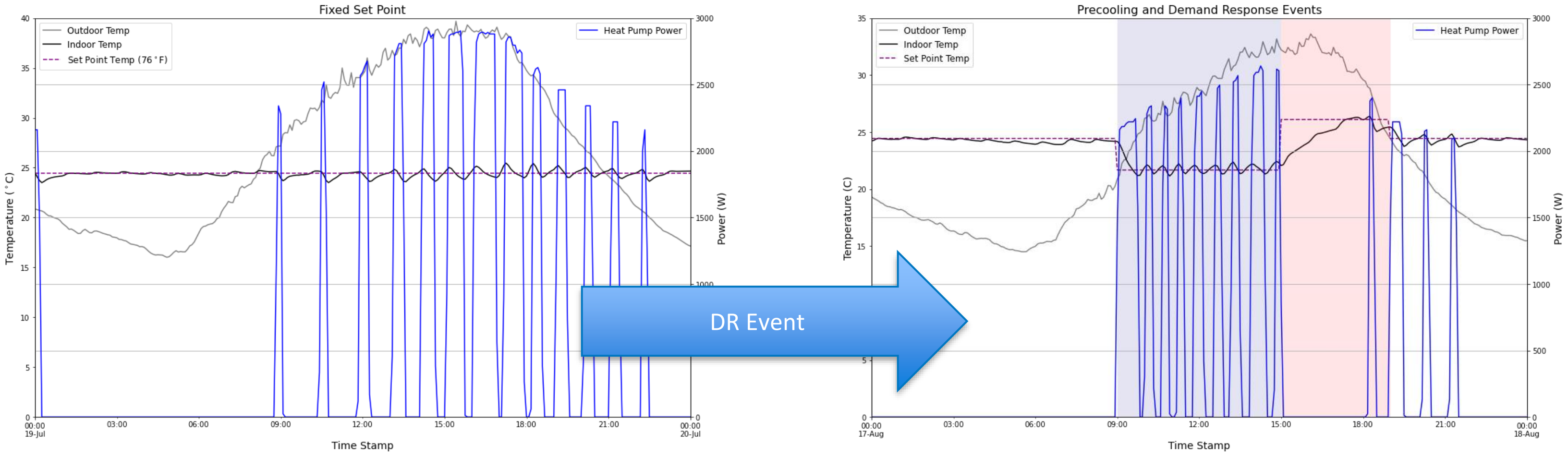
Original method for controlling residential air conditioners was Direct Load Control: a relay on the outdoor unit that could be turned off by the utility during periods of extreme grid congestion.

- Control usually cycles units on and off, rather than just keeping them off for the entire duration of event.
- Homeowners had no way to override event and may not understand why house was too warm.
- Utilities would typically give participating customers an annual bill credit.

Demand Response via Set Point Control

Smart thermostats can be enrolled in utility Demand Response programs.

- Allows for set point control, which ensures that AC still runs during DR events
- Can also implement pre-cooling before DR events
- Also makes it easier for homeowners to override if they are uncomfortable.



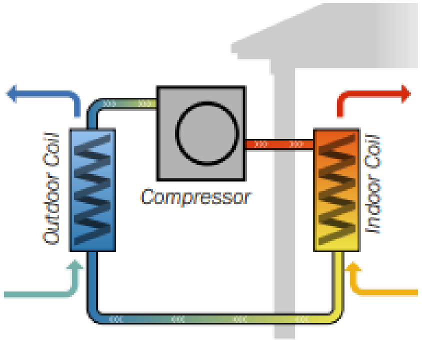
Demand Response via Variable Speed Control

DOE announced the Cold Climate Heat Pump (CCHP) Challenge in 2021 to accelerate the development and deployment of CCHPs. Performance requirements include ability to reduce speed of variable speed compressors.

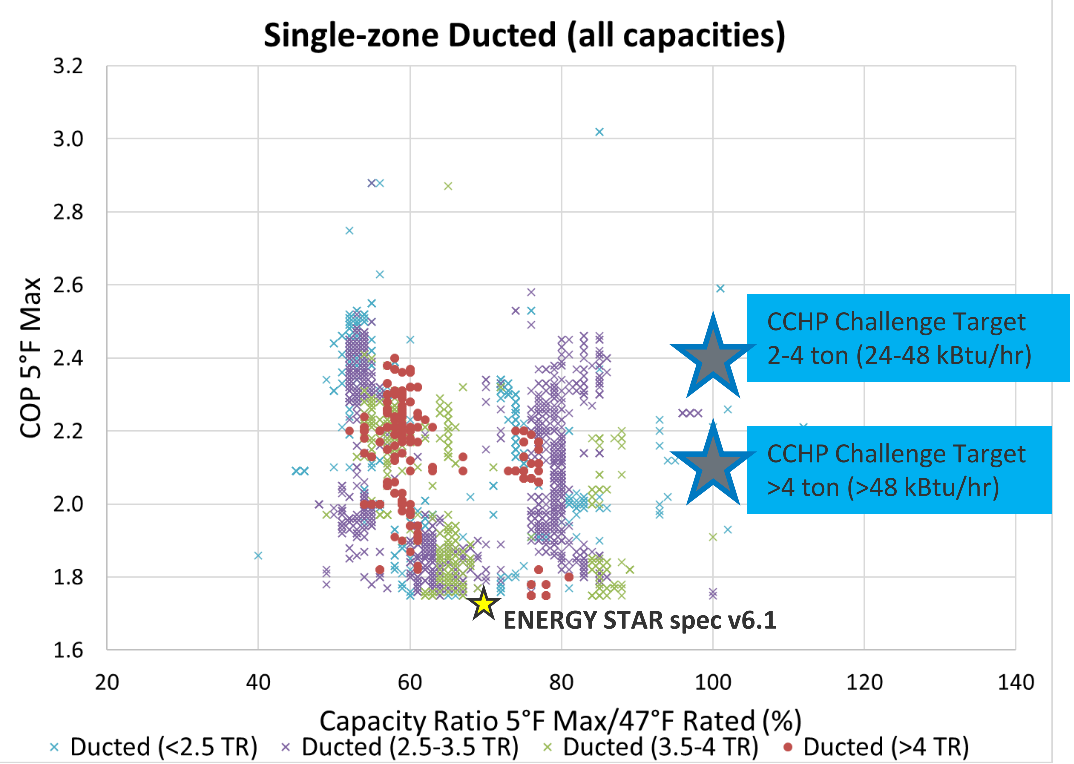
U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

CCHP Performance Metrics: residential, centrally ducted, electric-only heat pumps:

- Nominal cooling capacity 24,000 – 65,000 Btu/hr.
- High efficiency (COP): 2.1 (>4 ton) or 2.4 (2-4 ton) COP at 5 °F
- Capacity turndown at 47 °F ≥ 30%
- Strong capacity maintenance (i.e., 100% heating capacity at 5°F, strong performance to below 0°F)
- Employ low-GWP refrigerants (< 750 GWP, AR4 100 year)
- Grid-interactive capabilities to assist with installation, fault detection, demand response, and other activities (AHRI 1380).



