ET Summit 2024

Presented by

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Optimizing Heat Pump Load Flexibility for Cost, Comfort, and Carbon Emissions

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Outline

- Background, demand flexibility and water heating
- Our solution:
  - Open-source cloud-based supervisory economic model predictive control (MPC) framework
  - Co-optimization of utility bill cost and GHG emissions
- Lab testing results
  - Cost can be reduced
  - Peak runtime was reduced
- Field testing status
- Acknowledgements

Background: Residential Water Heating

Nationally

18%
Energy Use

15%
GHG Emissions

California Specific

- HPWHs are **~0.6%** of CA water heating market, 2019 RASS
- Significant load will be added to the grid as water heating is electrified

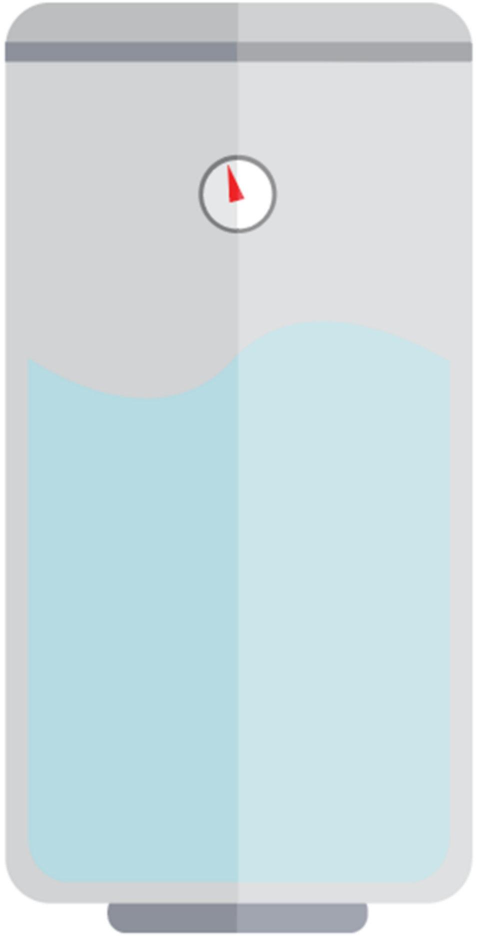
Background

- Electricity demand (kW) fluctuates throughout the day, with certain periods experiencing higher levels than others.

Demand flexibility **is one tool that can shimmy, shed, shift or shape load profiles to help match demand with available supply.**

Dynamics and Comfort

- Ability to provide demand flexibility via shimmy, shed, shift, and shape depends on:
  - Equipment dynamics
  - Size and availability of storage
  - Control system
  - End-user behavior and comfort requirements

