# Using Flexible Load Control in Residential Buildings to Support Grid Reliability

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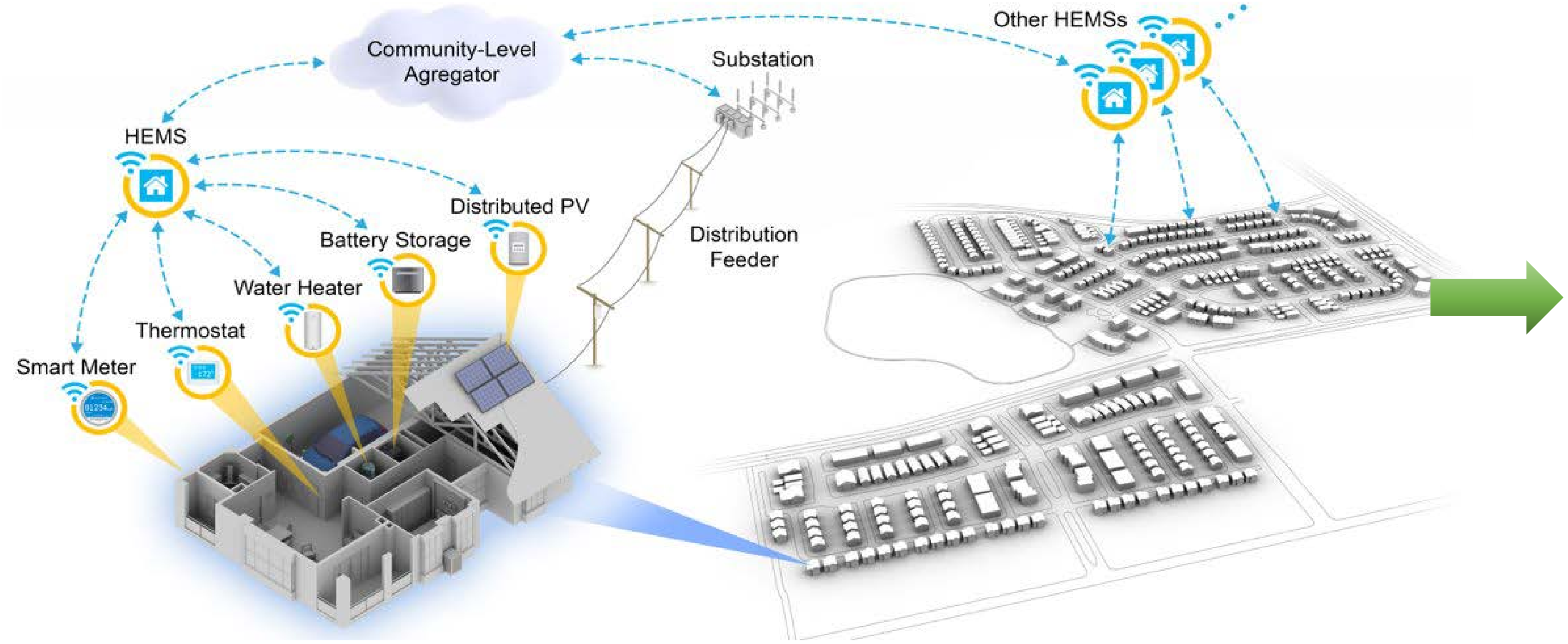
# Smart Community Control Project in Basalt Vista, CO

**Objectives**: Develop and demonstrate a community-scale solution to resolve crucial distribution grid issues arising from high-penetration PV, including overvoltage, voltage flicker and degraded power factor in distribution systems.




**PV Self-Consumption** (reduce PV curtailment with flexible loads and batteries)

**Grid Reliability** (reduce voltage violation; demand response; virtual power plant)

**Grid Resilience** (100% critical load support with local DERs during emergencies)

**Hardware-in-the-loop Lab Experiment** (grid reliability, grid resilience)

# Basalt Vista: Habitat for Humanity Community

Habitat for Humanity®
Roaring Fork Valley

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## Basalt Vista Affordable Housing Community

To address the affordable housing crisis for teachers and others essential to our community, Habitat for Humanity RFV, Roaring Fork Schools, and Pitkin County have come together in an innovative and unprecedented community collaboration to build 27 homes behind Basalt High School.

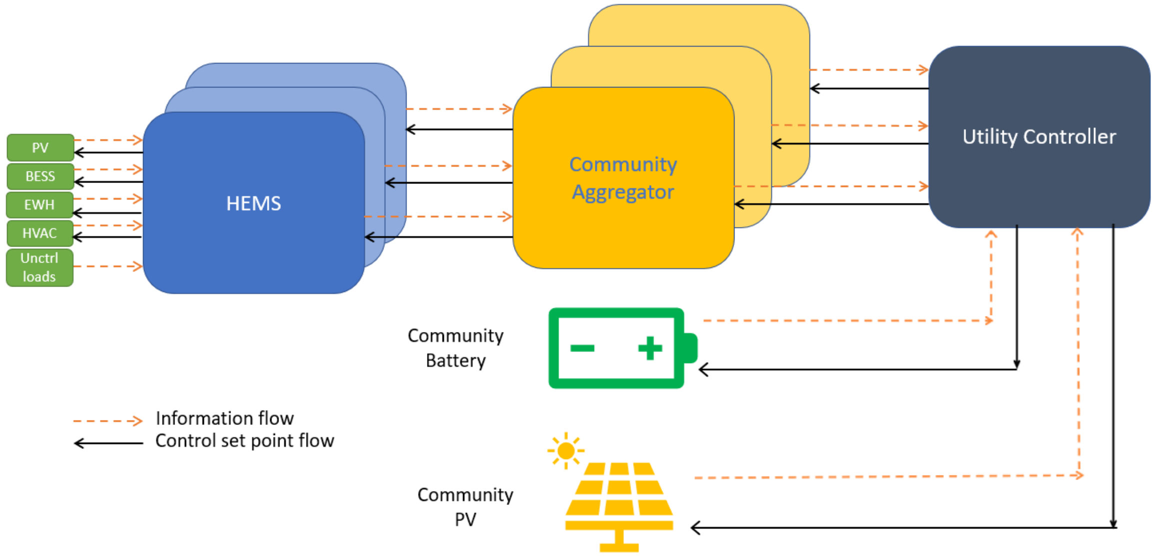
# Overall Project Timeline

This recently-completed project was broken up into three phases:

1. Control Development and Simulation Study
2. **Laboratory Evaluation**
3. Field Deployment

This presentation will be focused on the laboratory evaluation component.