Challenge Specification Comparison with Available Products Today



NEEP database extract: June 2021

Full specification and test procedure is found on the Challenge website:
https://www.energy.gov/eere/buildings/residential-cold-climate-heat-pump-challenge

8 HVAC manufacturer partners have passed Challenge:

Carrier, Daikin, Bosch, Trane Technologies, Lennox, Midea, Rheem, Johnson Controls

DR Requirements – AHRI 1380

Verification of AHRI 1380 Demand Response functionality with native-control system operation.

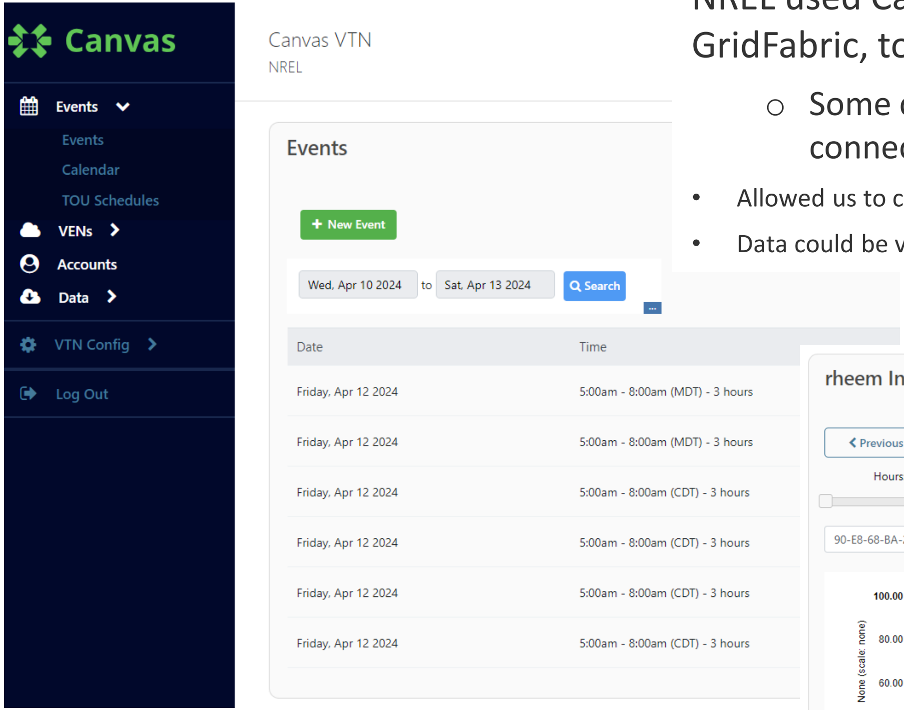
- Requires the use CTA-2045 and/or OpenADR communication protocol (All participants opted for OpenADR)
- Requires some data reporting (operating mode, override status, and thermostat data)
- "General Curtailment" that reduces compressor speed to provide a 30% power reduction over the event period, lab tested at 47°F ambient temperature.
- "Critical Curtailment" that provides 60% power reduction over event period, and electric resistance heat shutoff as long as room temperature remains above 62°F, lab tested at 5°F ambient temperature.
- Max Indoor Temperature Offset (MITO) specifies maximum temperature offset from setpoint during a curtailment event.

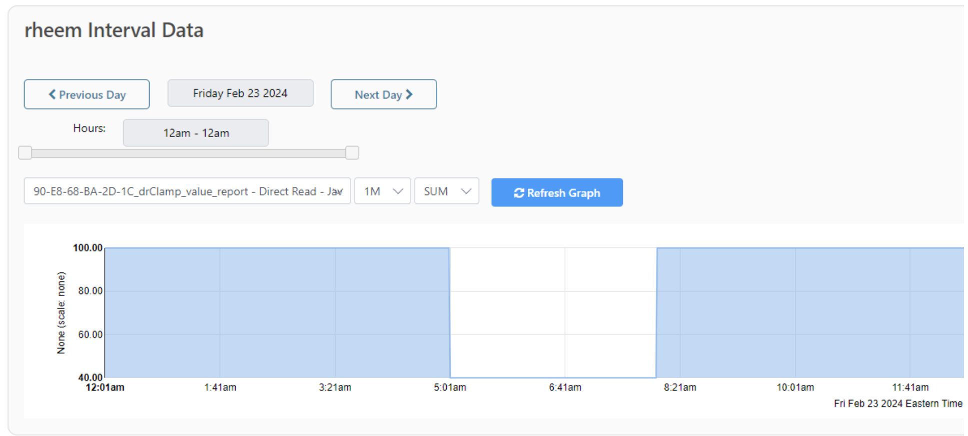
Canvas Cloud VTN for OpenADR

NREL used Canvas™, an online Virtual Top Node (VTN) tool built by GridFabric, to send events for lab and field tests.

- Some companies implemented OpenADR in the cloud and connected the thermostats to the cloud layer.

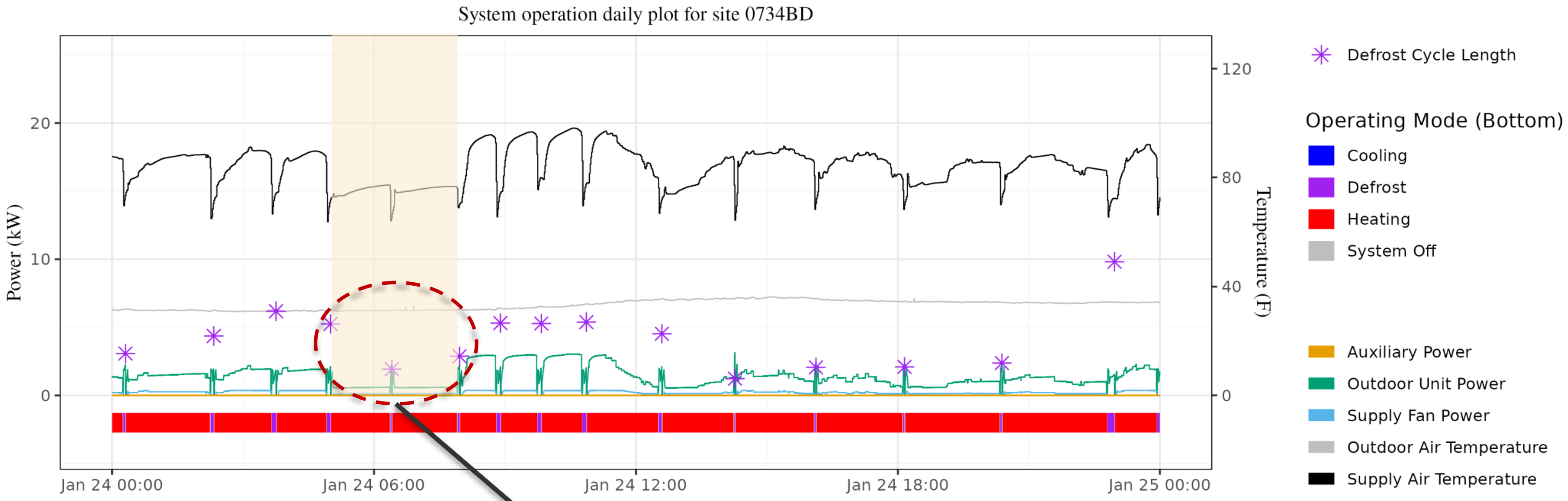
- Allowed us to confirm that they could connect over OpenADR and could respond to DR signals.
- Data could be viewed or exported from Canvas.