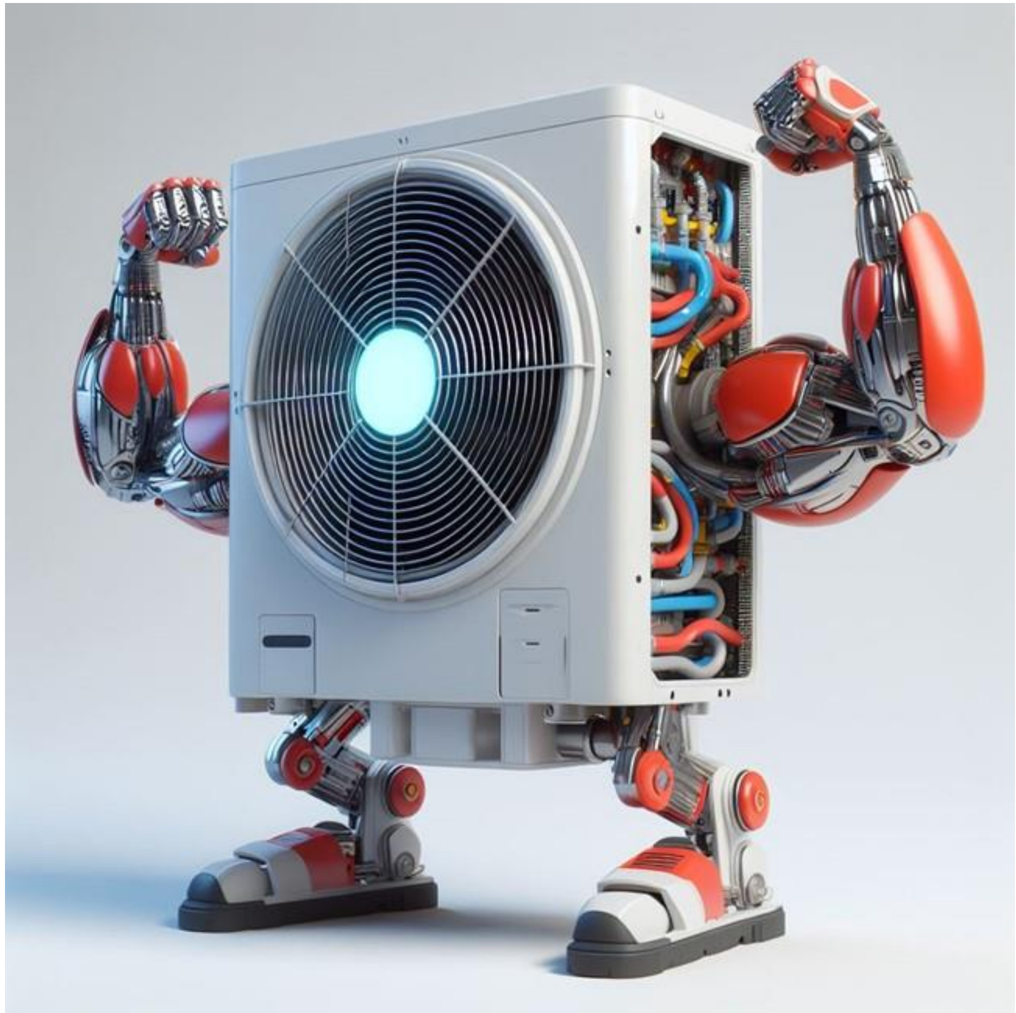


WCEC's Work

1. Develop an open-source cloud-based supervisory economic model predictive control (MPC) framework

2. Formulate co-optimization of utility bill cost and GHG emissions

3. For residential unitary HPWHs, compare demand flexibility potential (cost and carbon) using:
   - MPC and OEM rule-based control
   - OEM rule-based control only



Restaurant Analogy: MPC vs Rule-based

Rule-based control: Reactive
No Reservation

- No planning required
- Wait until hungry and then pick a place to eat
- Might be sat immediately, but depends on uncontrolled factors
- Ability to wait for a table depends on hunger level and remaining plans