# Home Energy Management System (HEMS) + Community Aggregator




**Hierarchical control system consisting of HEMS, community aggregator, and utility controller**

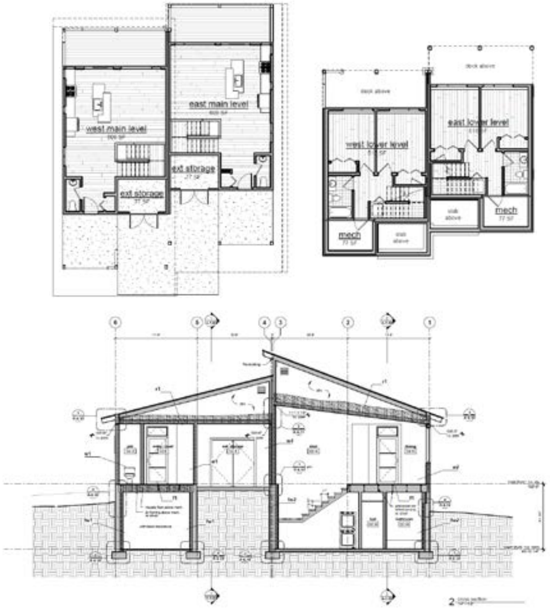
**Coordinated home energy management can enable a "smart community"**

- A home energy management system (HEMS) can help:
  - reduce energy use,
  - save on utility bills, and
  - ensure thermal comfort
- Coordinated control of homes can help utilities:
  - improve demand flexibility,
  - host more renewables on the grid, and
  - improve grid reliability and resilience

# Modeling the Community


- The Basalt Vista community consists of 12 multi-family buildings with a total of 27 units
- Affordable housing for schoolteachers in town
- Highly efficient all-electric net zero energy homes
- Building types include 2/3/4-bedroom duplex and 3/4-bedroom triplex
- Phase 1 & 2 were completed and occupied, Phase 3 still under construction
- PV on the triplex buildings are shared among the 3 units

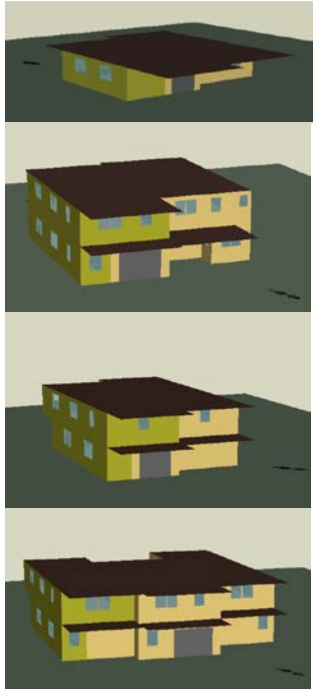
# Building Modeling – from floor plan to OCHRE model



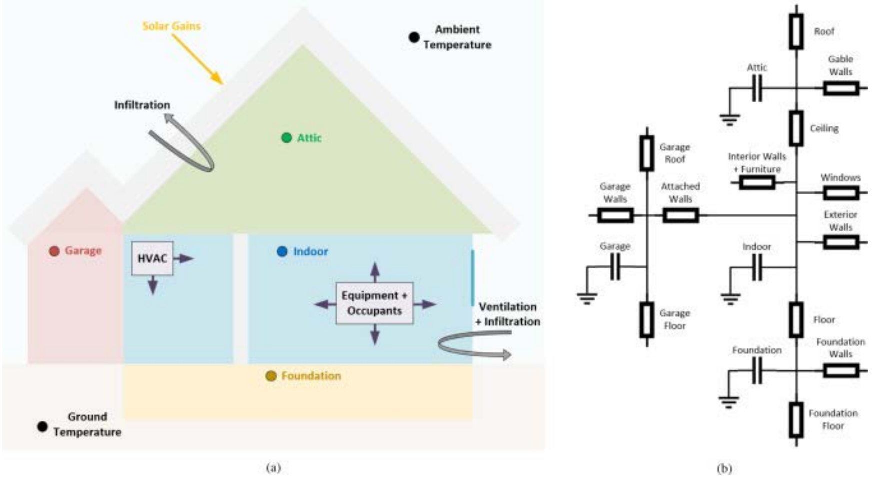
Floor Plan

**BEopt simulation model input**

| Simulation Input | Values |
| --- | --- |
| Foundation Wall Insulation | R-19 |
| Exterior Wall Insulation | R-30 |
| Attic Insulation | R-49 |
| Roof Insulation | R-50 fiberglass |
| Window | Double Pane (U: 0.3 \| SHGC: 0.3) |
| Air Leakage | 2.5 $ACH_{50}$ |
| Mechanical Ventilation | ERV (89 CFM) |
| HVAC Equipment | Mini-split heat pump (SEER: 22 \| HSPF: 10.2) |
| Water heating | Heat Pump Water Heater (UEF: 3.45) |
| Lighting and Appliance | 100% LED lighting, EnergyStar Appliances |