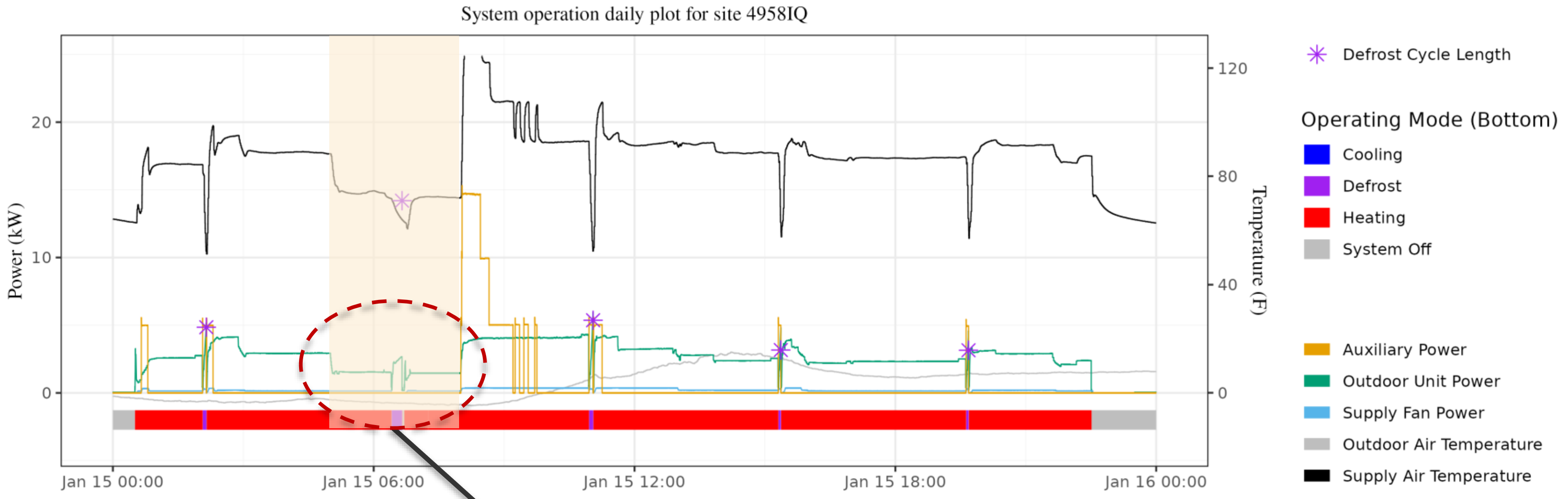
GridFabric

Critical curtailment event at Site A



Event runs from 5-8 AM: Outdoor unit curtails power draw and modulates to lower speed during the event. Aux. heat remains off.

General curtailment event at Site B



Event runs from 5-8AM: Outdoor unit curtails power draw and modulates to low speed during the event. Aux. heat remains off.
However, at the end of the event - big spike in aux. power to make up room temperature.

Demand Response Events

Key takeaways:

- Overall, all units were observed to respond to the DR event calls by curtailing heat pump power predictably: 30% reduction for general curtailment events and 60% for critical curtailment events.
- Indoor air temperatures rarely exceeded the Maximum Indoor Temperature Offset (MITO) specified for each site (default value of 4°F) even on the coldest days
- Variable speed modulation enabled units to maintain indoor temperature longer by running at lower compressor speeds for longer periods of time.
- Some units used the Aux electric resistance after the DR events to recover to initial setpoint temperature

Comfort Impacts from Demand Response

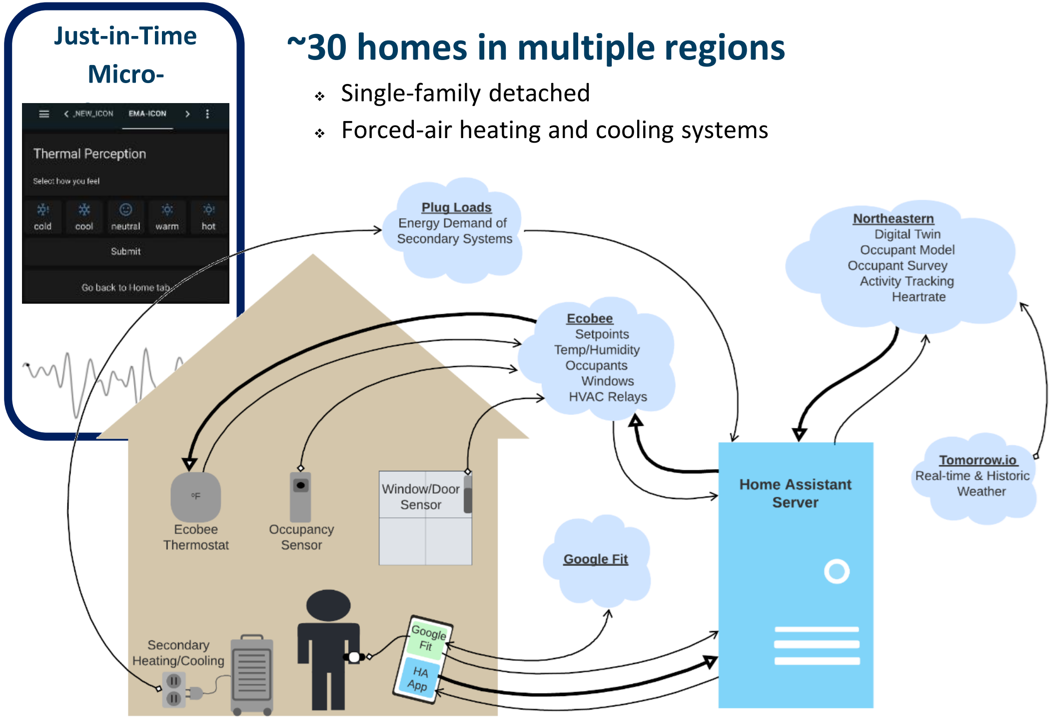
A Scalable Hardware-and-Human-in-the-Loop (HwHuIL) GEB Building Equipment Performance Dataset – BENEFIT Project led by Northeastern University with NREL