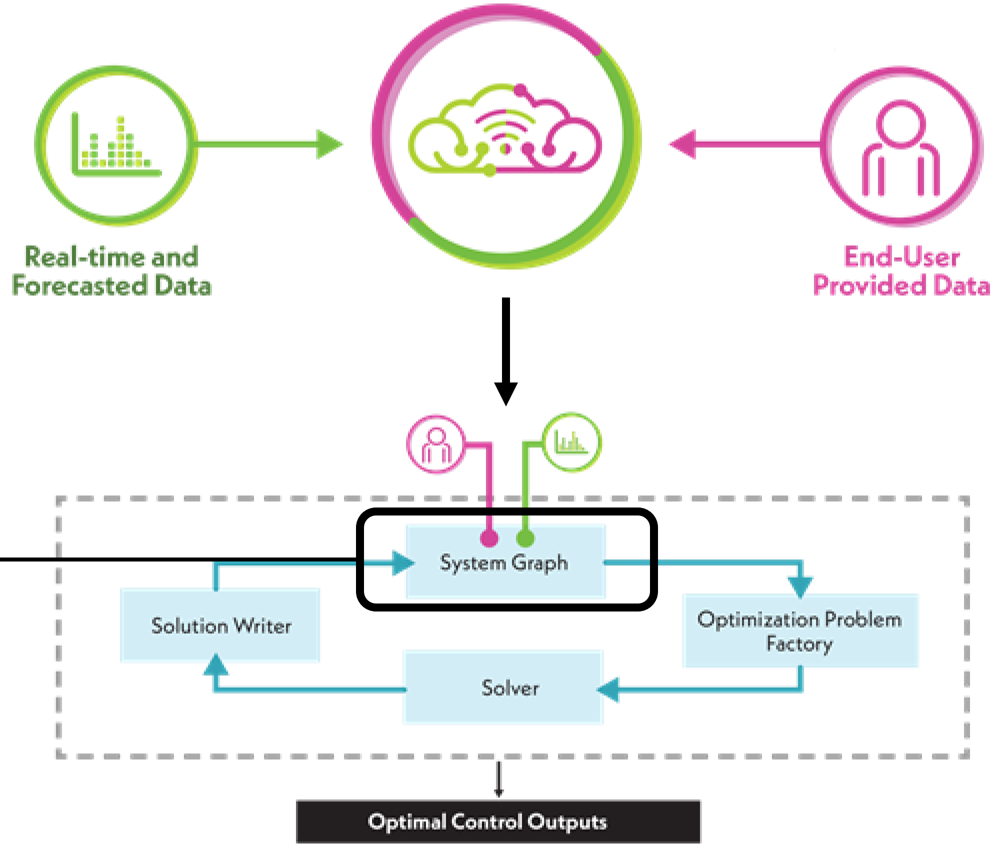
MPC: Proactive
Reservation

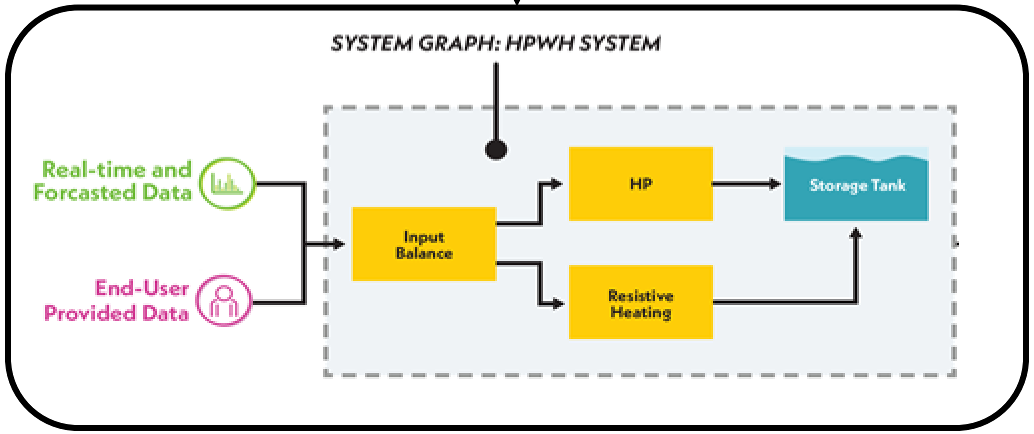
- Requires prior knowledge
- Planning required, might include inputs like travel time, time to find parking, etc.
- Must contact restaurant
- Enables interactive communication and informed decision making
  - Restaurant could offer free appetizer if outside seating is chosen
  - Customer can ask for a different time

Control Architecture

- Two-part cloud-based framework
- Data layer for collecting, storing, and sending data
- MPC for calculating setpoints, modular, directed graph approach
- Cost function, optimizes based on:
  - Energy Cost, time-of-use or “hourly”
  - Marginal Green House Gas Emissions (WattTime)
  - Comfort (soft penalty)
- Used for lab and field testing