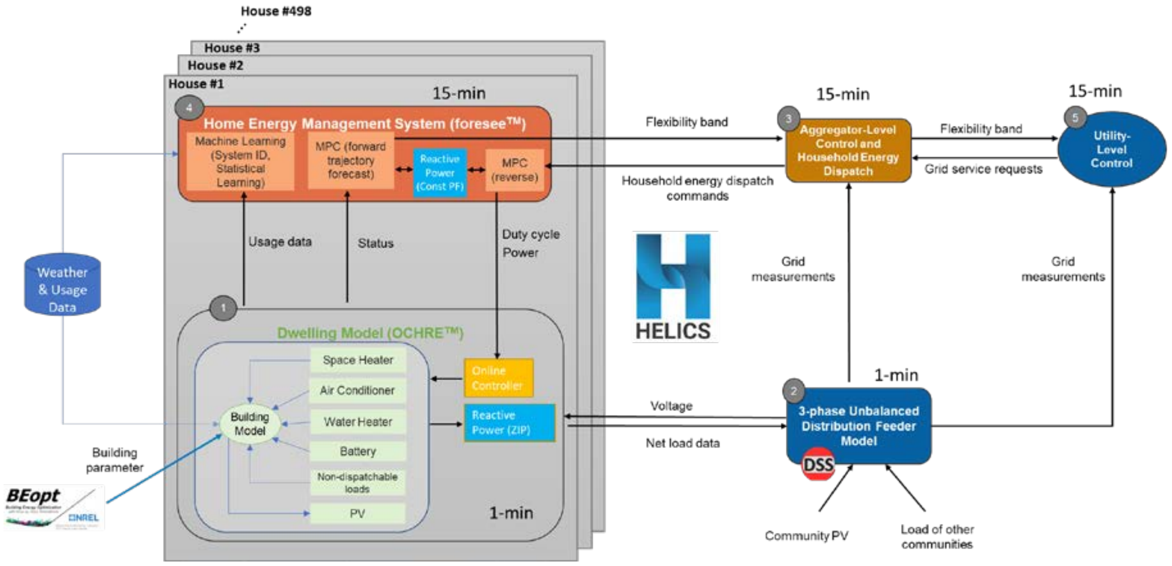


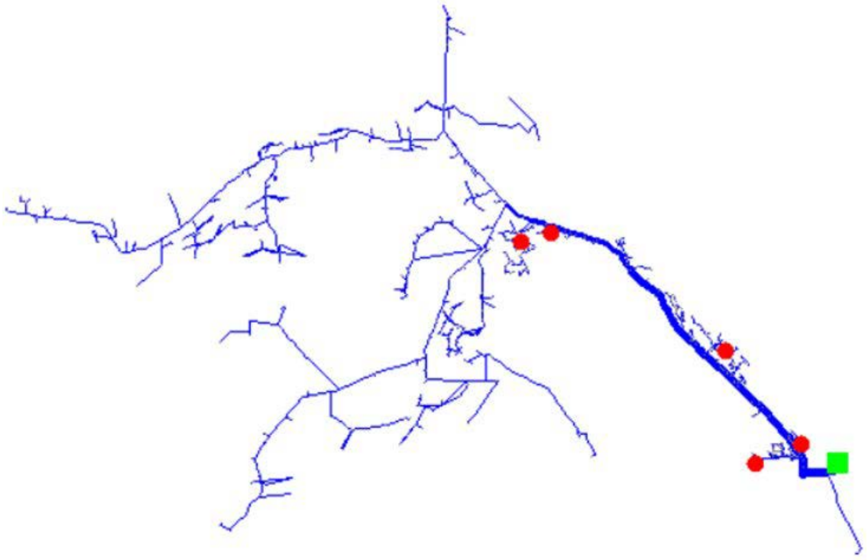
BEopt/EnergyPlus Model




OCHRE Model

# Distribution System Modeling

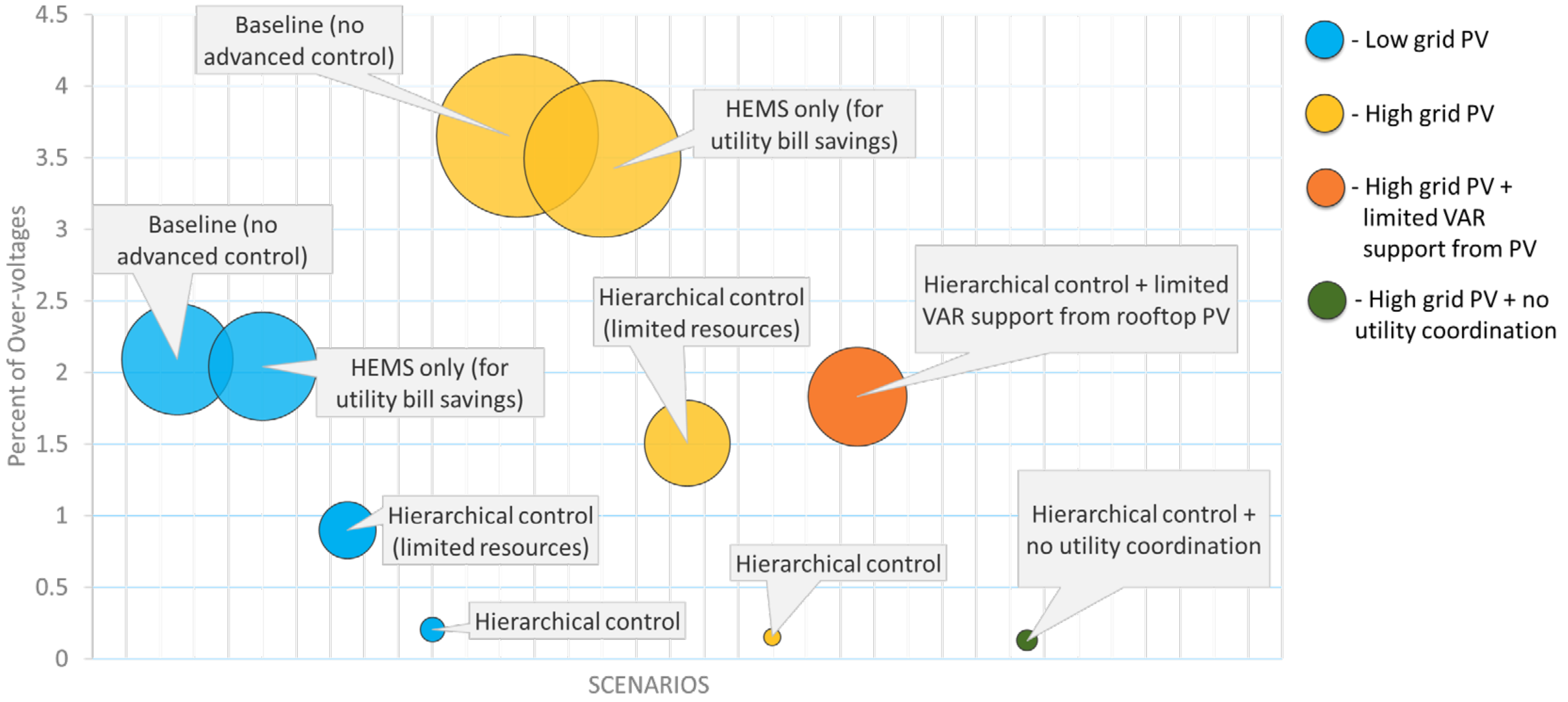


Topology of the distribution feeder serving Basalt Vista

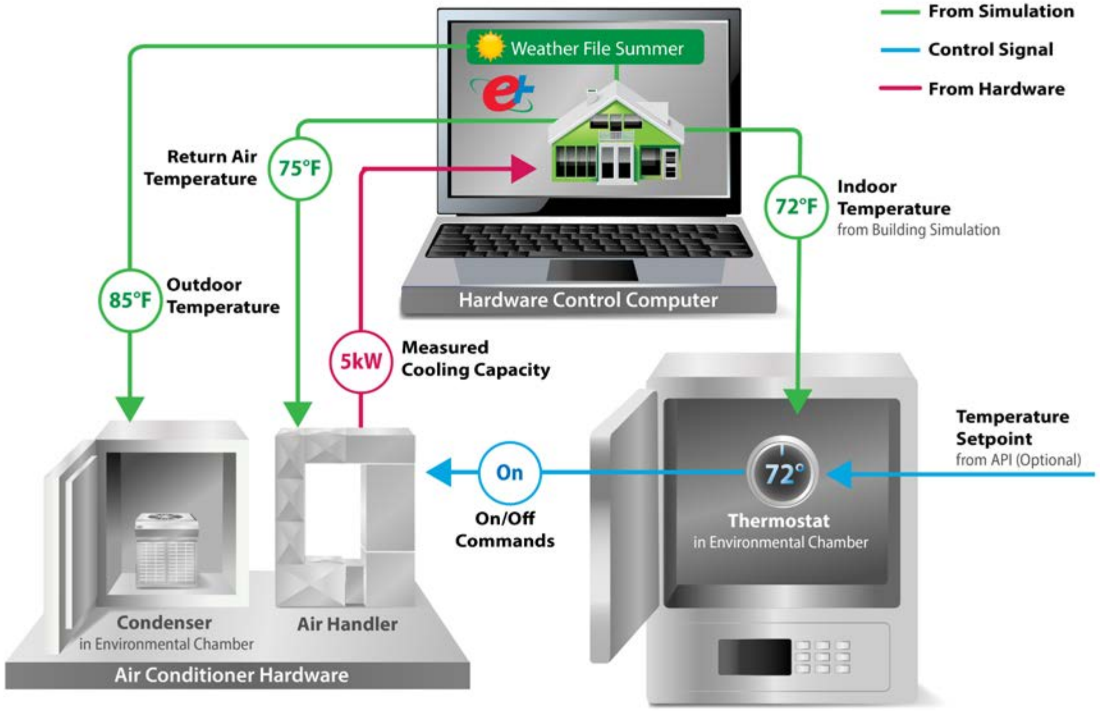
- The feeder that serves Basalt Vista has 4039 nodes and 480 service transformers. There are 1137 loads with the mix of commercial, industrial and residential customers.
- We obtained 2017 AMI measurements, and peak energy demand was 4 MW occurring in January. In the feeder, there are: a 200 kW PV farm, multiple residential PVs, and three Level-3 public EVSEs.
- The community distribution circuit is connected to the feeder via a single point of common coupling.
- The distribution system model has been incorporated into the co-simulation platform.

