MH retrofit case study using a neighborhood-scale approach

Paulo Tabares

Rowlinson Associate Professor

Department of Mechanical Engineering

Colorado School of Mines

ORNL Manufactured Housing Workshop
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Advanced Multi-scale Building Energy Research (AMBER) Lab: Building Science Innovation with Impact

- Focused on making an impact on society
- These are the problems that we are working hard to address
  1. **Our existing housing stock (~50M) needs to be healthy, affordable & resilient**
  2. Lack of affordable solutions for space-constrained housing
  3. Lack of energy professionals in the energy/building science industry
  4. Shortage of affordable housing that is resilient and grid-friendly
  5. Grid-edge flexibility & community resiliency during extreme events (heat, cold, and air pollution)

Advanced Multi-scale Building Energy Research (AMBER) Lab

Gabriel Flechas
Mass Timber

Karlyle Munz
Community Scale

Erin Blackley
HPWH HX-PCM

Dan Safronov
IoT

Janelle Domantay
HPWH controls

Andy Gloor
Mass Timber Homes

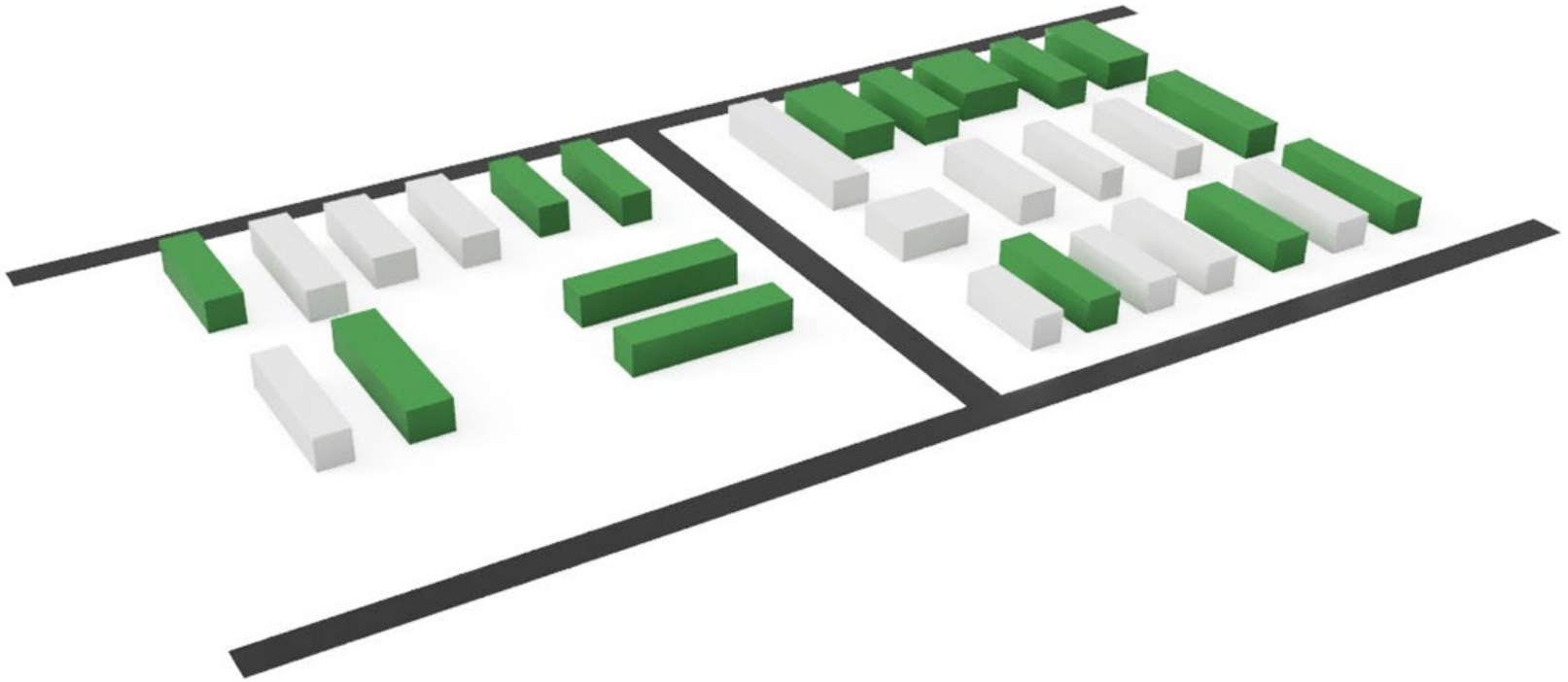
Quin Guy
Resilient Homes

Emily Royal
DERs

Elon Yates
Mass Timber

Reza Saeidi
Batteries and Indoor Air Quality

Community-Scale Electrification



R. Saeidi, K. Munz, A. Feiertab, L. Ilderton, and P.C. Tabares-Velasco, "Community Scale Retrofit and Electrification: Results and Lessons Learned After More Than 3 Years of Field Project," accepted in 2026 ACEEE Summer Study Conference, August 2-7, 2026, Pacific Grove, CA

K. Munz and P.C. Tabares-Velasco, "Comparison of Weatherization Approaches at Community-Scale: Weatherization vs Optimal Retrofit in Manufactured Home Parks," *Buildings XVI Conference*, December 8-11, 2025, Clearwater Beach, FL.

R. Saeidi and P.C. Tabares-Velasco, "Field Indoor Air Quality Findings for a Rural Home Park in Colorado," *Buildings XVI Conference*, December 8-11, 2025, Clearwater Beach, FL.

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What does it take to decarbonize a manufactured home community?

A community-scale retrofit project in Colorado offers a path toward lowering pc bills for a population that faces high levels of energy insecurity.

Published Oct. 18, 2024

By Leslie Nemo

YALE Climate Connections ARTICLES EN ESPAÑOL RADIO PROGRAM ABOUT NEWSLETTER

AUDIO

A Colorado manufactured home community is getting more energy efficient

A project is helping to retrofit 16 homes with more insulation, sealing, and electric stove tops and heat pumps.

by YCC TEAM
AUGUST 29, 2025

(Image credit: U.S. Army Corps of Engineers / Public Domain)

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Mines Team

Colorado School of Mines:

Paulo Tabares
Mechanical Eng.

Qiuhua Huang
Electrical Eng.

Gabe Fierro
Computer Science

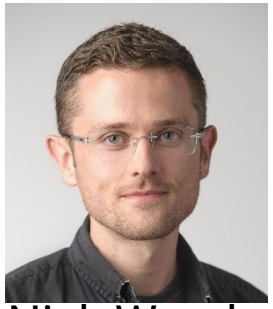
Kathleen Hancock
Political Sciences

Ben Gilbert
Economics & Business

Karlyle Munz
Mechanical Eng.

Daniel Safronov
Mechanical Eng.

Patrick Salter
Electrical Eng.



Nick Wunder
Computer Science

Sowndarya Krishnan
Computer Science

Ian Lange
Economics and Business

Challenge

- Approximately 22 million people living in 8.4 million manufactured homes (MHs)
  - 5% of households nationwide
  - Up to 30% of rural housing in certain states
  - Energy expenditures/income can reach 16% in Colorado
  - About 1-1.5 million MH were built before 1976

- What do we do with these houses?
- What is the best approach to improve the quality of life and affordability of US families living in MH housing?
  - Not a lot of work done at the community-scale…

Objective

- Quantify broad benefits of community-scale, holistic energy retrofits and electrification in manufactured home community
- A holistic community retrofit*:
  - an energy-efficient envelope
  - heating, ventilation, air conditioning (HVAC) and water heating systems,
  - home energy management systems with community feedback and
- Combination of energy retrofit with electrification and **PV/batteries**
  - reduce energy-related costs by 50% or more
  - provide power through outage events longer than 4 hours

*No costs to residents but need to meet Weatherization Assistance Program (WAP) requirements

Overall Project Tasks

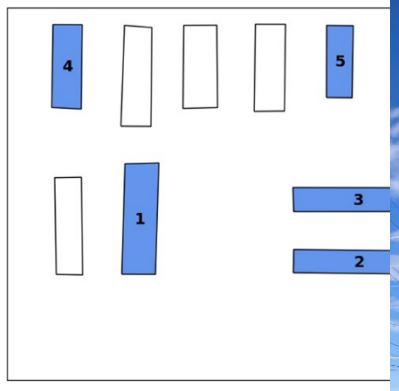
- Task 1. Engage and train the communities.
- Task 2. Develop smart controls and dashboards.
- Task 3. Retrofit Communities.
- Task 4. Test community scale retrofit/decarb performance and resiliency.
- Task 5. Extrapolate results for larger-scale analysis in different locations.
- Task 6. Assess effectiveness of community retrofit and real-time feedback.
- Task 7. Analyze supportive policies.