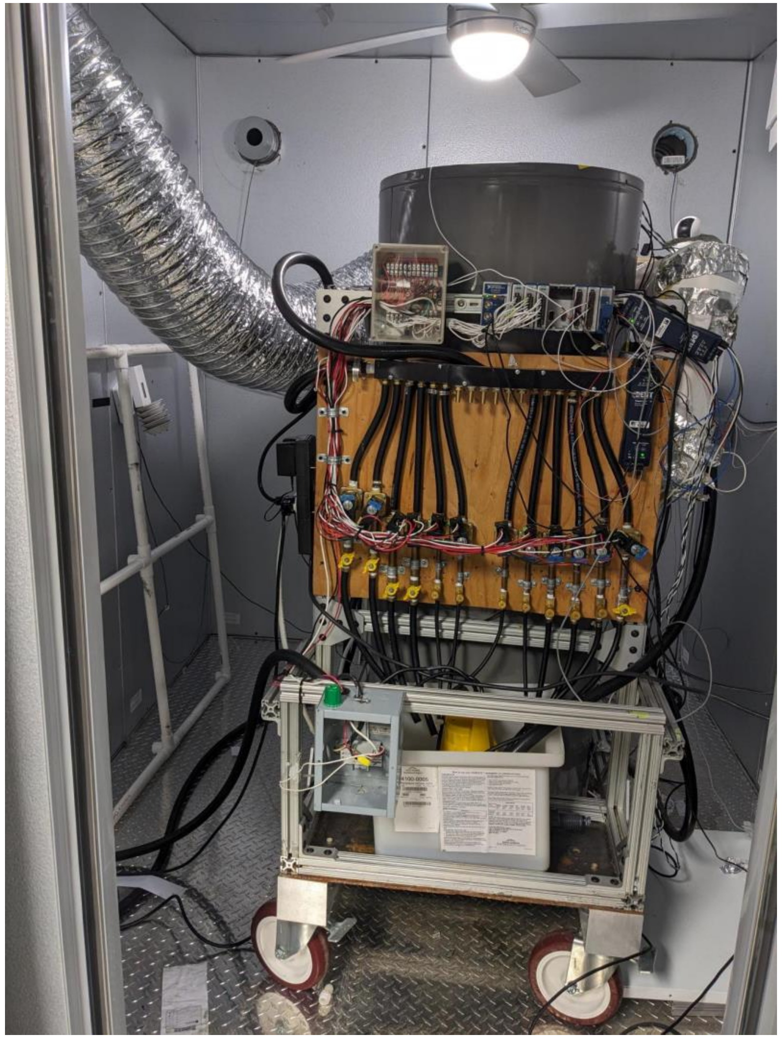
Data Layer Framework





Test Process

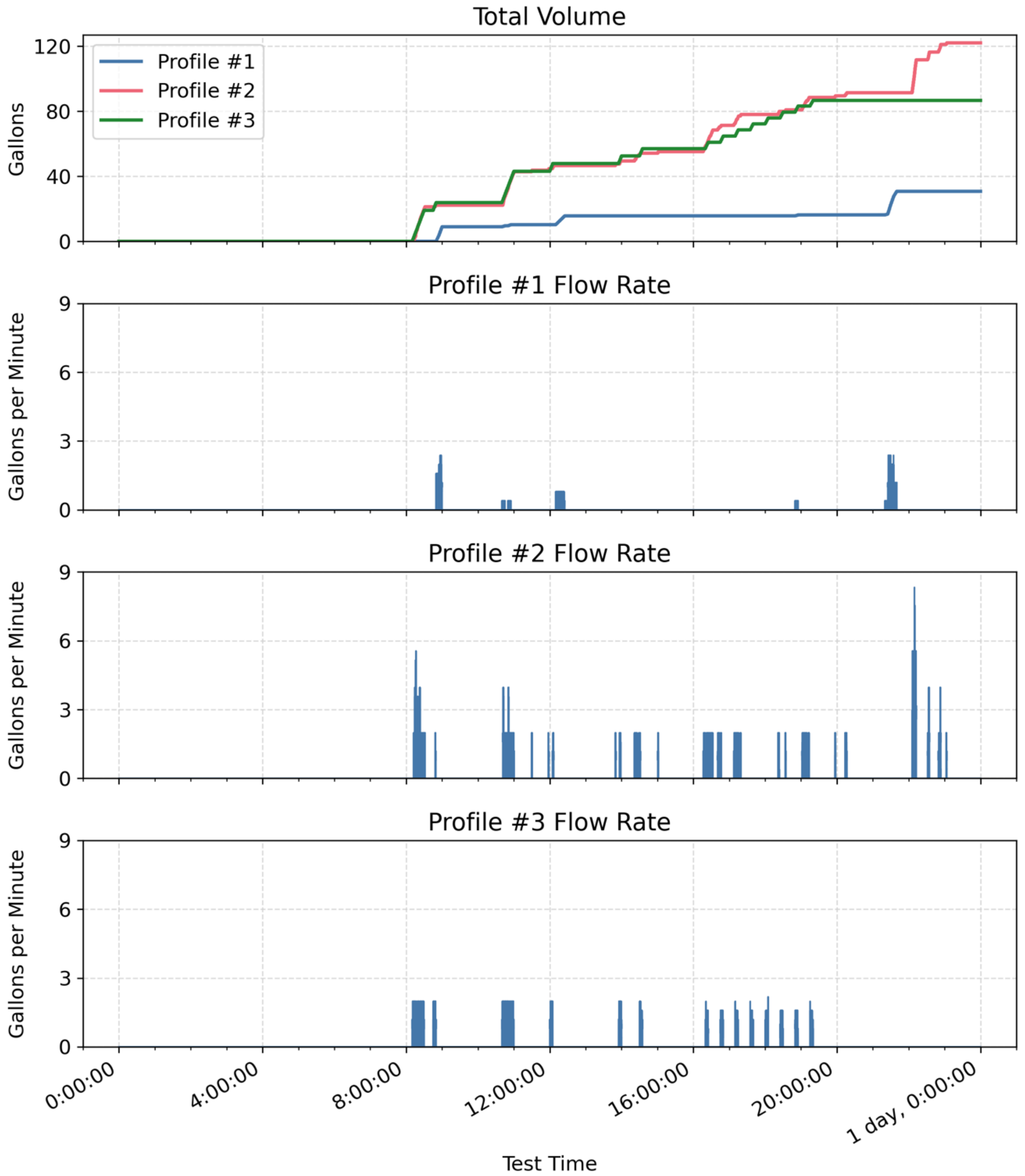
1. Initialization – partially drain and recharge tank
   - Ensures consistent initial conditions
2. Synchronize – Tell data layer start and end time
3. Run – Follow flow profile
4. Baseline test Rule Based Control (RBC)



Water Flow Rate Profiles

- 24-hour long profiles
  - 1 & 2 are field data
  - 3, was generated from 2 to capture max load shift

1. Low draw with small load shifting potential
2. Highest draw (so far) with high load shifting potential
3. Modification of #2, removed draws after 10pm and re-distributed the flow during peak