# Simulation Study for Grid Reliability

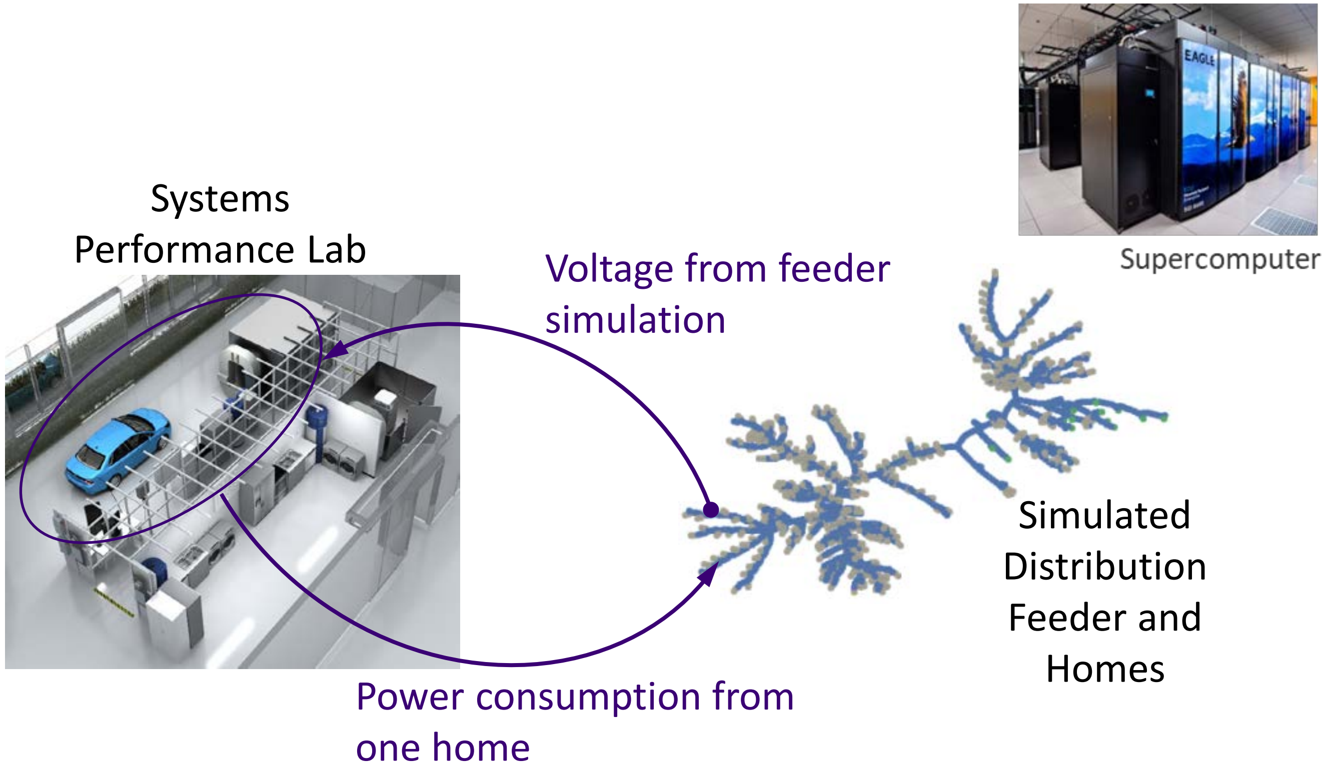



Hierarchical control algorithms successfully reduced the frequency and severity of overvoltages.

# Hardware-in-the-Loop Experiments

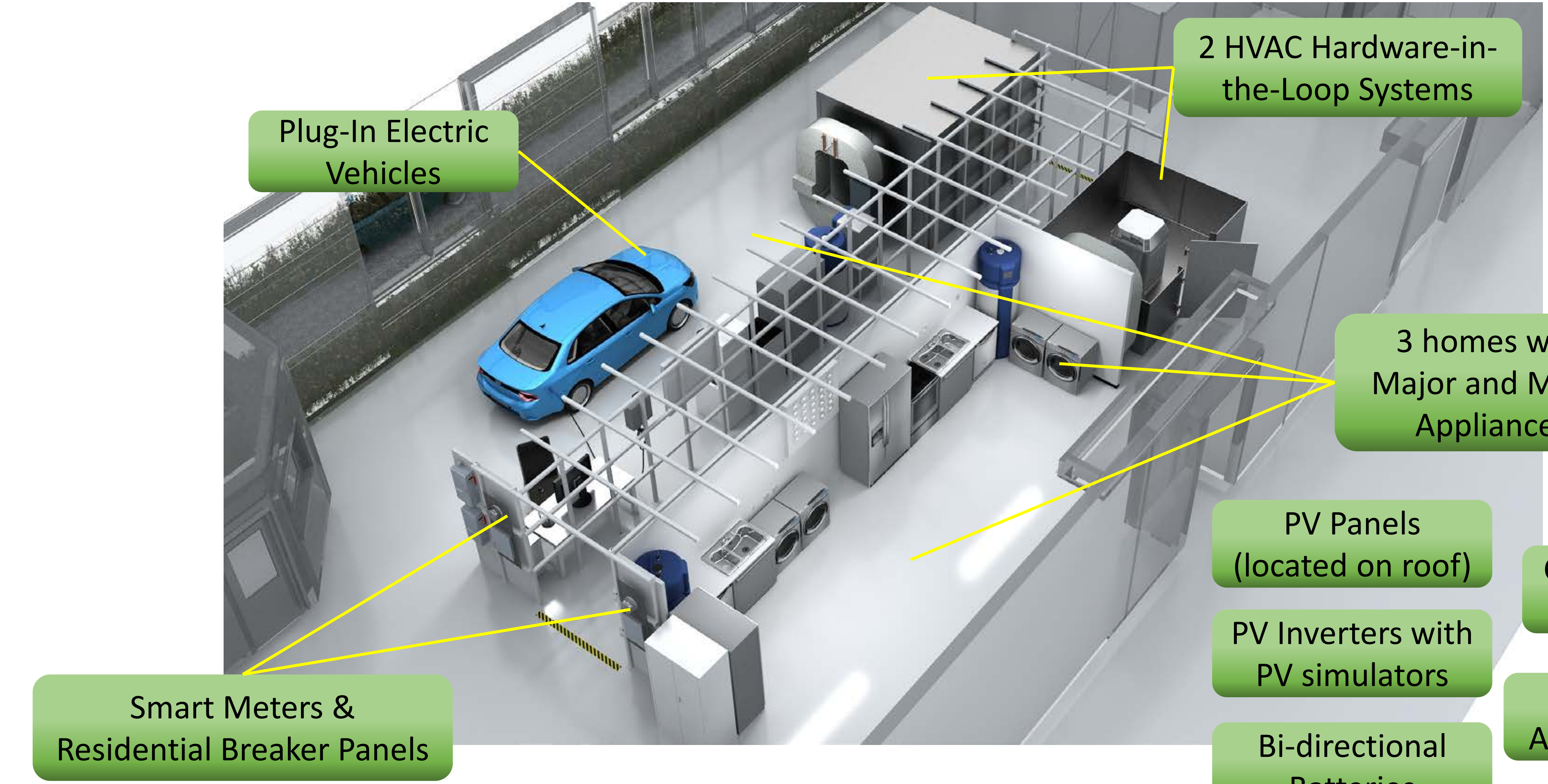



**HVAC Hardware-in-the-Loop**
Allows HVAC hardware to operate under different weather and control schemes in concert with building simulation




**Smart Home Hardware-in-the-Loop**
Allows co-simulation between residential controls and grid impacts.

# NREL's System Performance Laboratory




PV Panels (located on roof)