Outline

1. Background and Project Objective
2. **Project Description**
3. Methodology
4. Results
5. Lesson Learned

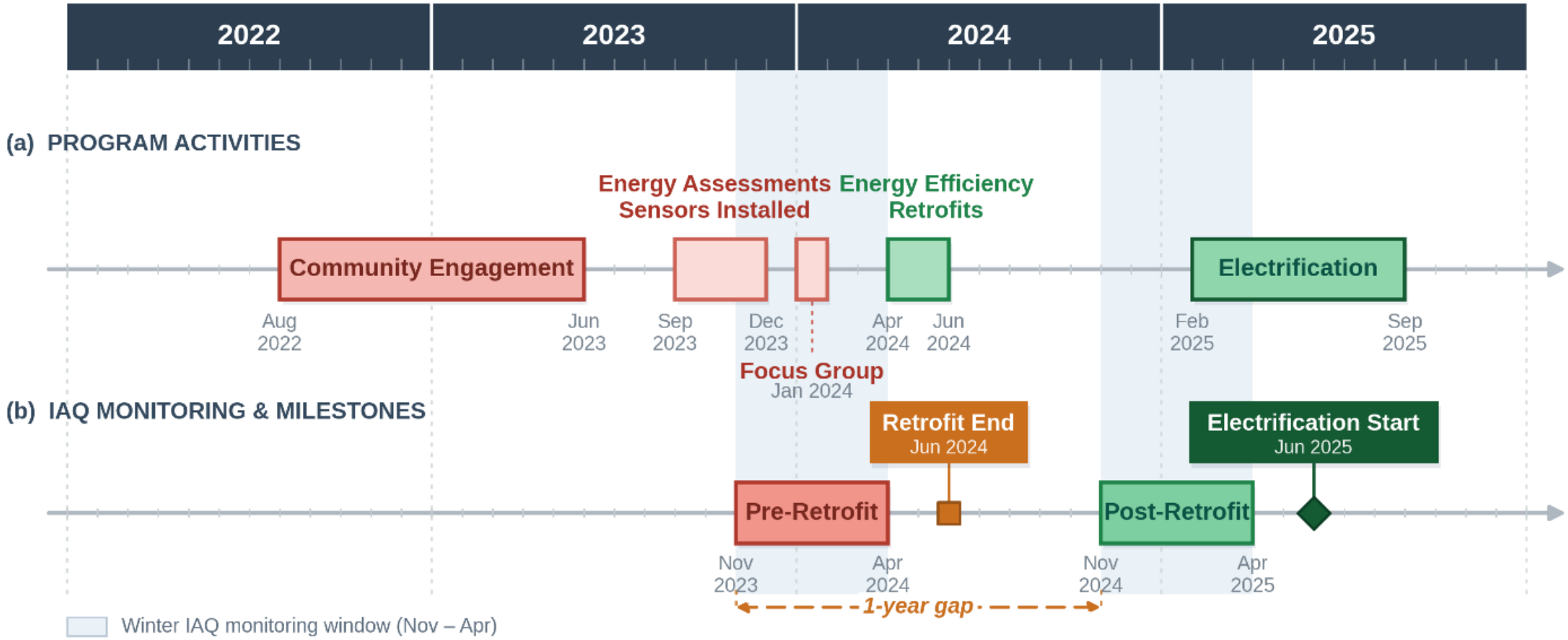
Methods: Community Details

- ~30 manufactured homes
  - 14 homes participating in retrofits (shaded **blue**)
  - 2 additional homes nearby
- Homes built: 1960s-2000s
- Located in Lake County, CO
- Community is being electrified and retrofitted by the Colorado WAP (We Assistance Program)
- Lots of relatives
- Community leader helped with the signing-in process



Methods: Community Details

- Community Work Timeline:



Background: Community Details

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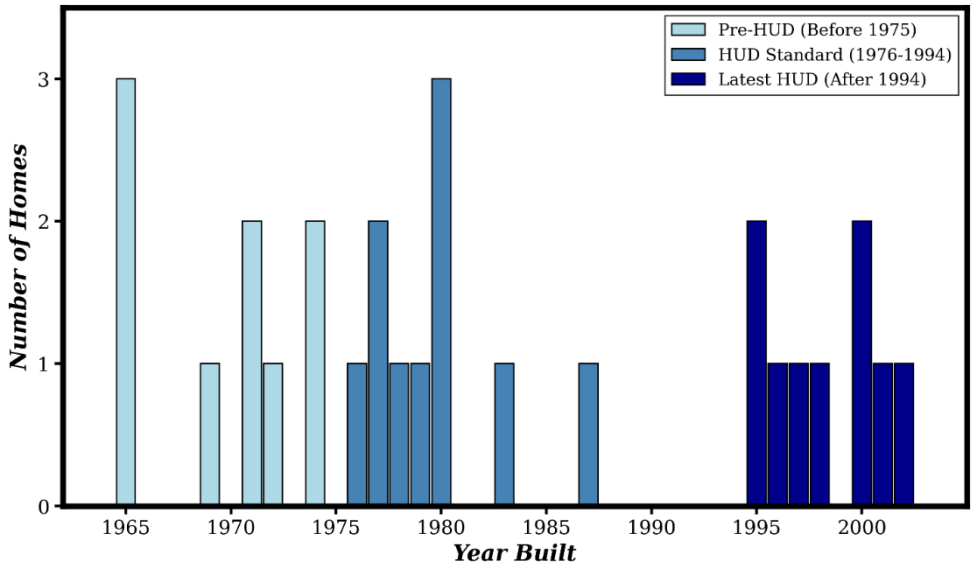
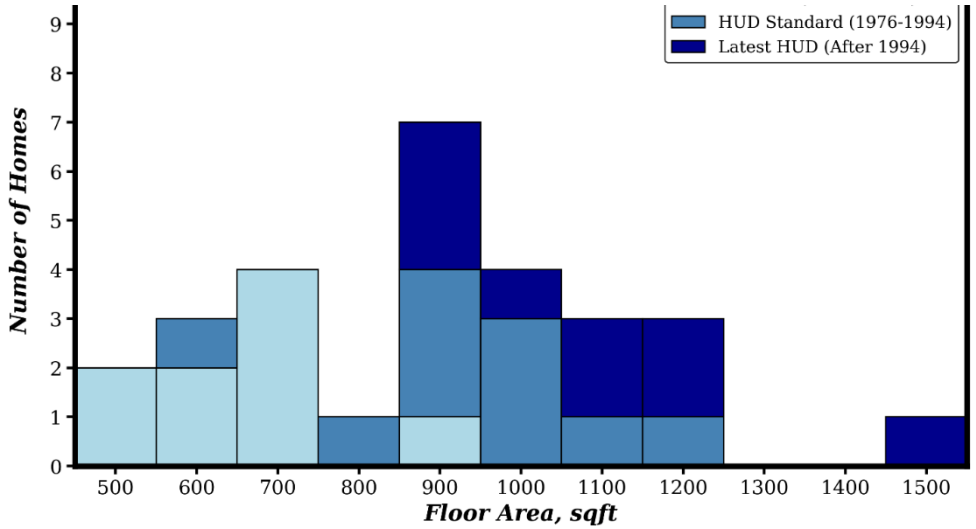
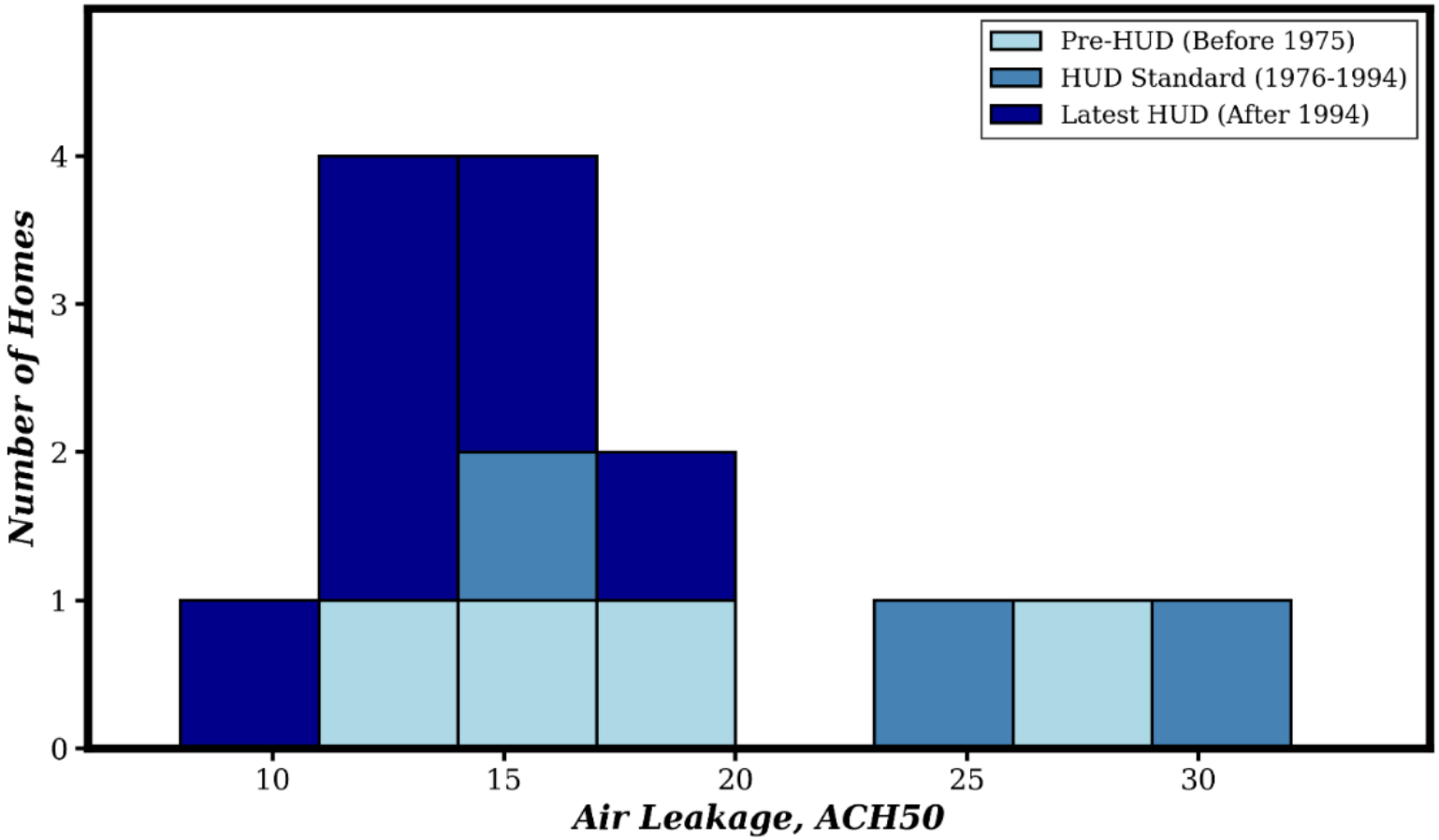