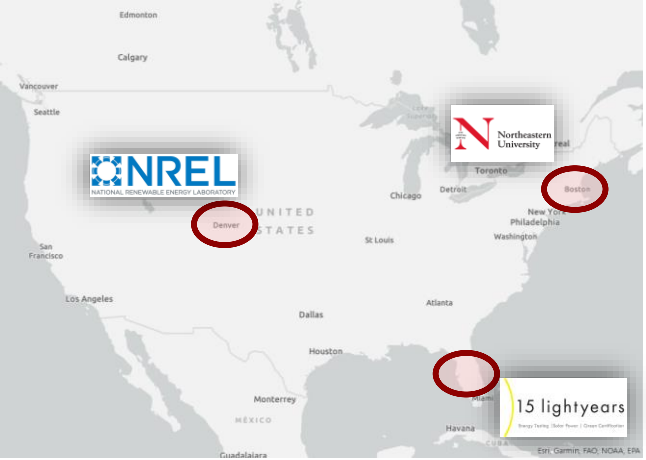
~30 homes in multiple regions

- Single-family detached
- Forced-air heating and cooling systems

Two-year duration

- Participant Interview & Initial Documentation
- Phase 1 – Monitoring - *complete*
- Phase 2 – Setpoint control – *in progress*





Occupant Comfort and Behavior

Responses Compared to ASHRAE 55 Prediction

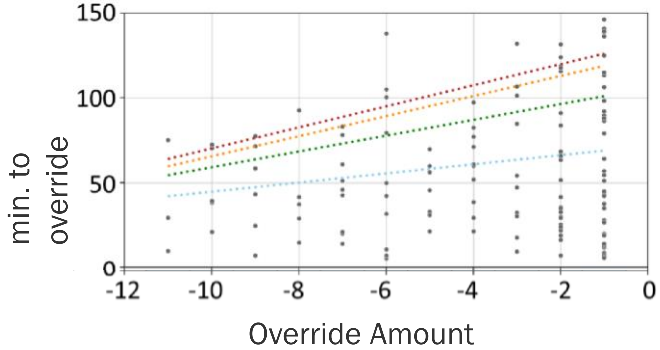
Steady state ASHRAE 55 Adaptive Comfort Model

		Predicted: Within 80% Acceptability Limit (Negative)	Predicted: Outside 80% Acceptability Limit (Positive)	Total
Actual	Satisfied Votes (Negative)	71.78% N=1,071	15.35% N=229	87.13% N=1,300
Actual	Dissatisfied Votes (Positive)	10.12% N=151	2.75% N=41	12.87% N = 192
	Total Votes	81.90% N=1,222	18.10% N=270	100% N_{total}=1,492

Predicts comfort well (accuracy = 0.75), but poorly predicts discomfort (F1 = 0.18)

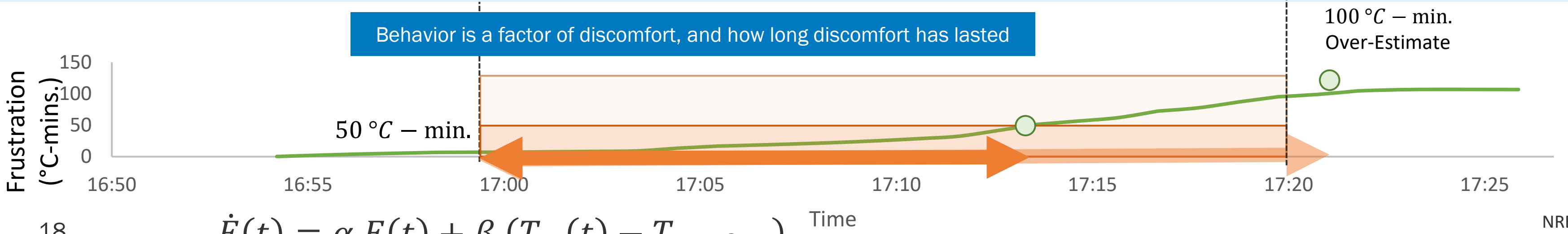
*For GEB controls, it is important to accurately predict **discomfort** that drives overrides*

Thermostat Override Dynamics



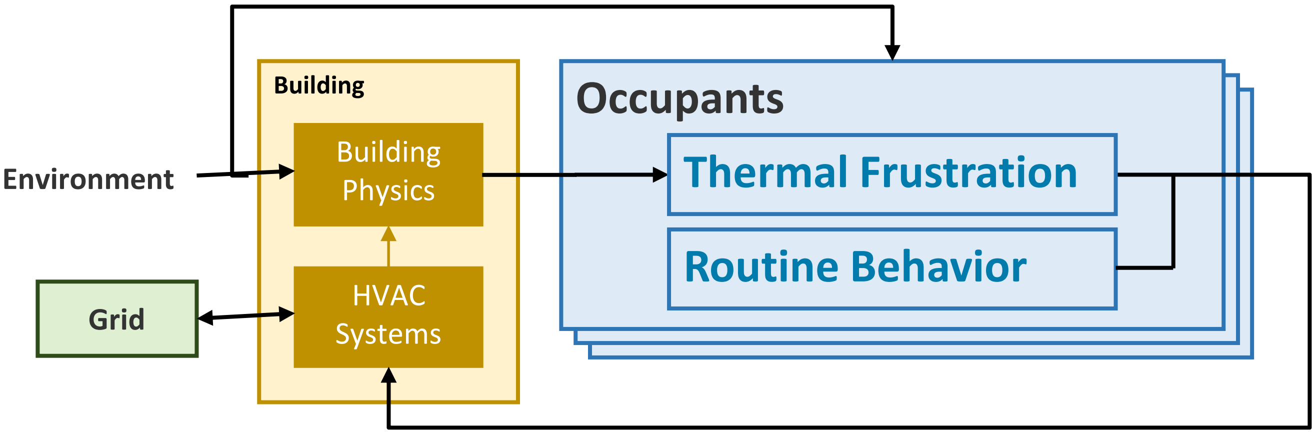
Larger automated setpoint changes are overridden faster

Thermal Frustration Theory (TFT) Overrides occur when **accumulated thermal discomfort** exceeds a threshold



$$\dot{F}(t) = \alpha\, F(t) + \beta\, (T_{in}(t) - T_{\text{comfort}})$$

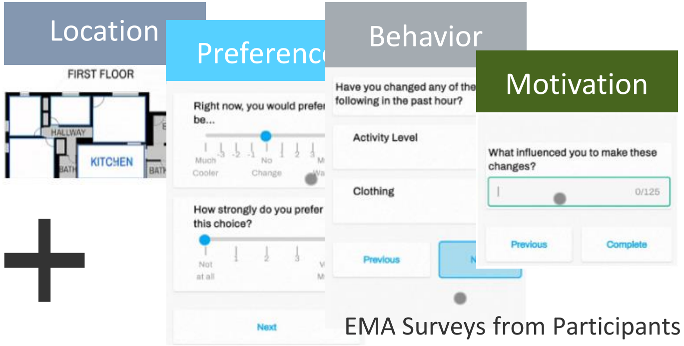
Modeling Occupant Comfort



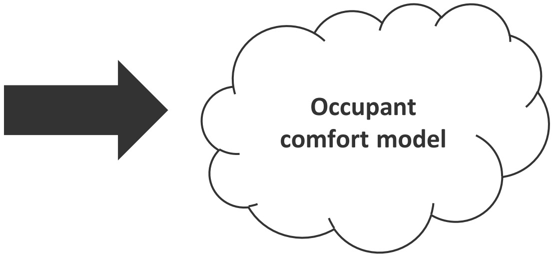
This project is wrapping up in Spring 2025

Ecobee Donate Your Data

+



EMA Surveys from Participants



Thanks to CCHP Challenge & NEU Research Teams!