PV Inverters with PV simulators

Bi-directional Batteries

Circuit-level sub-metering

Dedicated Data Acquisition System

# Laboratory Configuration

Heat pump water heater

HVAC loop

"Outdoor" Chamber


EV charged via level 2 EVSE

Thermostat chamber

PV inverter

Battery inverter

Home battery system

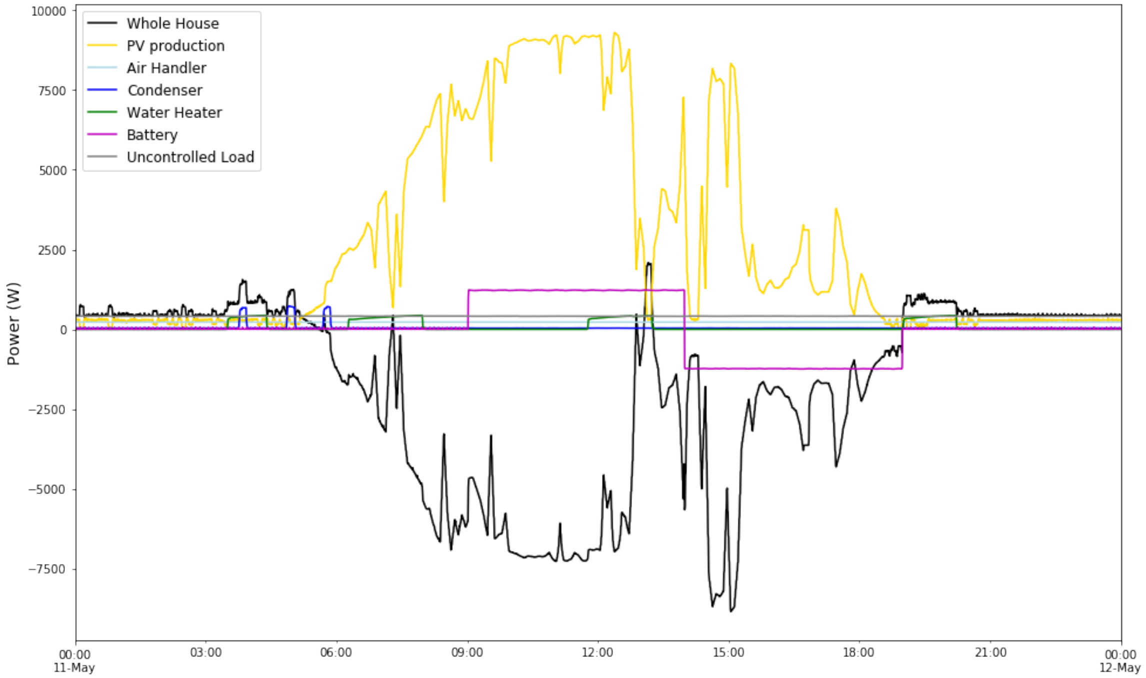

Opal RT real-time simulator

# Laboratory Testing Objectives

- Laboratory Experiments were used to verify interoperability and control responses for suite of BTM equipment with HEMS control system.
- Additionally, we used controlled lab environment to quantify expected impacts from different control strategies.
- Utility concerns included:
  - High PV penetration on the feeder – how to avoid curtailing without causing voltage violations?
  - Remote mountain region vulnerable to snow, wildfires – can the advanced controls reduce need for utility power during extended periods?

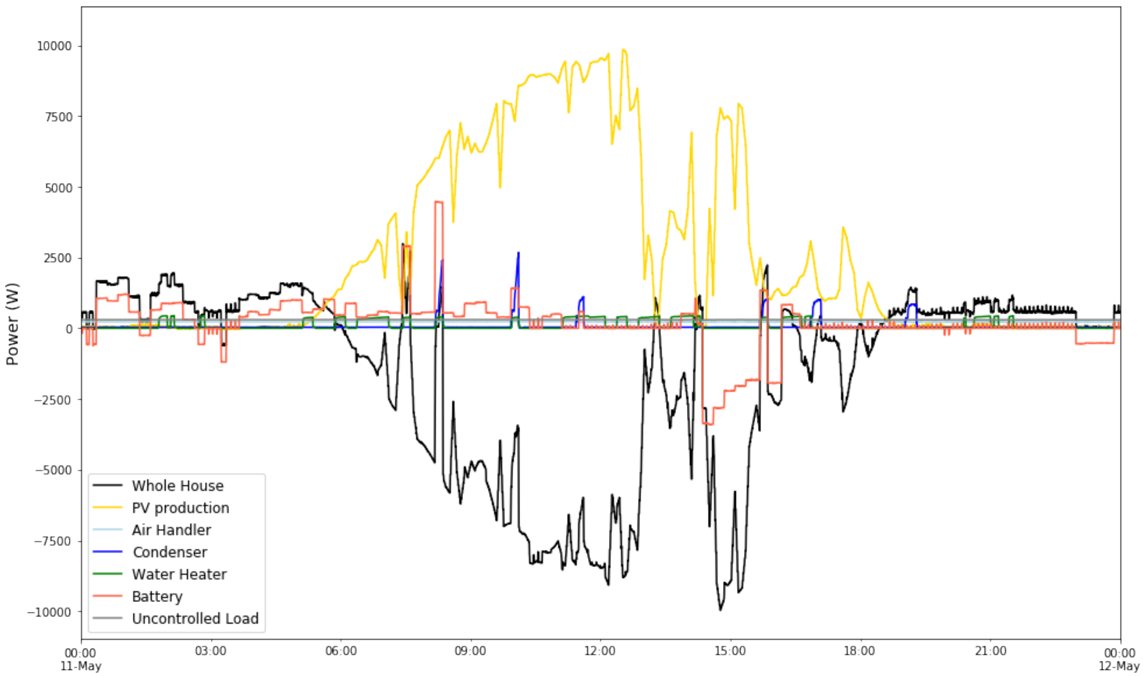
| Season | Scenario | Duration | HEMS | Aggregator | Utility Control | Home Battery |
|---|---|---|---|---|---|---|
| Shoulder | Baseline | 1 day | No | No | No | Schedule |
| Shoulder | Hierarchical Control | 1 day | Normal mode | Normal mode | Normal mode | HEMS controlled |
| Summer | Resilience: Hierarchical Control | Multi-day | Resilience mode | Resilience mode | Resilience mode | HEMS controlled |