Background: Instrumentation

Background: Instrumentation

- Outdoor contaminants: PurpleAir
  - $PM_{2.5}$

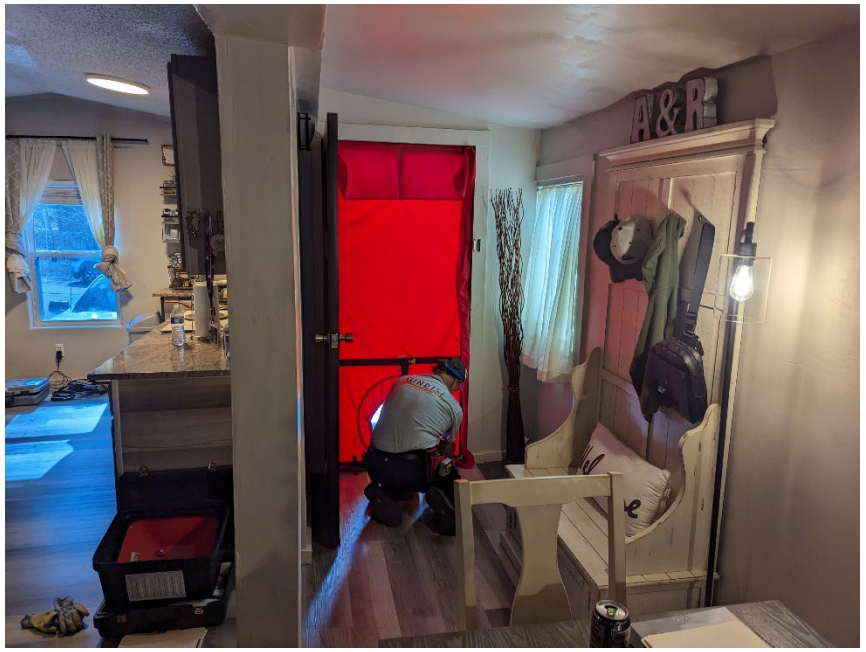
Each home will have:

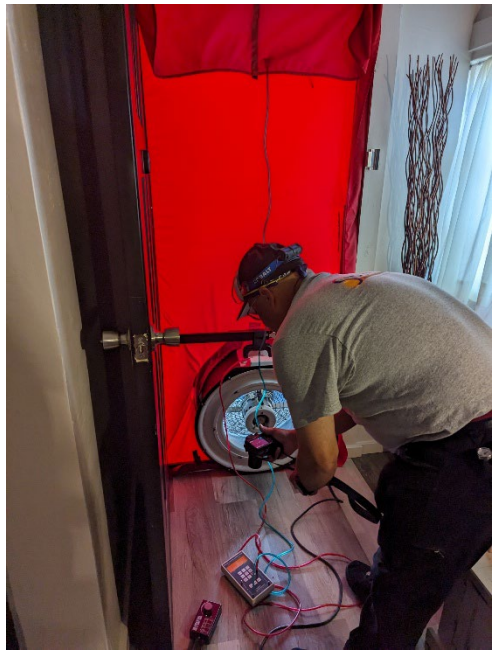
- Indoor air quality and comfort (at every home): AirThings
  - Radon, $PM_{2.5}$ and CO_2
  - Air temperature and RH

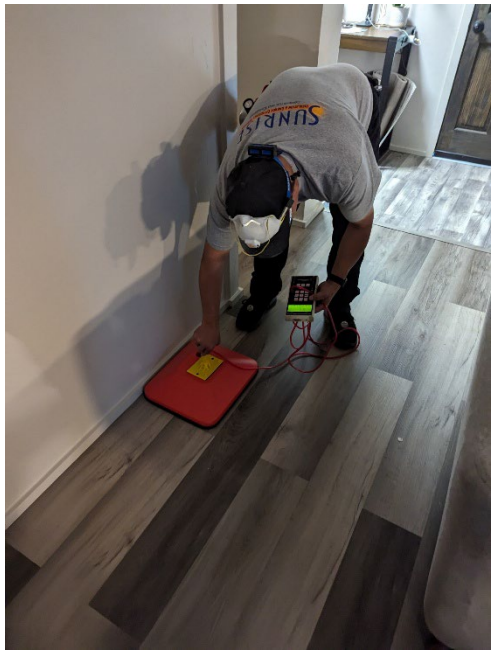
Energy

- CT meters at every breaker in the house electrical panel
- **Smart plugs** in 8 outlets