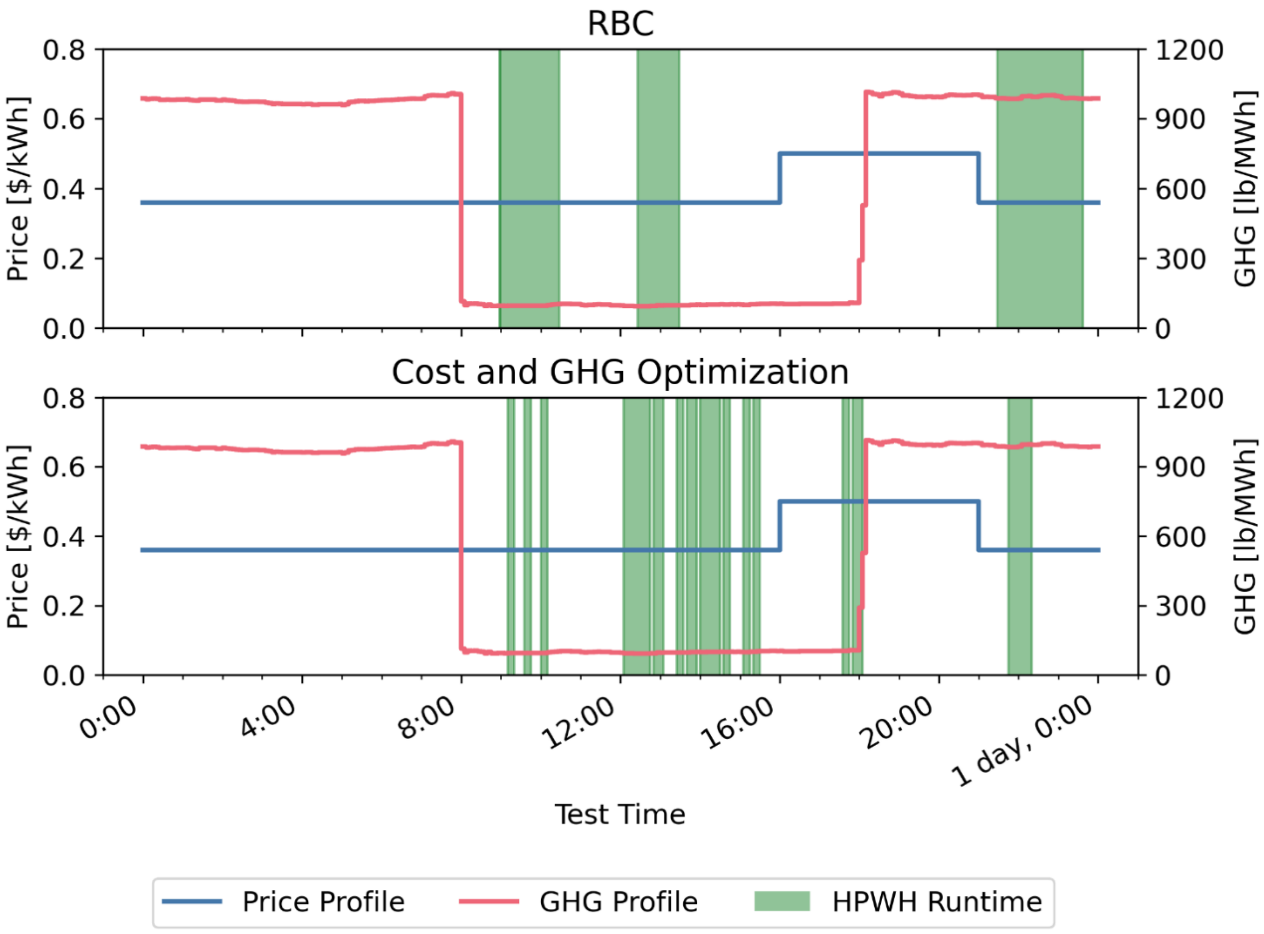


Profile #1: Low draw, small load shift

- Total of 31-gallons
- “Best-case” baseline, no runtime in 4-9pm peak
- Mixing valve outlet temperature (MVOT) range satisfied comfort for all tests

Results:

	RBC Baseline	MPC cost and GHG
Cost [$]	0.557	0.481 (-14%)
CO2 [lb]	0.771	0.301 (-61%)
Peak Price Runtime [min]	0	25
Peak GHG Runtime [min]	129	35 (-73%)
Mean MVOT [F]	117.2	117.2
Min MVOT [F]	115.3	115.3
Max MVOT [F]	119.4	119.4