Pacific Northwest NATIONAL LABORATORY

Guidehouse

OAK RIDGE National Laboratory

Northeastern University Civil and Environmental Engineering

ENERGY350

MichaelsEnergy

Thank you!

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NREL Transforming ENERGY

Chitra Nambiar

PNNL

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Thermal Comfort Impacts of Demand Response Strategies:

Findings From a Field Study in Rural Alaska

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PhD Candidate, UC Berkeley

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April 25, 2024

PNNL is operated by Battelle for the U.S. Department of Energy

Introduction

- Coastal Alaska (CZ 7)
- Population: 2,609 (2020 Census)
- Electric generation: hydro + diesel
- Residential heating fuel: heating oil
- Study Sample: 3 residences
- DR Data Collection: September 2023 – April 2024

Research Goals

Develop demand response strategies for rural, cold-climate communities:

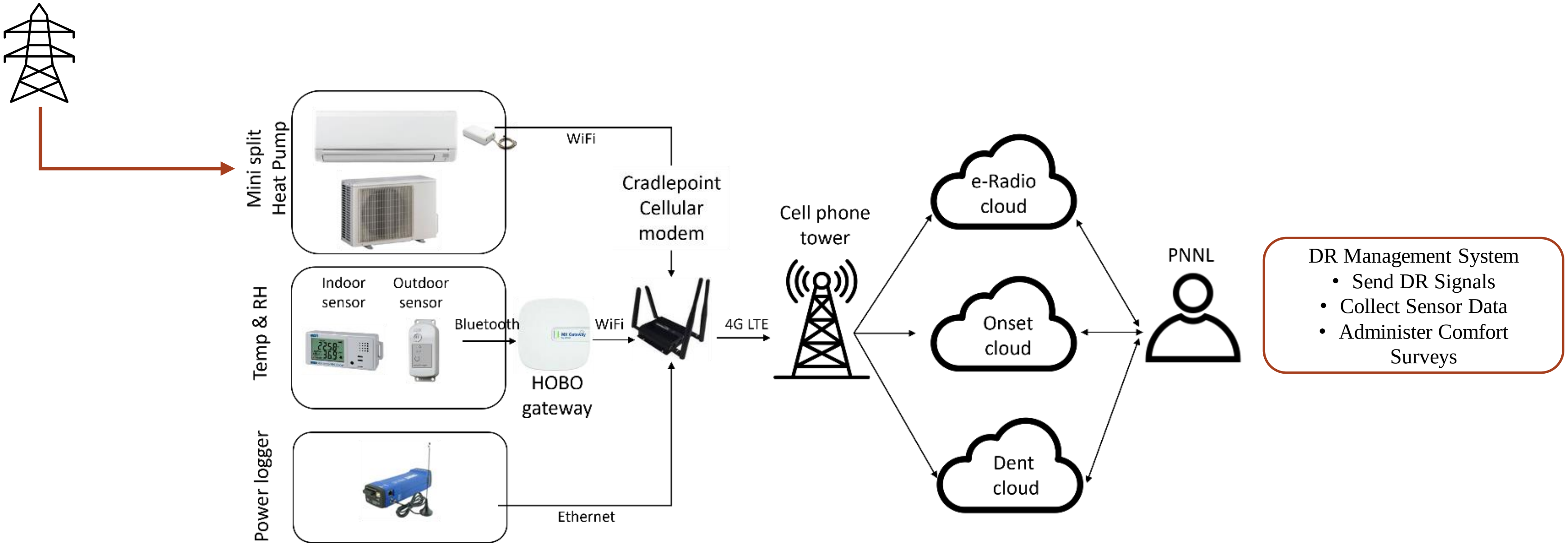
- Testing/validation of DR implementation method using ANSI/CTA-2045
- Testing/validation of demand responsive control of heat pump in winter conditions
- Evaluate impact of demand responsive strategies on thermal comfort of residents
- Evaluate how thermal comfort impacts demand response event success

Study Sites




- 3 single family detached homes
- 2 own, 1 rent

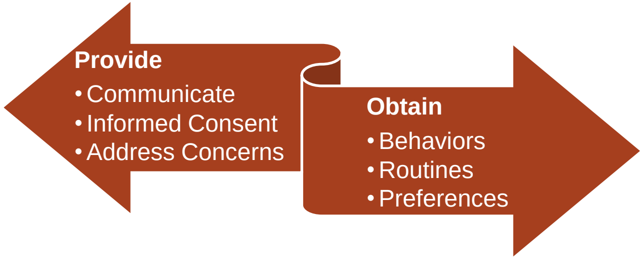
Physical Set-Up



Data Collection

1. Site Survey
   - *Building/Space Characteristics*

2. Pre/Post Study Interviews
   - *Demography*
   - *Comfort Expectations*
   - *Attitudes/Preferences*
   - *Daily Routines*

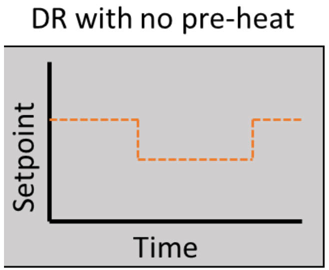


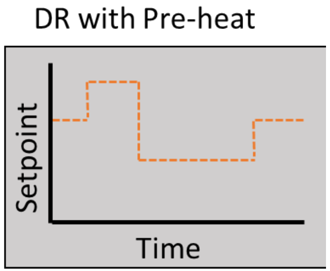
Pre-Study Interview Findings	
1. Sociodemographic of Participant Households	
Gender	Male: 3 Female: 5
Age	Below 18: 4 18-65: 5 Above 65: 0
Ethnicity	White: 8
2. Household Energy Use	
Typical space heating source	Primary HVAC + supplemental heating
Typical thermostat use habits	Occasionally changes: 2 Frequently changes: 1
3. Thermal Comfort	
General satisfaction (before technology intervention)	Satisfied: 1 Unsatisfied: 2
Main factors that influenced indoor comfort (self-reported)	Non-uniform HVAC service quality between rooms, poor envelope insulation, single-pane window, window size and orientation, HVAC system location and sizing
4. Motivations	
First priority	Energy cost : 1 Comfort: 2
Second priority	HVAC control autonomy: 2 Comfort: 1