Background: Energy Assessment

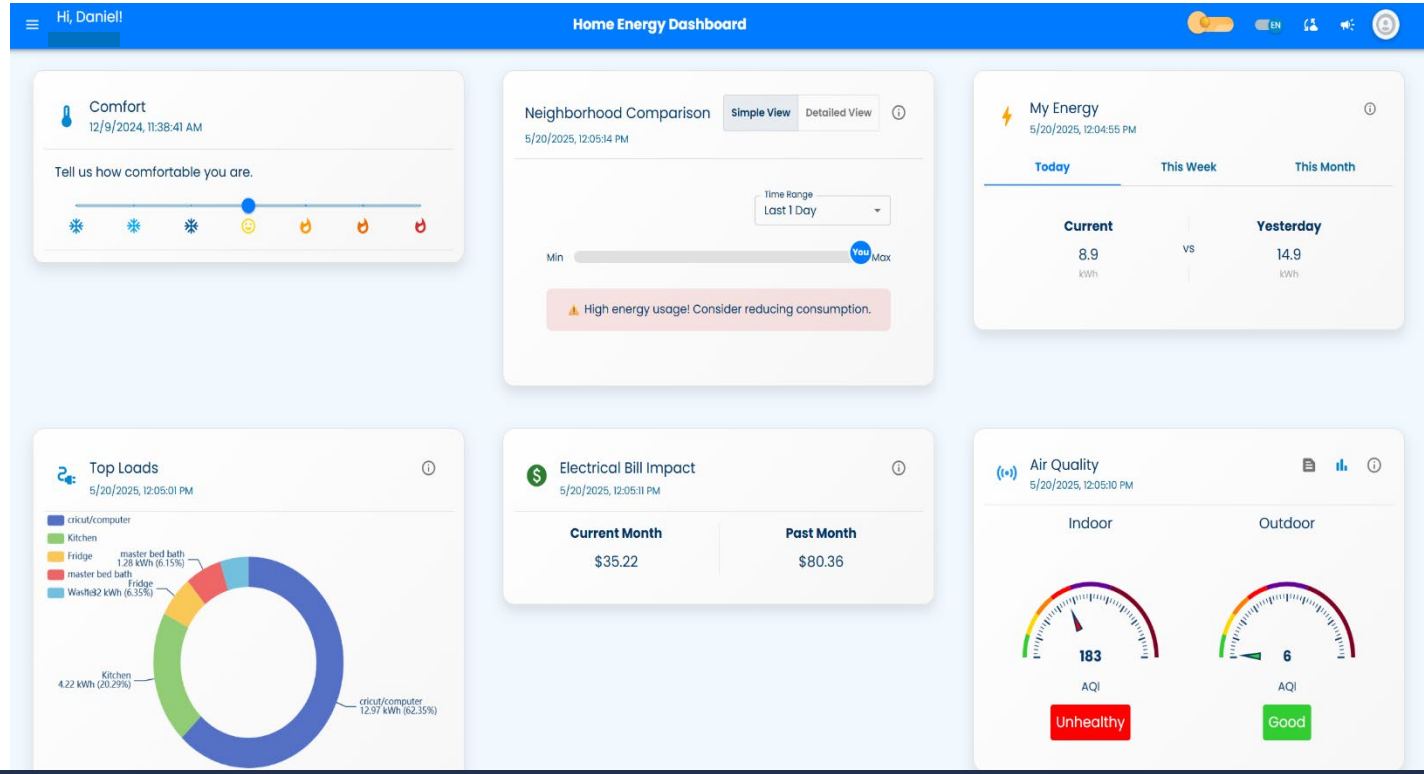




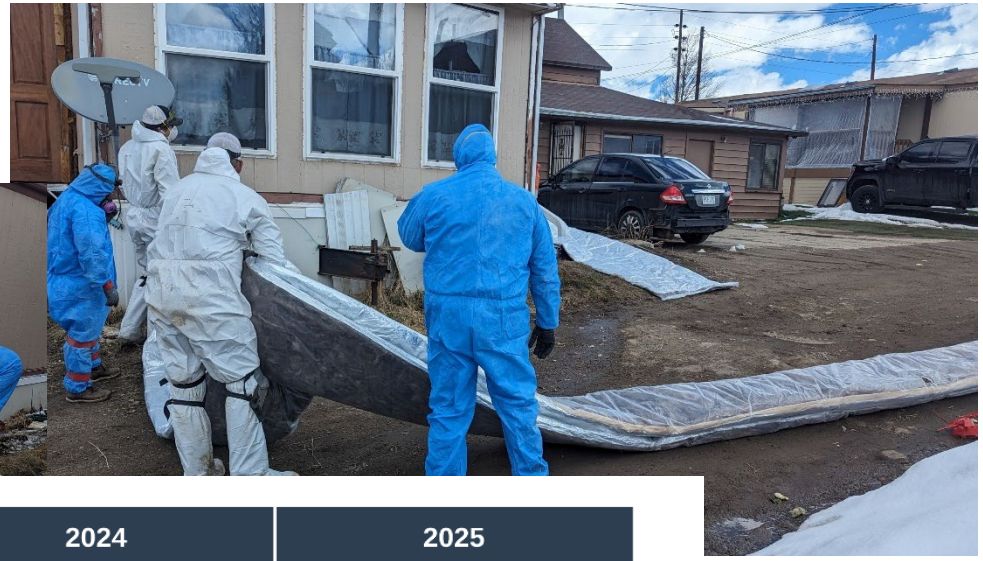


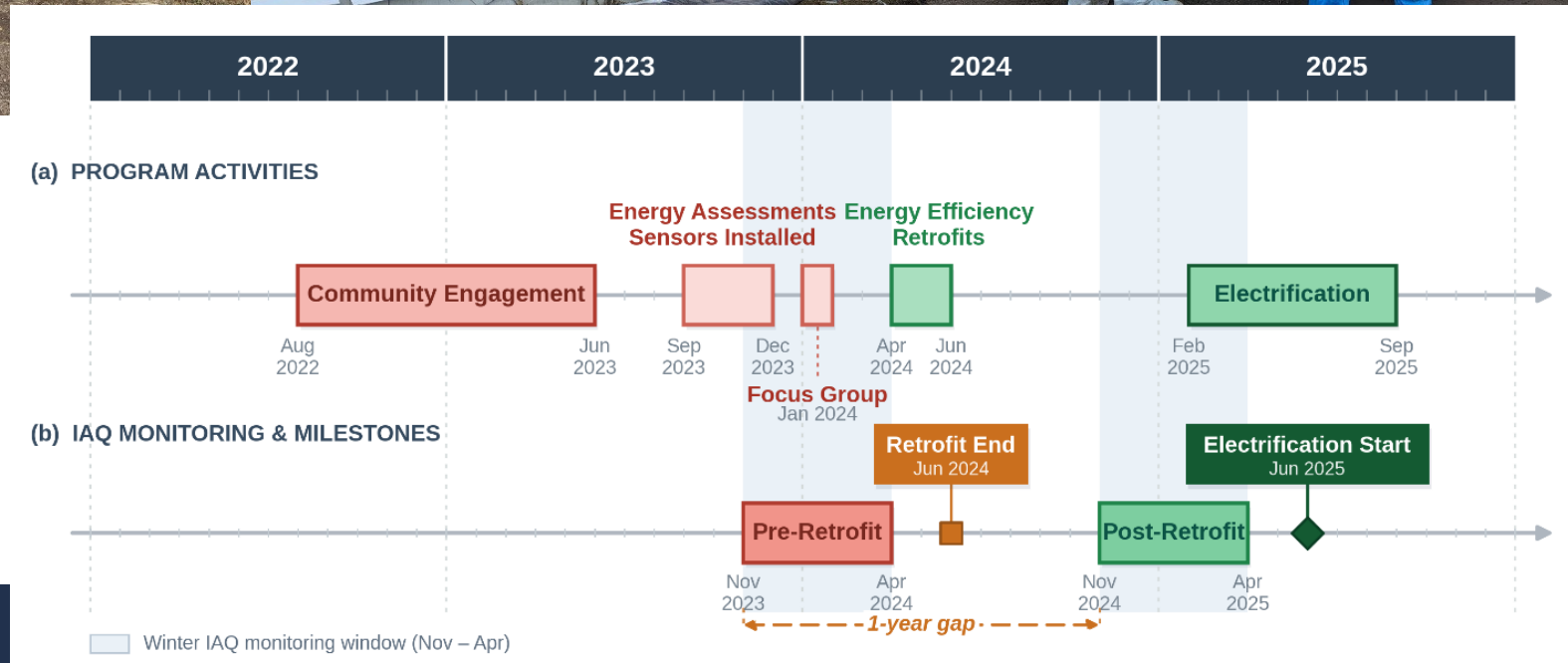
Informative Dashboard in each home

- Share information with you about how you use/consume energy
  - Real-time peer comparison w/n neighborhood
  - Tips on how to save more energy…
- Data access through a dashboard and smartphone app
- Community co-design
  - Focus groups to get feedback