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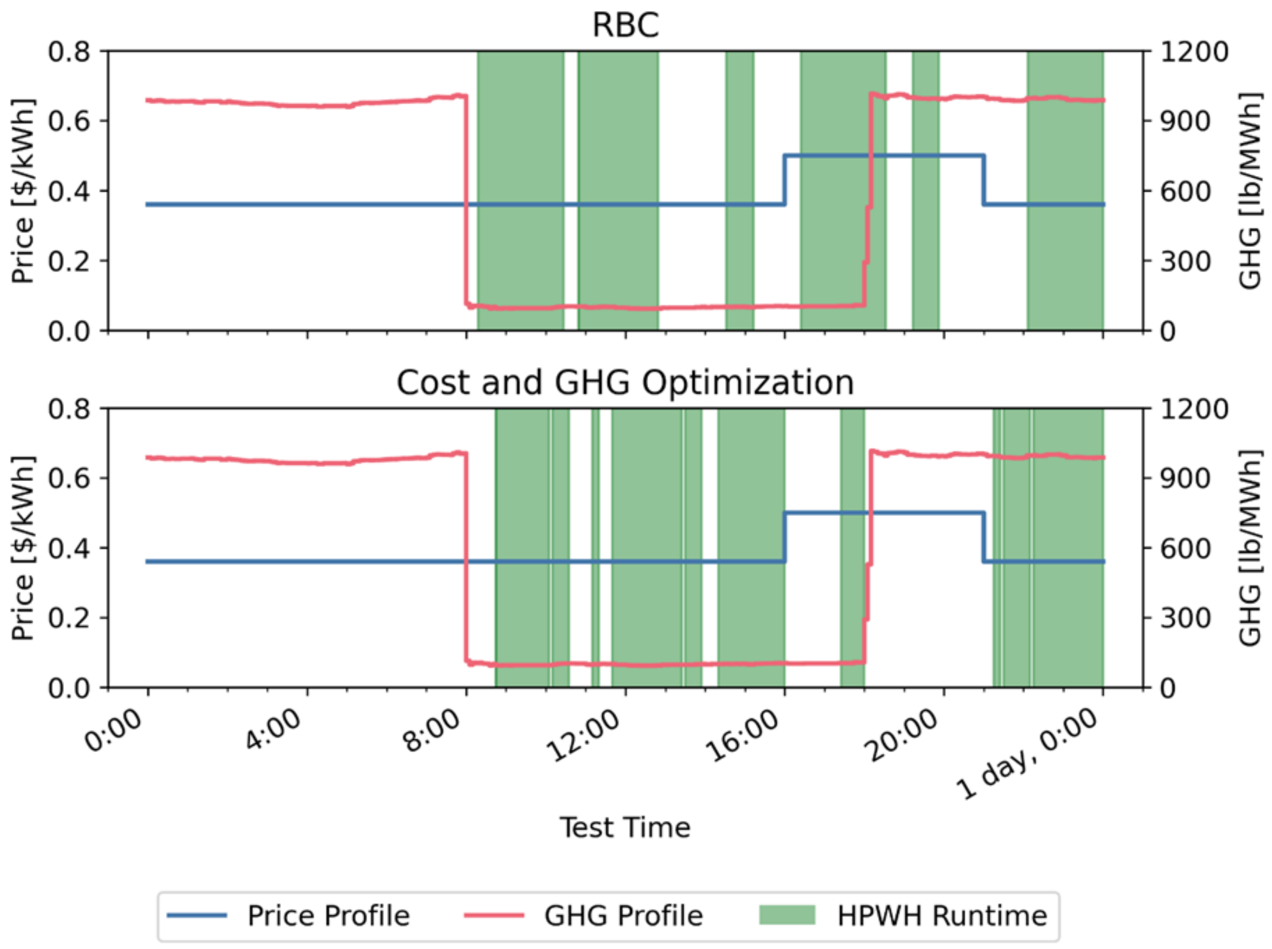
Profile #2: High draw, high load shift

- Total of 121-gallons
- 2 hr 47 min of baseline runtime in 4-9pm peak
- Mixing valve outlet temperature (MVOT) range satisfied comfort for all tests



Results:

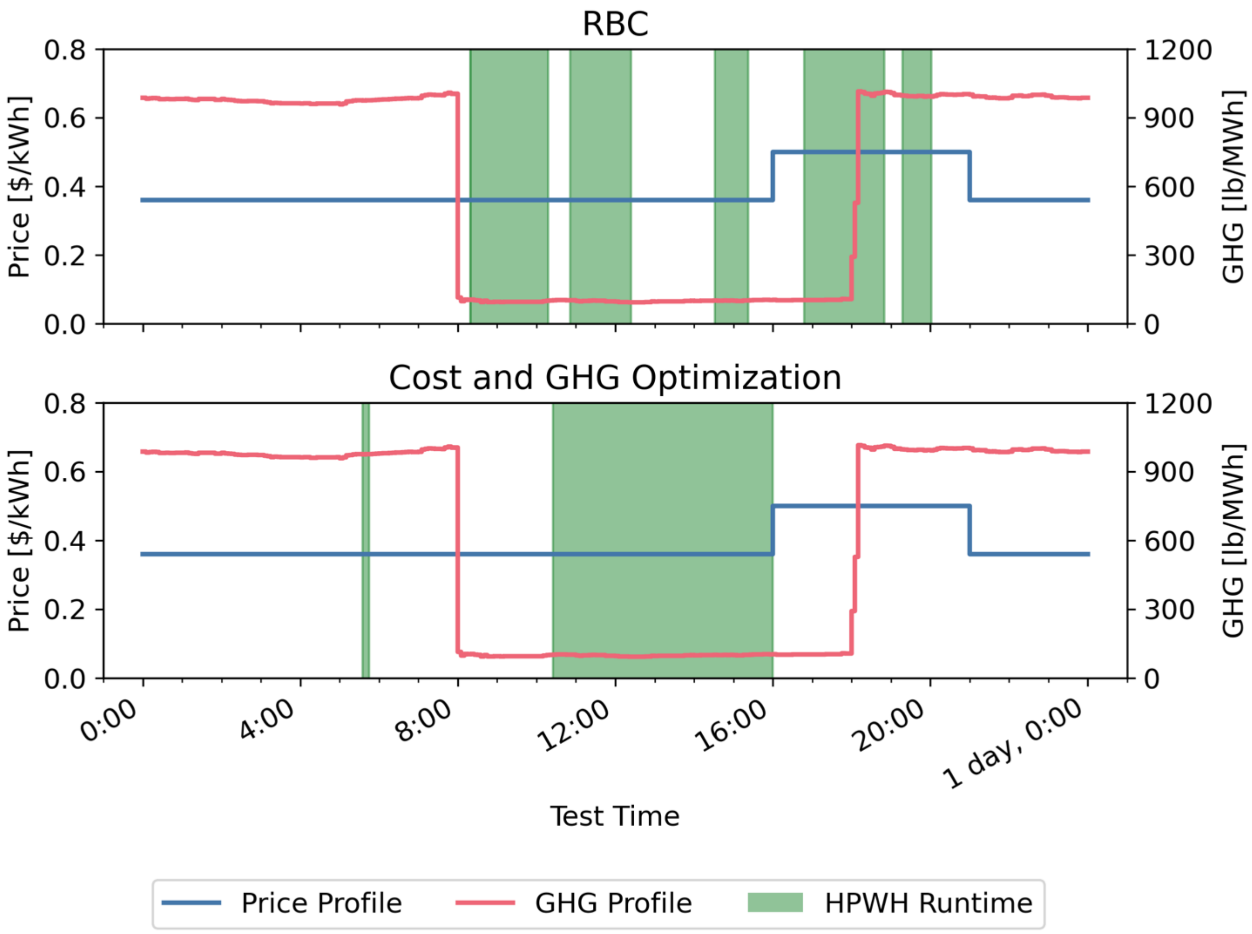
	RBC Baseline	MPC cost and GHG
Cost [$]	1.266	1.075 (-15%)
CO2 [lb]	1.175	0.999(-15%)
Peak Price Runtime [min]	167	35 (-79%)
Peak GHG Runtime [min]	175	155 (-11%)
Mean MVOT [F]	119.9	122.4
Min MVOT [F]	115.4	121.1
Max MVOT [F]	122.2	123.9

Profile #3: High-ish draw, highest load shift

- Total of 82-gallons
- Modified profile #2 so tank could remain depleted after peak
- Mixing valve outlet temperature (MVOT) range satisfied comfort for all tests

Results:

	RBC Baseline	MPC cost and GHG
Cost [$]	1.027	0.714 (-30%)
CO2 [lb]	0.708	0.246 (-65%)
Peak Price Runtime [min]	166	0
Peak GHG Runtime [min]	84	10
Mean MVOT [F]	122.3	121.9
Min MVOT [F]	114.8	114.8
Max MVOT [F]	123.1	125.2



Field Demonstration

Mutual Housing – Spring Lake
Woodland, CA
Climate Zone 12

RCD Housing - Quetzal Gardens
San Jose, CA
Climate Zone 4

Field testing with 24 HPWHs controlled with MPC officially started September 3rd, 2024.

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Contact:

California Energy Commission:

- Dustin Davis (dustin.l.davis@energy.ca.gov)
- Final report expected Summer of 2025

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