# Hierarchical Control for Grid Reliability




**Lab home power data of the Baseline Scenario**

**This work has not been published in a peer-reviewed format.*




**Lab home power data of the Hierarchical Control Scenario**

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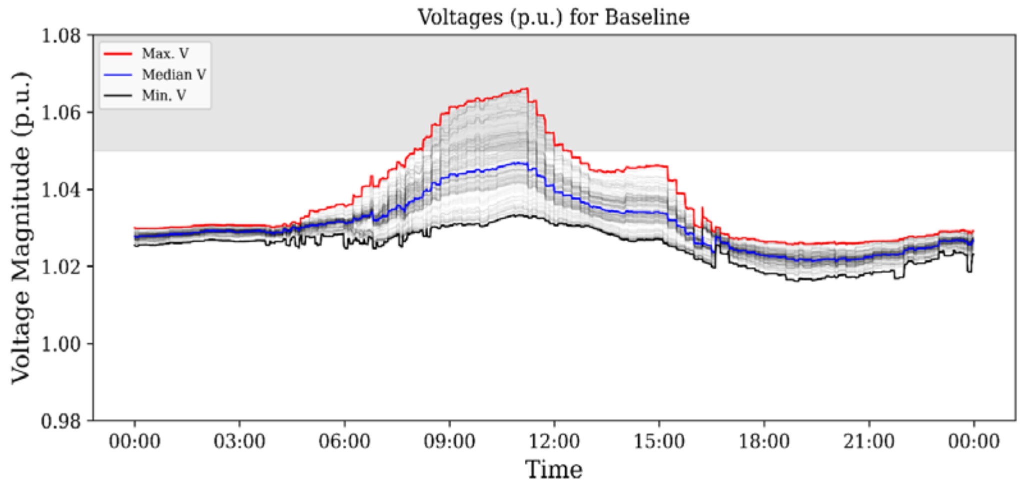
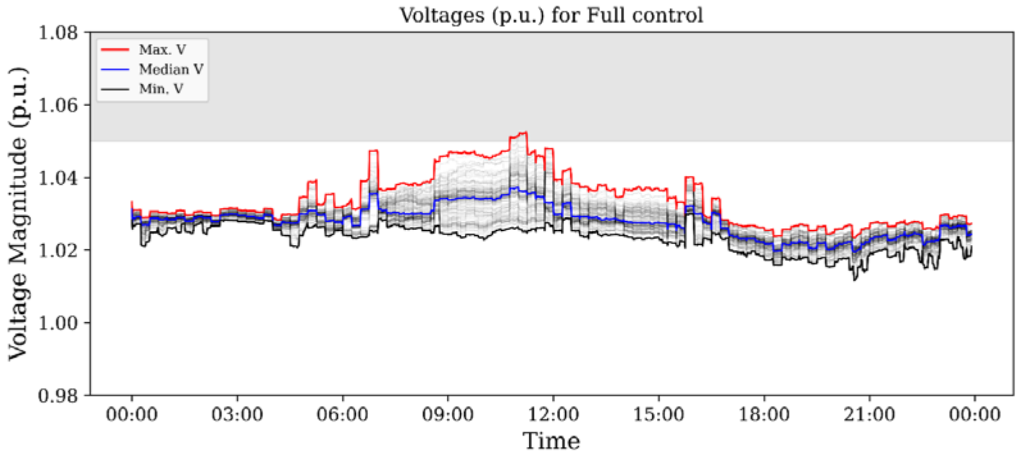
- Use case was a spring day with cool nighttime temperature, warmer daytime temperature and some variability in solar insolation.
- For Baseline Scenario, all the devices were controlled using on-board thermostatic controls or some other fixed schedule.
- For Hierarchical Control Scenario, the battery charges at low levels throughout the morning, before discharging again in the afternoon. The water heater operates in small heating cycles throughout the day. The HVAC system operates with a few heating cycles in the morning, followed up cooling cycles in the afternoon.

# Community-Level Results for Grid Reliability




**Voltage time series for homes in the community (baseline)**
**This work has not been published in a peer-reviewed format.*




**Voltage time series for homes in the community (full control)**
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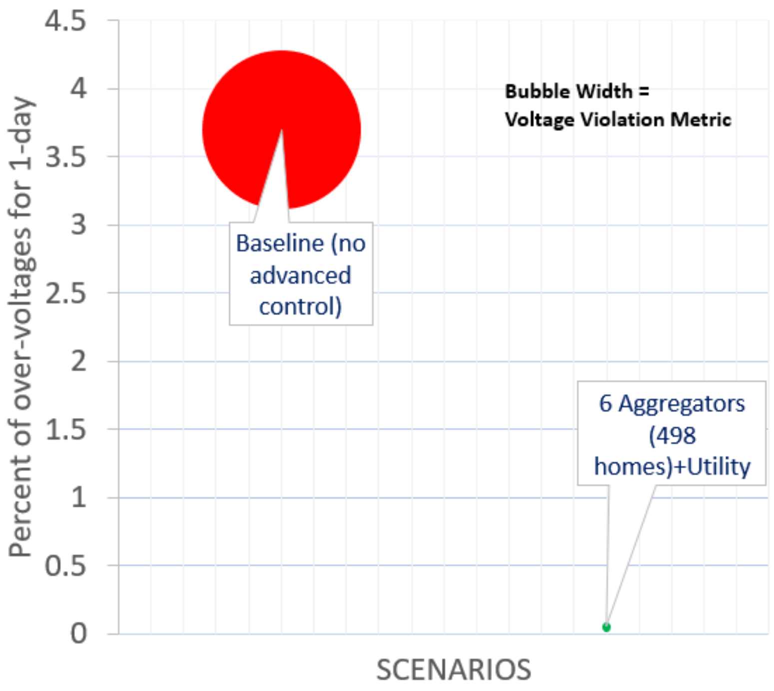