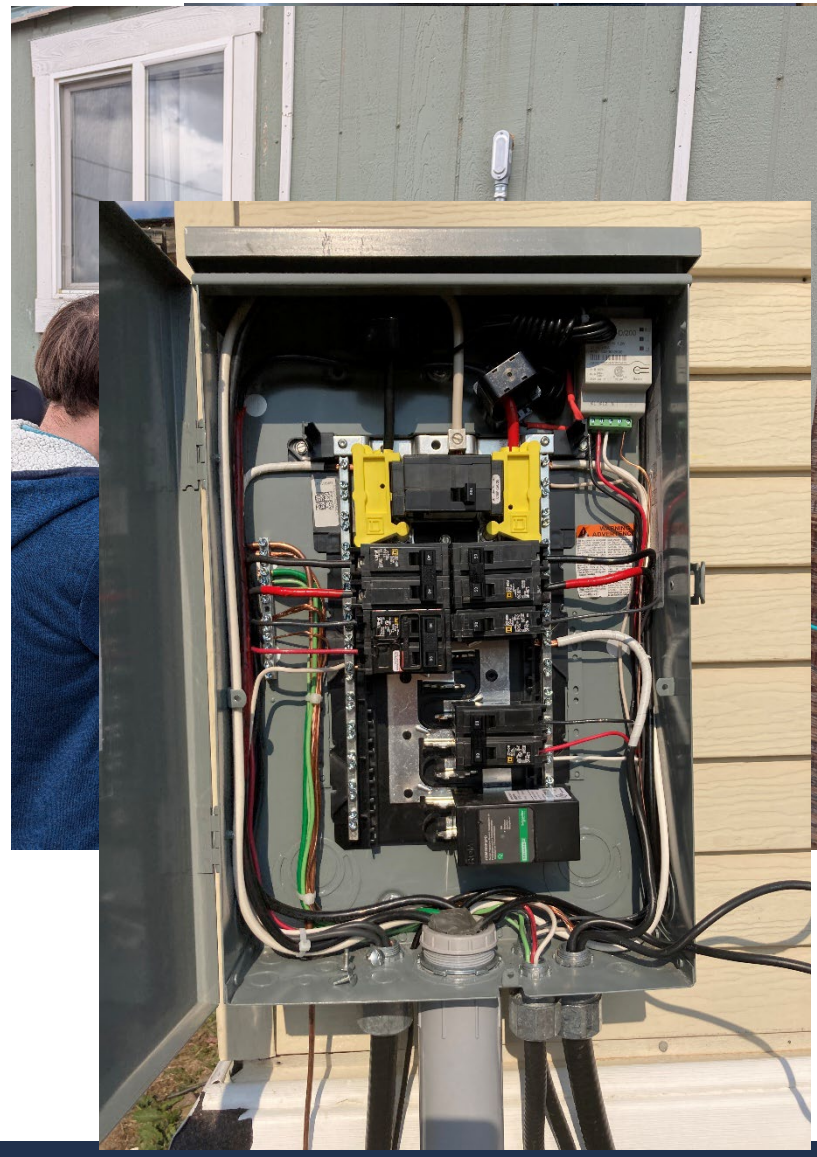
Background: Retrofits





Background: Work to Enable Electrification

Background: Electrification



- Concrete pads poured by a hired community member
- Some residents wanted to get involved and train
- New 100A exterior panel that feeds house panel
- Mini-splits in every bedroom and living room

Retrofits

Most common retrofits (90%)

- Low-flow showerhead
- LED lighting
- **Air sealing**
- **Floor & pipe insulation**
- **High AFUE Furnace**
- **Bathroom fans**

Less common

- New door or window
- Roof insulation, fridge..

Electrification

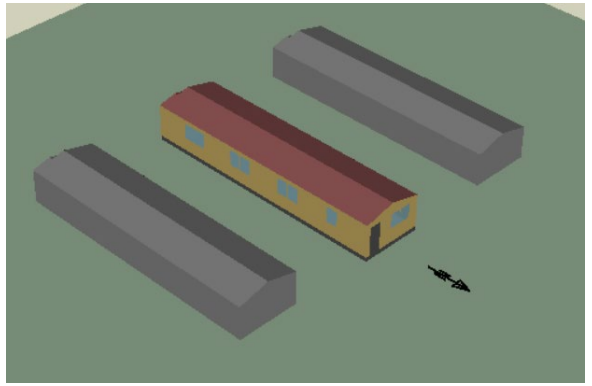
- Cold-climate mini-splits (with furnace)
- Electric water heater (no HP)
- **Induction stove***
- 100 amp^{+} electrical panel

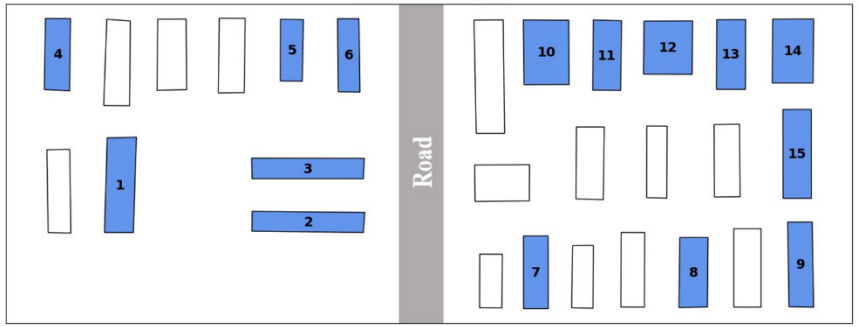
DERs

- 9.6 kW AC Inverter
- 16.4 kWh Battery
- PV subscription

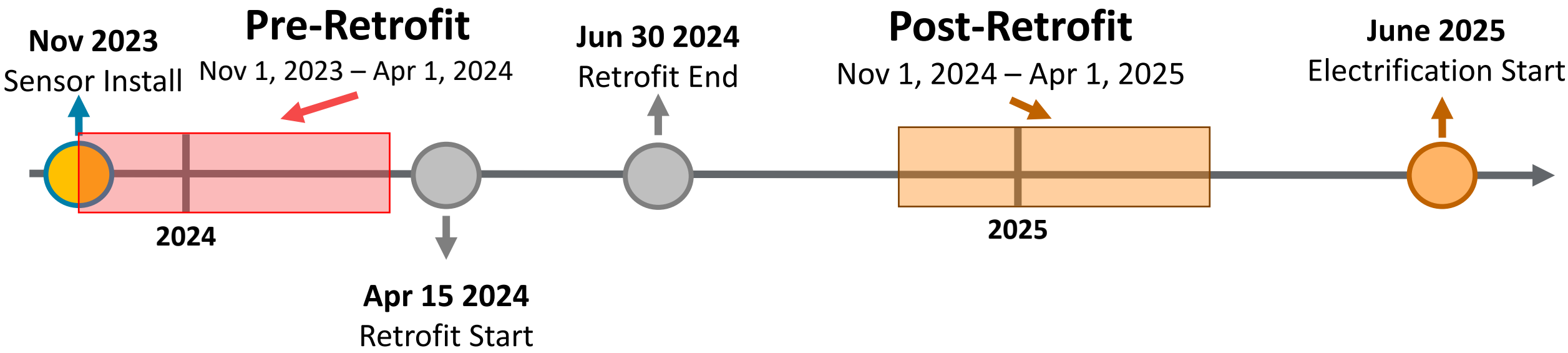
Modeling Process for holistic analysis

- BEopt:
  - Individual Building modeling
- URBANopt:
  - Community modeling
- REopt:
  - DER optimization
- OpenDSS:
  - Grid Modeling





Timeline


Nov 2023
Sensor Install
Pre-Retrofit
Nov 1, 2023 – Apr 1, 2024
Jun 30 2024
Retrofit End
Post-Retrofit
Nov 1, 2024 – Apr 1, 2025
June 2025
Electrification Start
2024
Apr 15 2024
Retrofit Start
2025

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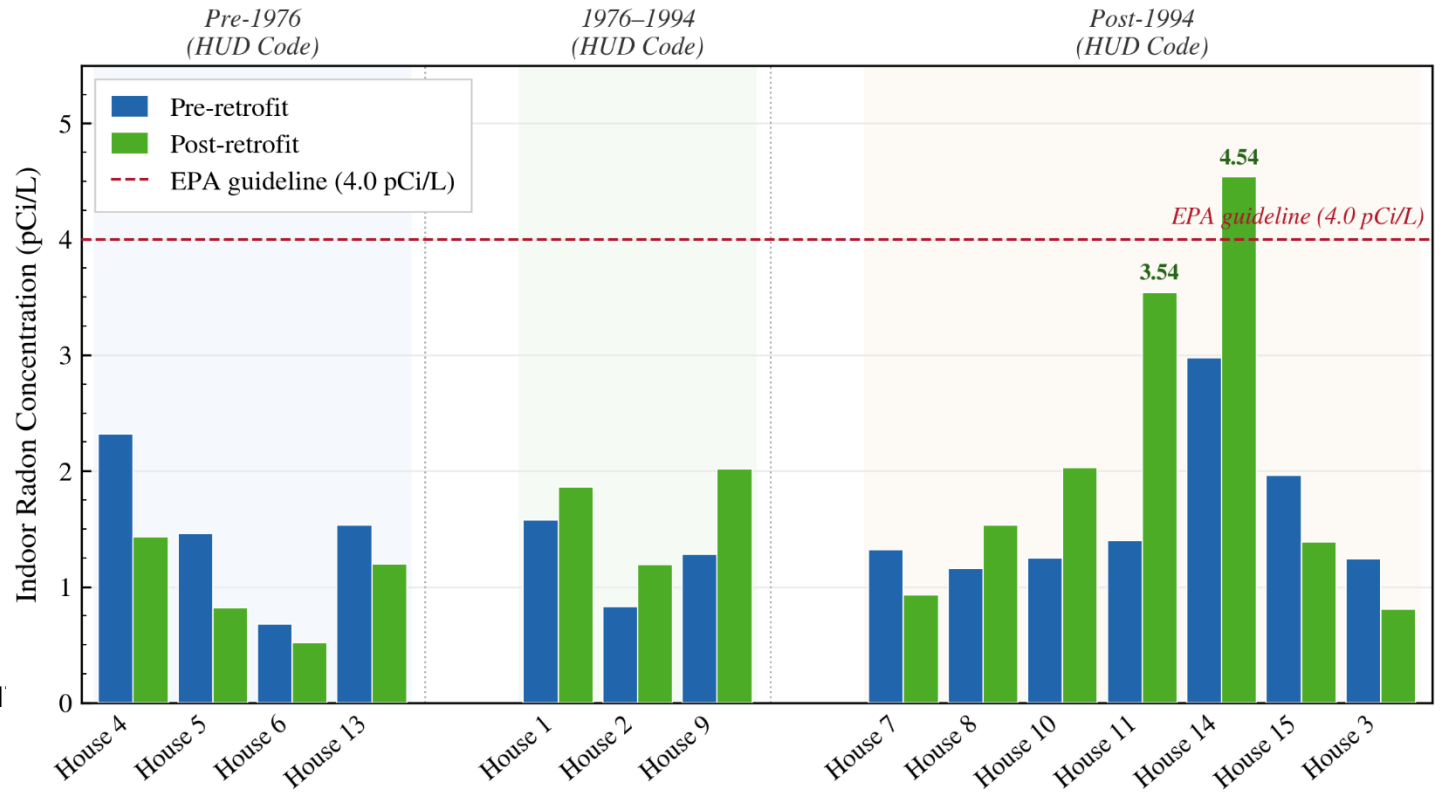
Radon Concentrations: Pre and Post