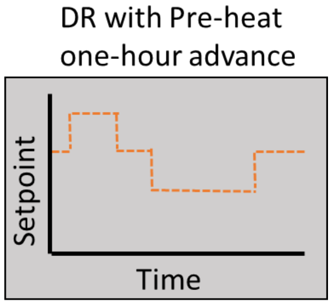
DR Experiment Design

Demand response experiment design:

- Thermostat offset
  - temperature offset (2°F to 6°F)
- Duration
  - duration (1 to 3 hours)
- Start time
  - occupants are typically home
  - pre-heat
- Each DR event type repeated at least 3 times







DR Comfort Evaluation

Right-Now Surveys: Administered via Qualtrics sent to smart phone

Question 1: Right now, do you feel:

Cold   Cool   Slightly-Cool   Neutral   Slightly-Warm   Warm   Hot

Response captures "Thermal sensation votes (TSV)" in Likert scale

Question 2: Right now, would you prefer to be:

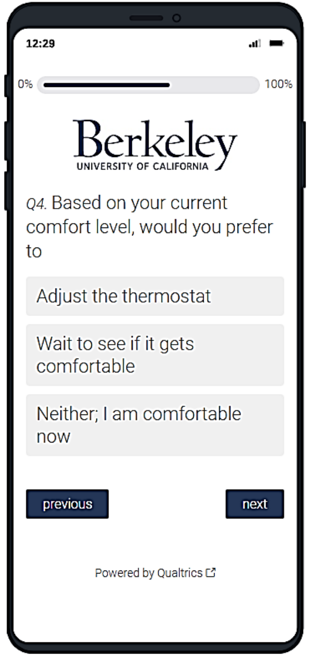
Cooler   No change   Warmer

Response captures "Thermal preference votes (TPV)" in Likert scale

Question 3: Based on your current comfort, would you prefer to:

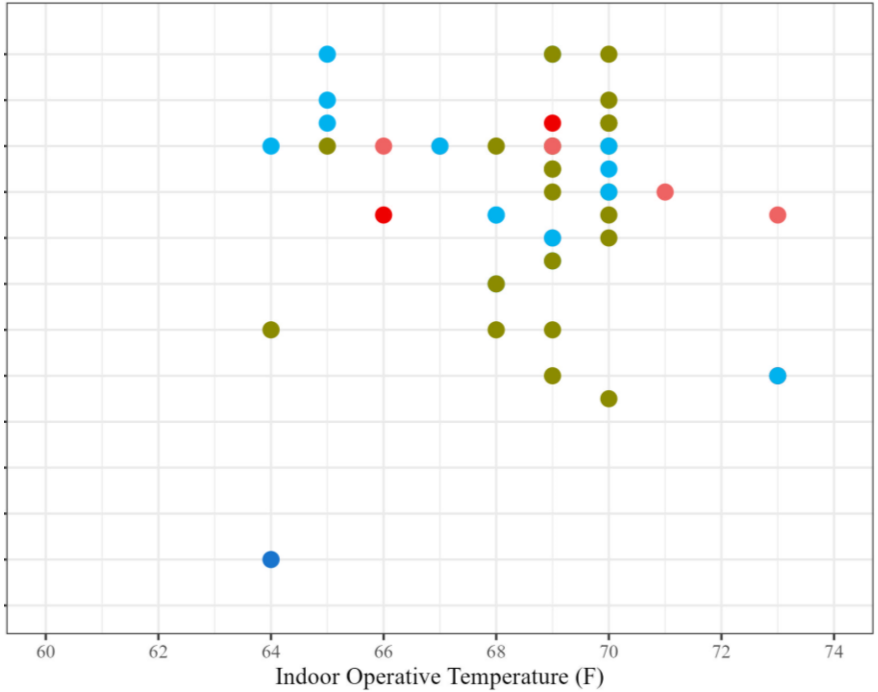
Adjust thermostat   Wait to see if it gets comfortable   Neither

Response captures potential near-time DR event behavior



Main Findings: Thermal Sensation

Right-Now Surveys + Indoor Temperature Data from Sensors



- 57 responses:

Cool:1

Slightly cool:11

Neutral:17

Slightly Warm:4

Warm:2

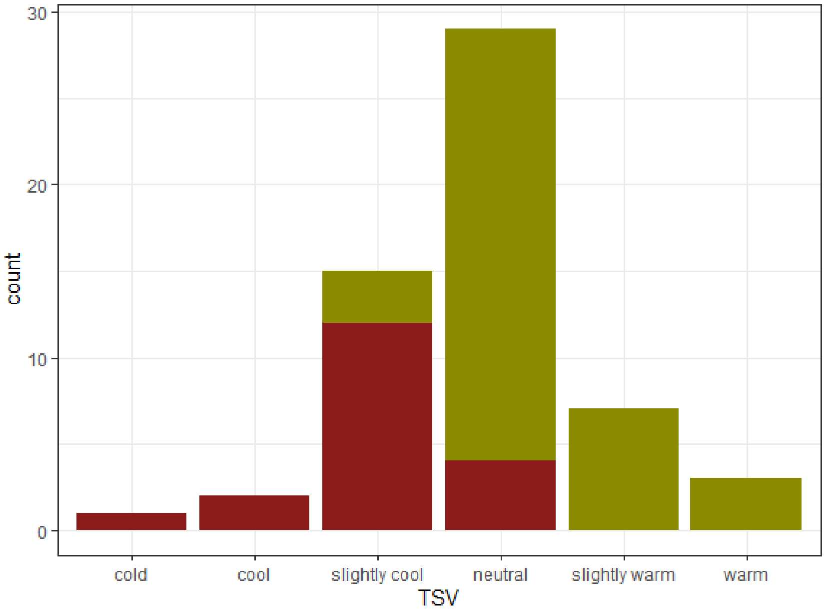
- 68°F to 70°F : Neutral thermal sensation dominates
- 65°F to 67°F: Slightly Cool
- **Indoor Temp > 71°F: energy/comfort inefficient**

Main Findings: Thermal Preference

Right-Now Surveys + Indoor Temperature Data from Sensors

How does Thermal sensation translate to Thermal preference?

Cooler No change Warmer

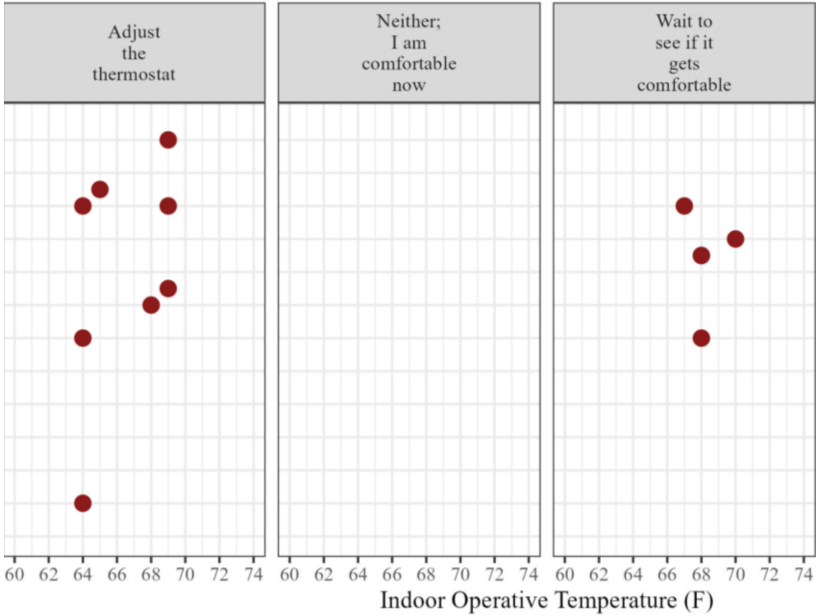


Even in Alaska, “Slightly cool” thermal sensations are sometimes preferable

Main Findings: DR Behavior

How do Thermal preferences translate to DR behaviors?

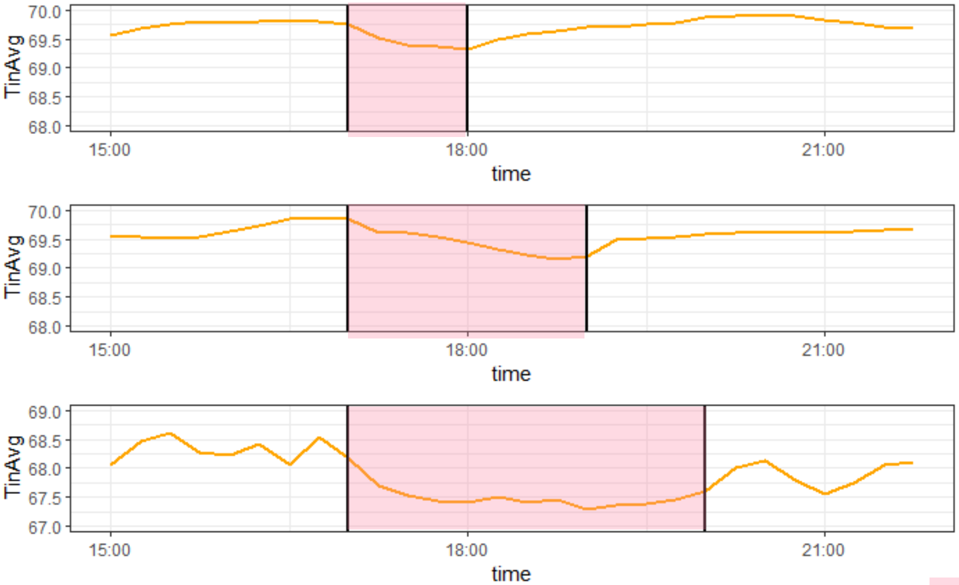
- 28% responses Warmer TPV
- 45% of Warmer TPV votes prefer waiting
  - Indoor T > 65°F



Winter DR flexibility range for Cordova: **65°F to 70°F**

Findings: Comfort and DR Event Success

Impact of DR Duration on Indoor Temperature & Early DR Termination



1-hour event 2°F offset:
- DR early termination: 0%
- DR event Indoor Δ T < 1°F
- Comfort action: 0%

2-hour event 2°F offset:
- DR early termination: 11%
- DR event Indoor Δ T < 1°F
- Comfort action: 11%

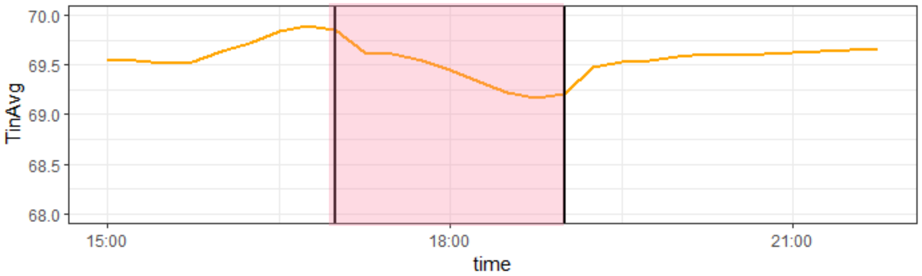
3-hour event 2°F offset:
- DR early termination: 22%
- DR event Indoor Δ T = 1°F
- Comfort action: 67%

Indoor operative temperature (°F) data from each representative event: shaded area is DR event

- Thermal lag in buildings can provide flexibility

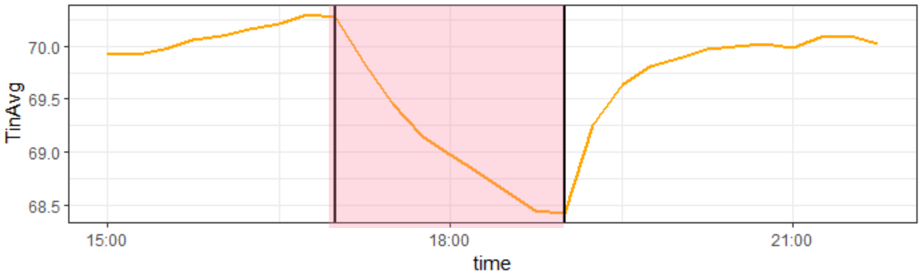
Findings: Comfort and DR Event Success

Impact of Temperature Offset on Indoor Temperature & Early DR Termination



2-hour event 2°F offset:

- DR early termination: 11%
- DR event Indoor Δ T < 1°F
- Comfort action: 11%



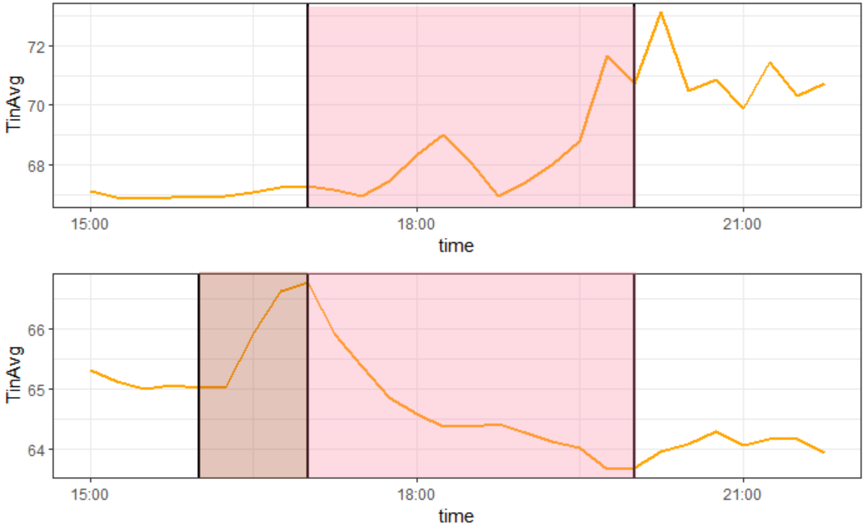
2-hour event 6°F offset:

- DR early termination: 11%
- DR event Indoor Δ T = 2°F
- Comfort action: 33%

Indoor operative temperature (°F) data from each representative event : shaded area is DR event

Findings: Comfort and DR Event Success

Impact of Pre-heat on Indoor Temperature & Early DR Termination



3-hour 2°F offset event without pre-heat

- *example shown is of DR terminated by resident*
- *Pre-DR Indoor T 67°F*
- DR early termination: 22%
- Comfort action: 67%

3-hour 2°F offset event with pre-heat

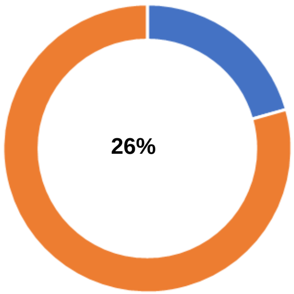
- *Pre-DR Indoor T 65°F*
- DR event Indoor Δ T ~ 1°F
- DR early termination: 22%
- Comfort action: 33%

Indoor operative temperature (°F) from representative events : shaded area is Preheat period & DR Event

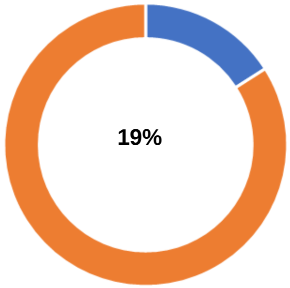
- Pre-heating can help maintain comfort in longer events
- Preheating one hour prior to DR had similar effect as immediately before DR

DR Comfort Interventions

- Residents took active steps to change their indoor thermal environment during DR events:
  - Supplementary heating
  - Thermostat setpoint override
  - Others



- Residents took measures that resulted in early termination of DR events:



Next Step: Compare comfort findings with energy findings

Conclusions and Recommendations

- This study demonstrates a data-driven approach to determine DR thermal comfort
- Thermal comfort is a range
  - Collecting local and building specific acceptability range can help maximize DR savings and improve program reliability
- Comfort evaluation must be an important component of all DR field studies

Questions?

Please contact:

Chitra Nambiar: chitra.nambiar@pnnl.gov

Thank you

Gabriel Kjos

Portland General Electric

Flex Load Implementation Multi-Family Water Heater Pilot

Gabriel Kjos, PGE

BBRN Peer Exchange | April 25, 2024

Current Customer Flexible Load Programs

22%

	Behavioral (Res) / Manual DR (C&I)	Direct Load Control / Auto DR (large C&I)
Residential	**Peak Time Rebates**: Customers receive day ahead and day of notifications for events and are asked to shift their electrical energy use outside event hours **Time of Day**: Customers shift energy taking advantage of lower prices for using less energy during the high demand weekday hours of 5–9 pm.	**Smart Thermostats:** PGE adjusts T-stat between 1-3 degrees during events **EV Chargers:** PGE stops charging EVs during events
Multi-Family		**MF Water Heater:** PGE adjusts **electric resistance** water heaters to times when demand is low. Controls ensure hot water is available for tenants.
Small/Medium Commercial		**Smart Thermostats (Sch 25):** PGE adjusts T-stat between 1-3 degrees during events
Large Commercial and Industrial	**Energy Partner (Sch 26):** Customers manually participate in events based on their load curtailment plan	**Energy Partner (Sch 26):** PGE dispatches event signal for automatic participation in events

Pilot Background

Purpose

- **Optimize resource delivery and program performance effectively**
- **Quantify energy shift from equipped water heaters**
- **Inform program design for demand response**
- **Determine appropriate incentives for participants**

Pilot Background

Target Market

- Target property management companies of multifamily buildings
- Assessed new construction multifamily properties
- Secondary target audiences included distributors and manufacturers

Pilot Background

Equipment

Wi-Fi Devices

- 22% of the Fleet
- Connectivity continues to degrade over time, needing regular maintenance

Cellular Devices

- 78% of the Fleet
- Exhibits superior connectivity rate through DR event seasons

CTA-2045

- Initially designed and offered to both existing and new construction to offset costs vs standard WH
- Delays of Planned Code Changes to make CTA-2045 new baseline

Pilot Background

Findings

- **Stable impact: 0.20 kW per device observed**
- **Improved event results by removing Wi-Fi devices**
- **Pilot will continue to address connectivity issues**
- **Collaborate with grid operations for dispatch strategy**

Pilot Background

Future State

- **Maintain Existing Fleet**
- **Stakeholder engagement to determine feasibility around CTA-2045**
- **Program design could include all water heater customers**
- **Gather insights from our Testbed and assess redesign opportunity**

Thank you

Gabriel.Kjos@pgn.com

Smart Tools for Efficient HVAC Performance (STEP) Campaign

Scan this QR code to visit our website

Contact: christian.valoria@pnnl.gov

The STEP Campaign aims to increase adoption of smart diagnostic tools to streamline HVAC system performance testing and troubleshooting, reducing energy-wasting faults and improving occupant comfort.

To join the STEP Campaign, visit: bit.ly/3DFmEaE

HVAC Contractors and Technicians

- Reduce callbacks, improve consistency and quality, streamline processes
- Find out where to get training on smart diagnostic tools
- Be recognized for successful adoption of smart diagnostic tools!

Utilities and Program Implementers

- Streamline quality installation and quality maintenance programs
- Improve engagement with your contractors
- Be recognized for programs that utilize smart diagnostic tools!

HVAC Training Organizations

- Offer qualified training on System Performance with smart diagnostic tools
- Promote your training events
- Be recognized for providing training!

Weatherization Organizations

- Ensure your ASHP/CAC installations are operating at optimized efficiency
- Develop pilot with PNNL team
- Be recognized!

ORGANIZING PARTNERS

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Explore the Residential Program Guide

Resources to help improve your program and reach energy efficiency targets:

- Handbooks - explain *why* and *how* to implement specific stages of a program.
- Quick Answers - provide answers and resources for common questions.
- Proven Practices posts - include lessons learned, examples, and helpful tips from successful programs.
- Technology Solutions NEW! - present resources on advanced technologies, **HVAC** & **Heat Pump Water Heaters**, including installation guidance, marketing strategies, & potential savings.
- Health + Home Performance Infographic – spark homeowner conversations.

https://rpsc.energy.gov

Health + Home Performance Infographic

DOE's Health + Home Performance Infographic reveals the link between efficiency and health – something everyone cares about. Efficiency programs and contractors can use the question-and-answer format to discover a homeowner's needs.

The infographic is ideal for the "kitchen table" conversations where people decide what to do – and who they want to do it. It also has links for homeowners to find a qualified contractor if they do not already have one.

Download this infographic from DOE's Better Buildings Residential Network.

Looking for photos to help tell your energy efficiency story? Visit our image libraries: https://www.energy.gov/eere/better-buildings-residential-network/articles/image-libraries

Thank You!

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Please send any follow-up questions or future call topic ideas to:
bbresidentialnetwork@ee.doe.gov