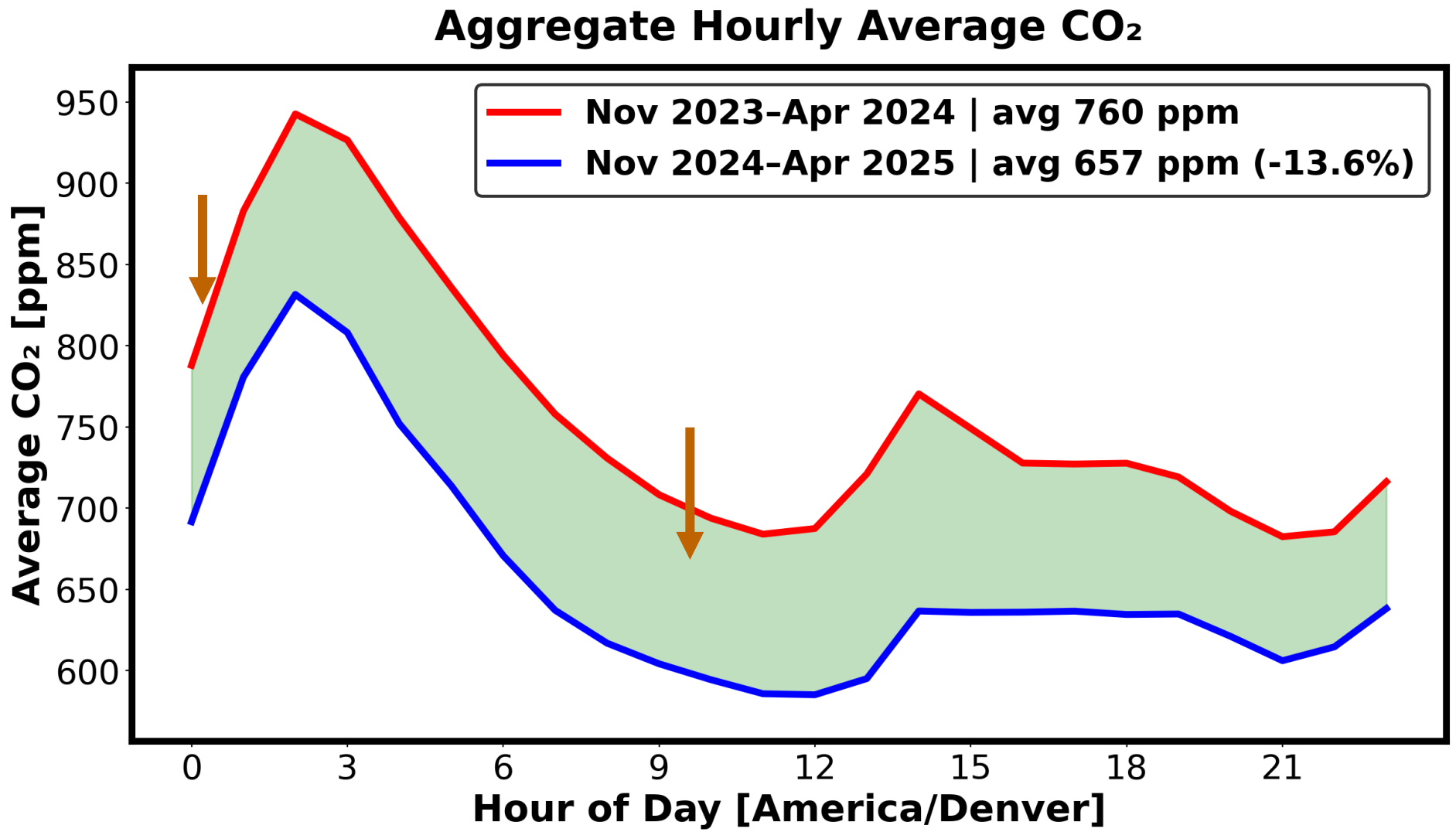
EPA guidelines*

- **+ 4 pCi/L or higher**:
  - install a radon reduction system
- **2–4 pCi/L**:
  - consider installing a radon reduction system
  - retest a few months after
- **Below 2**:
  - no action needed
- The average radon level in American homes is abou
  1.3 pCi/L

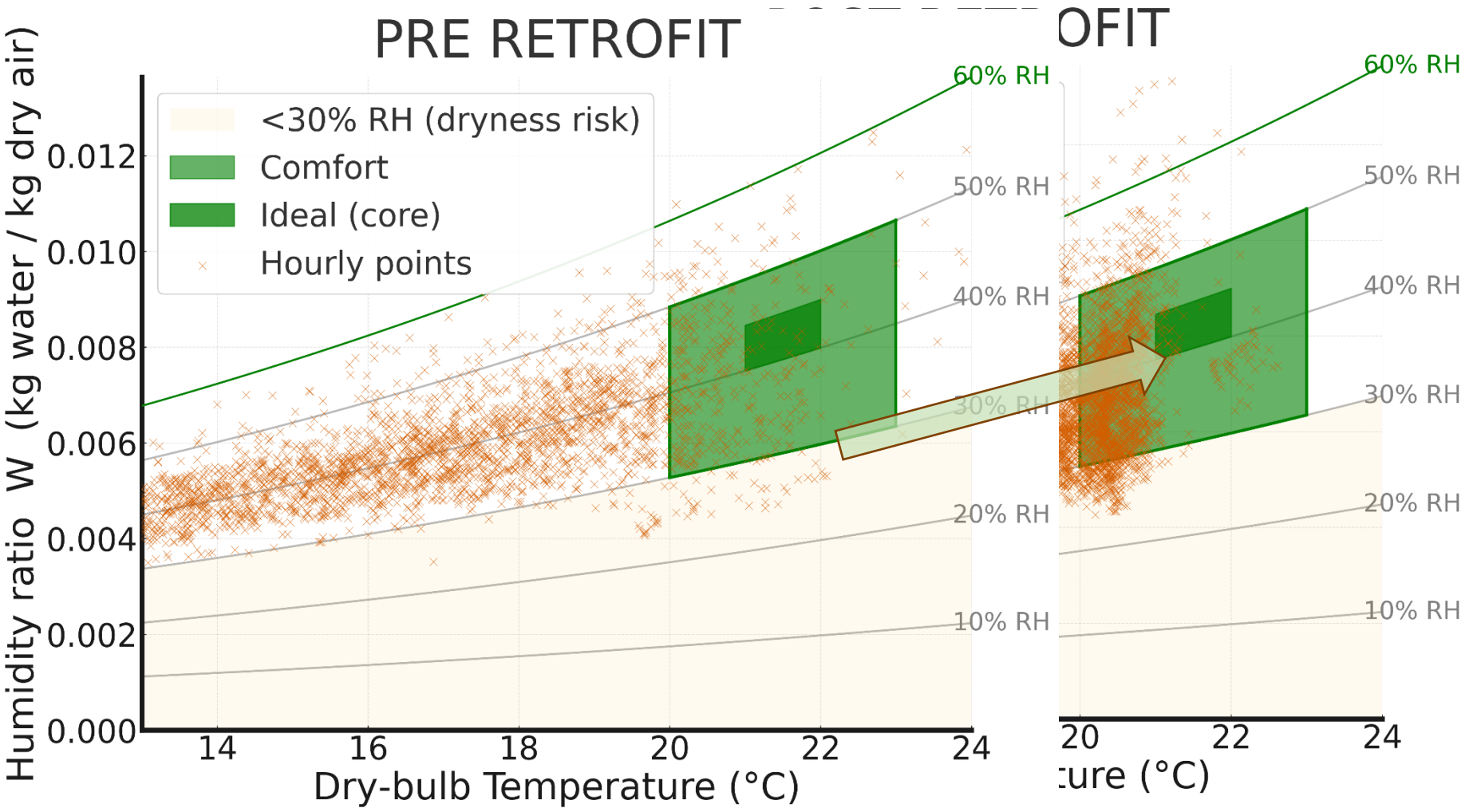


*https://www.cdc.gov/radon/testing/index.html

Changes in CO2 Pre and Post Retrofit

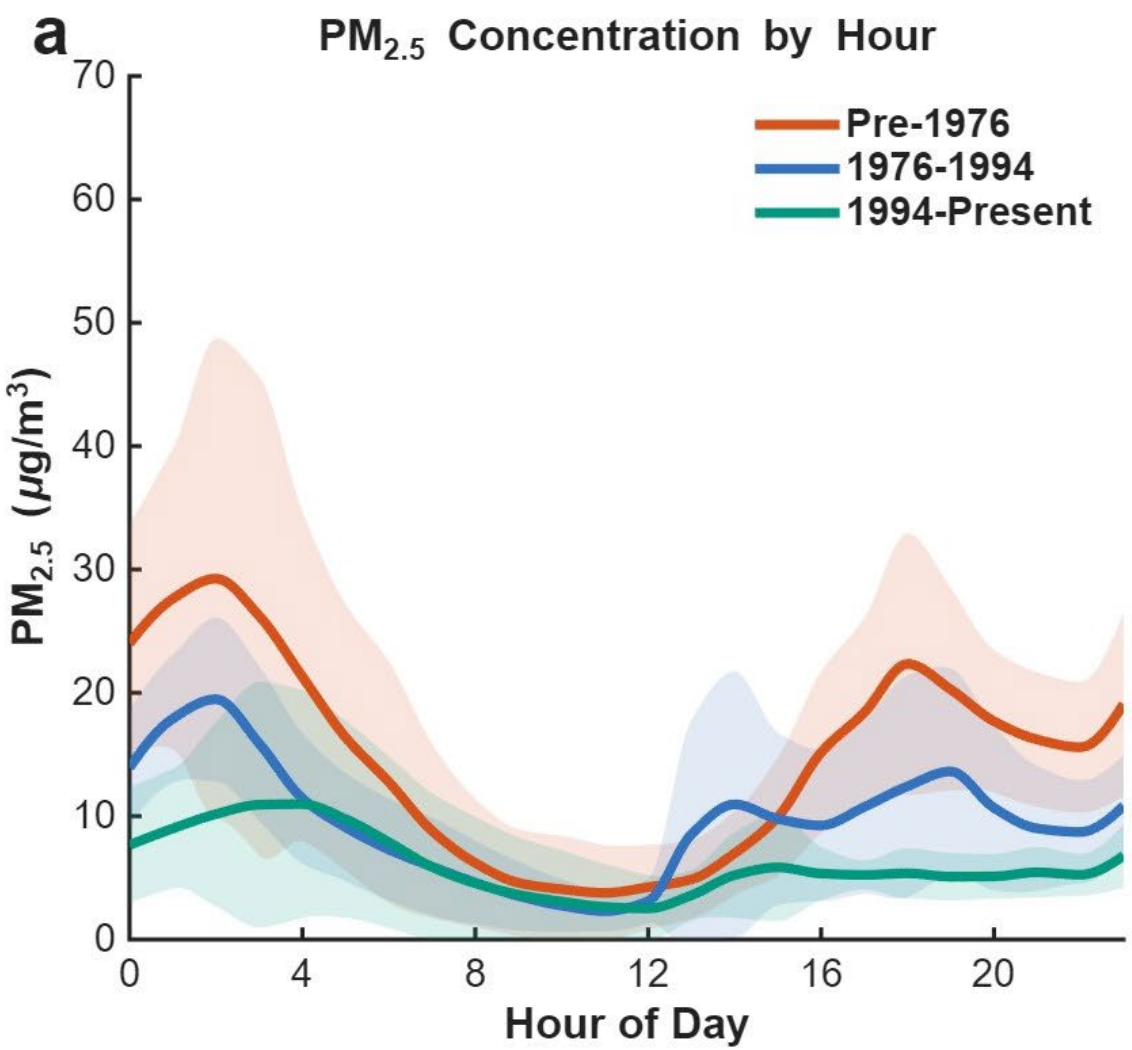


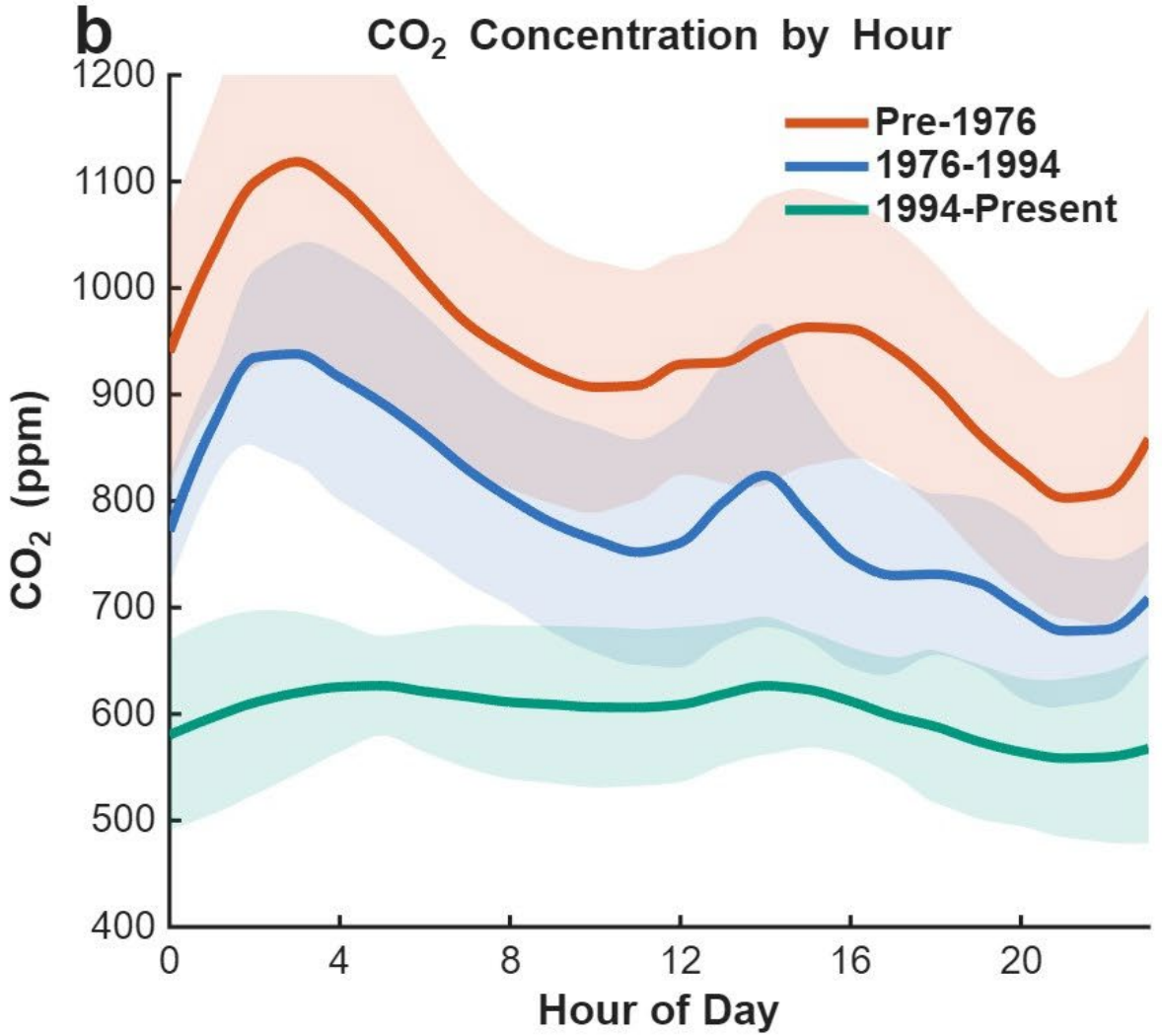
Temperature and Humidity- Comfort chart



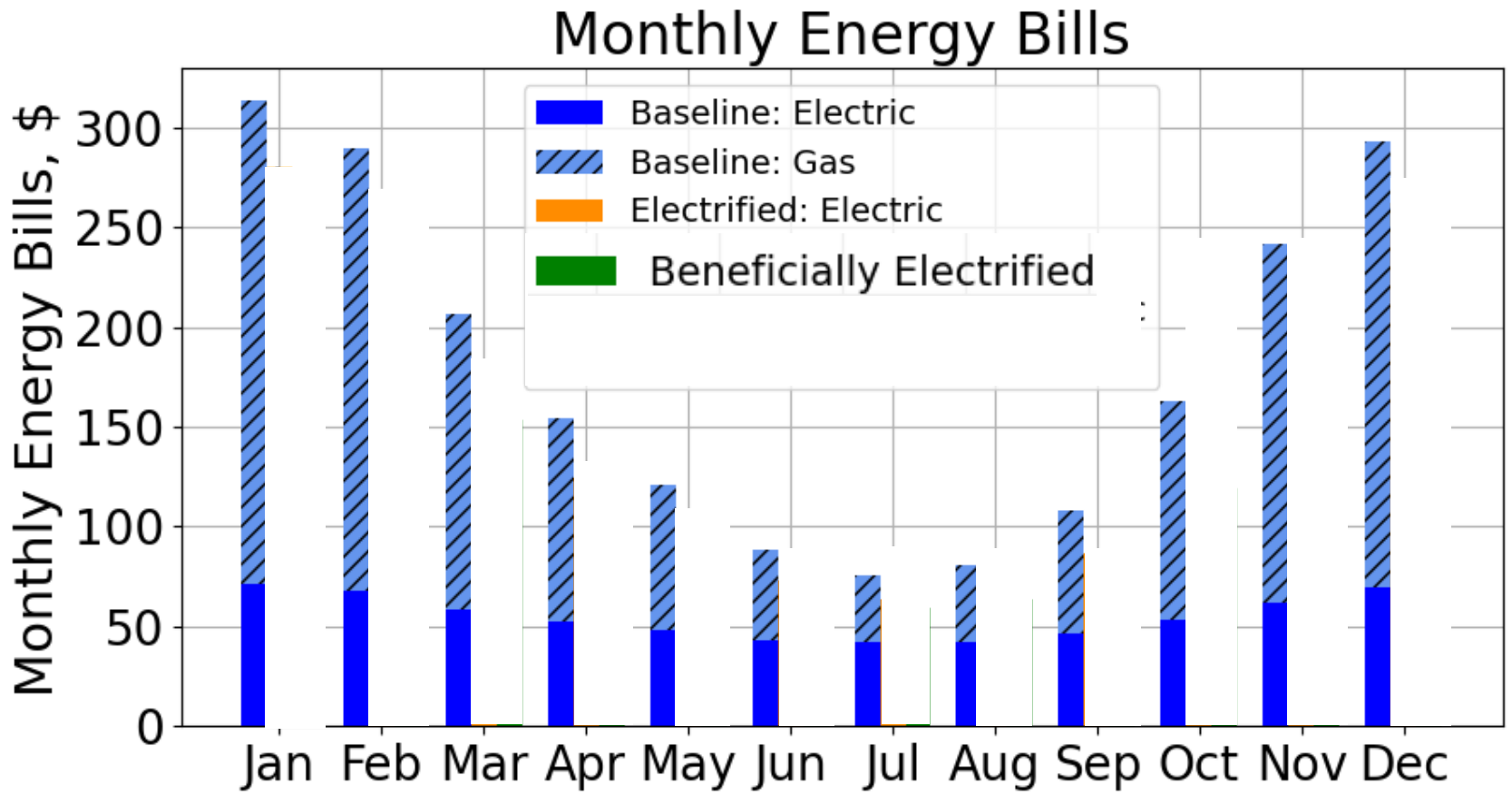
- **Pre** :Most hourly points sit outside the comfort zone.
- **9.1 %** of hours in comfort
- **Post** :The points shift into the green zone.
- **57.8 %** of hours in comfort

Indoor Environmental Quality by Building Age

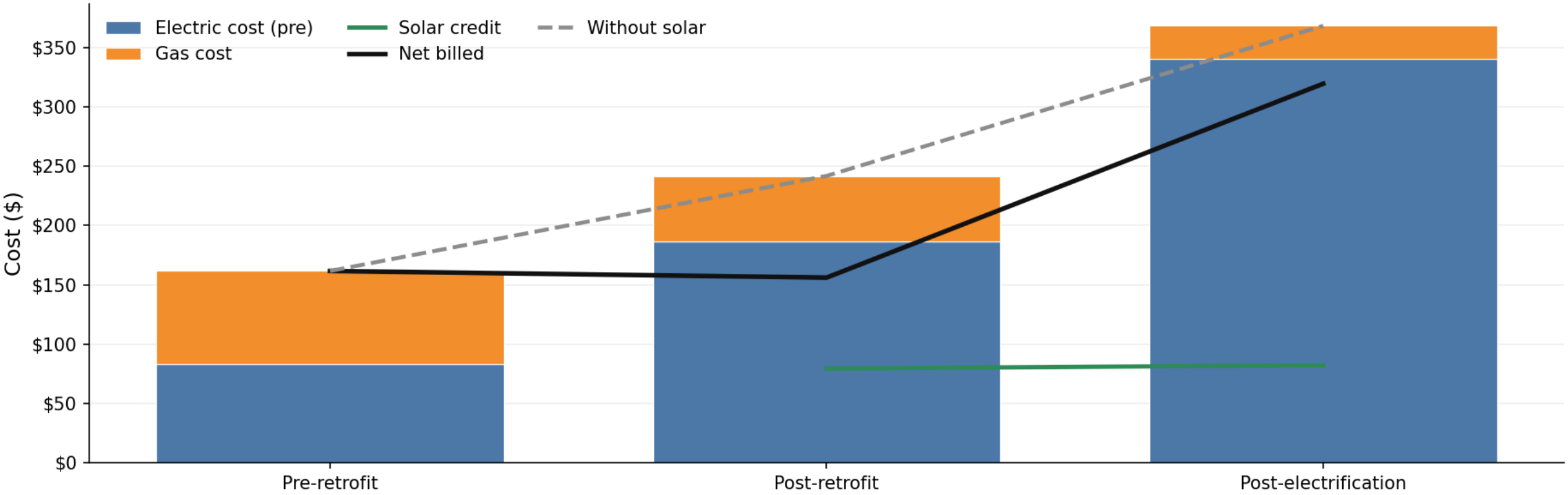




Modeling results: predicted energy costs



Modeling results: actual energy costs



Outline

1. Background and Project Objective
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4. Results
5. **Conclusions & Lessons Learned**

Conclusions

- One of first community-scale electrification projects in the US
- Overall positive feedback from the community
  - Issues with induction stove and furnace/mini-splits
  - **Rest of the community wants to join now->Community-scale works!**
- Radon concentrations varied from home to home
  - Important to monitor Radon
- Comfort hours increase by 6x from 10 to 60%
- CO2 concentration decrease by 100ppm or 14%
- Electrification can significantly increase utility bills
  - Due to long/cold winters and high electric/gas rates
  - **PV subscription only way to assure energy reduction (or replace home)**
  - **Deep energy retrofit??**
- Energy models struggle to predict energy bills

Challenges: Community & WAP

- 14+2 members signed to the program
- A few additional members want to join now
- WAP requires lots of paperwork, including income or taxes…

- For multi-family, an entire building can be eligible if
  - property is on the list prepared by HUD
  - 66% of the units in each building meet household income requirements (200% of poverty)
  - **It would be nice… to have WAP do the same for home parks**

Challenges & Lessons Learned: Community

- **Residents thrusts->community engagement**
- Find a local community-based organization
- Need to identify and engage community leaders
- All meetings are at a local community-based organization
  - Don’t expect a full house the first day
  - Relationships take time
- “This will make our houses last longer…”
- “Reduce risk for pipe freezing”
- “Surprised bills”

Challenges & Lessons Learned: Team

- Local community-based organization
- Professional Electrical Engineer and Mechanical Engineer
  - Initial walkover to inspect homes and property
- Strong Utility and local/State Gov collaboration
- Flexibility

Challenges & Lesson Learned: Electrification

- Electrification: electrical panel and transformer upgrades?
- Colorado Energy Office requires 200A panel
  - CEO approved waiver for a 100-125A panel

- Xcel Energy required loads analysis when upgrading panels
  - Upgrading transformer might add
    - 2-8 months delay
    - Costs for transformer, labor, and home connection/wiring
    - Newest update: no transformer is necessary
- Electrification first, retrofit right after

Challenges & Lesson Learned: Electrification

- Cold-climate heat pumps:
  - Selected dual-source due to utility and residents' concerns
  - Not many available dual-source for existing manufacturing housing
  - Find local mechanical contractor familiar or open to work with
  - Complains about mini-splits due to uneven heat
    - **Recommend ducted mini-splits or central heat pump**

- Water heating:
  - Current heat pump water heaters (22' diameter) do not fit most community closets' dimensions (18-20'' diameter)

Future Steps

Next 1-2 years

- Perform field studies for +1 year
- Document results
- Do the second half of the community (funding pending…)
- Expand work to 17 low-income detached homes in Denver
- Validate models and expand the analysis to other locations outside of CO

Longer term

- Modify Policies
  - **CEO rules for electrical panels**
  - **WAP rules for home parks**
- Expand work to more communities in/out of Colorado
- **Find an approach to do similar work without need for expensive electrical infrastructure**

Thanks!

> Unless someone like you cares a whole awful lot, nothing is going to get better.
> It's not.
>
> *Dr. Seuss*