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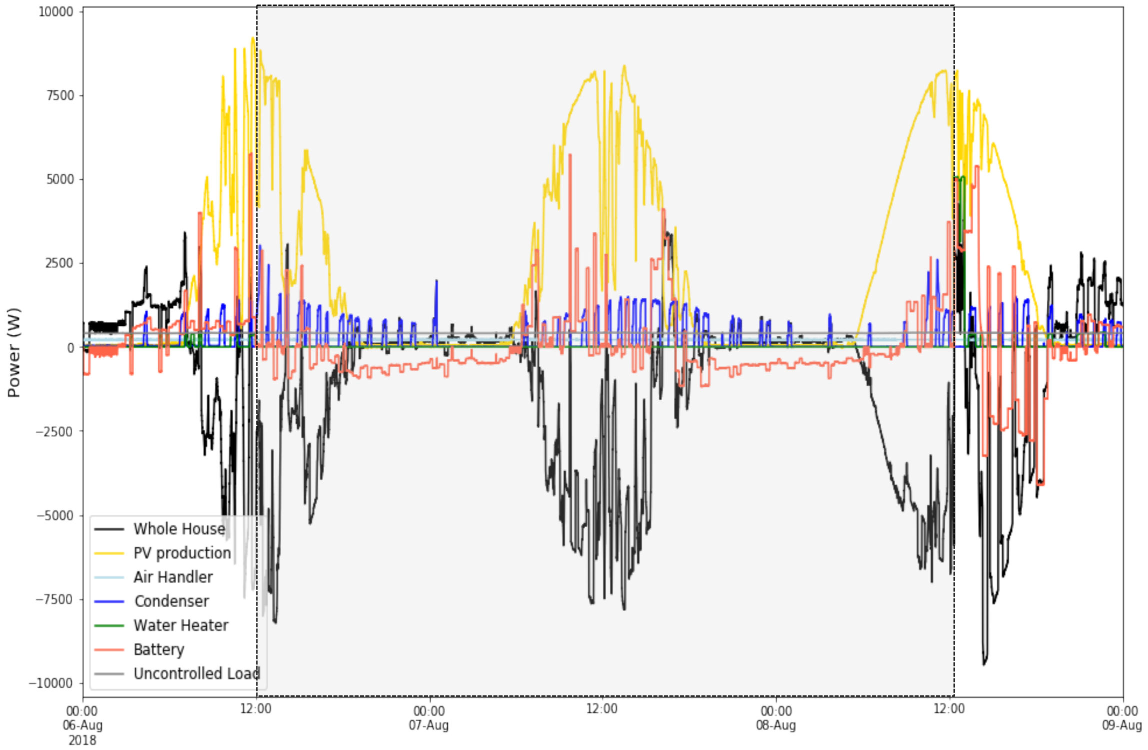
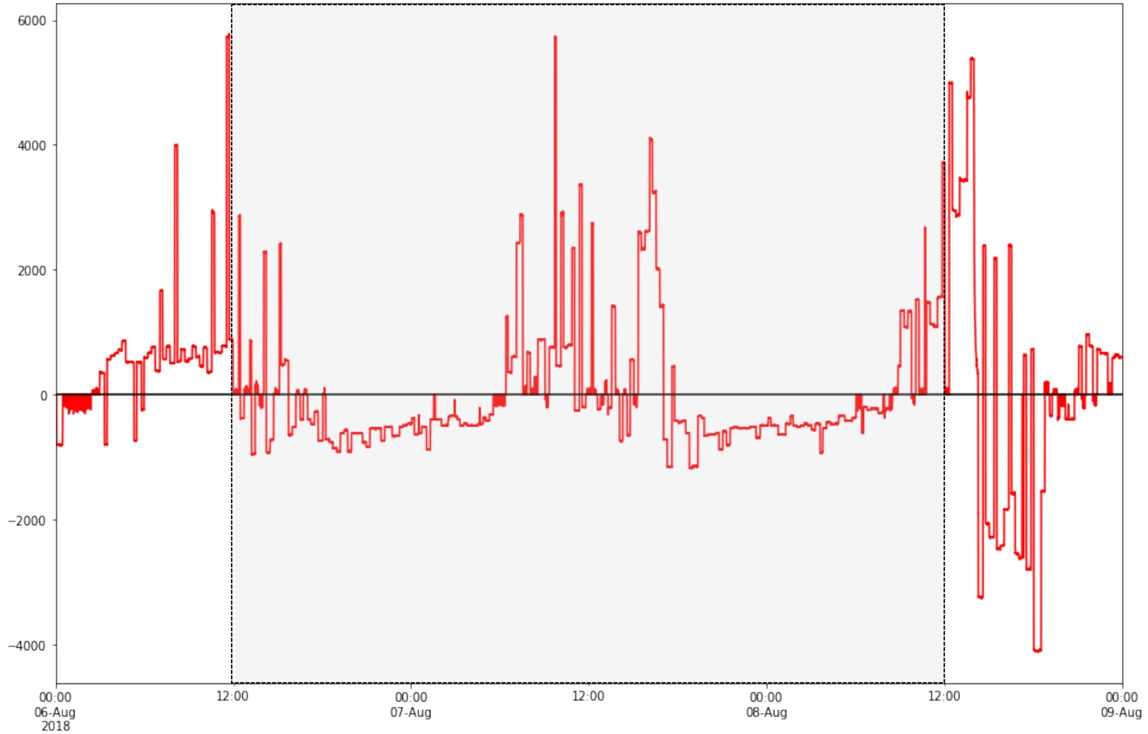
- Shoulder season was selected for HIL experiments because of the low load and high PV generation.
- The hierarchical control system significantly reduced over-voltages in the community.

# Multi-day Grid Resilience Results



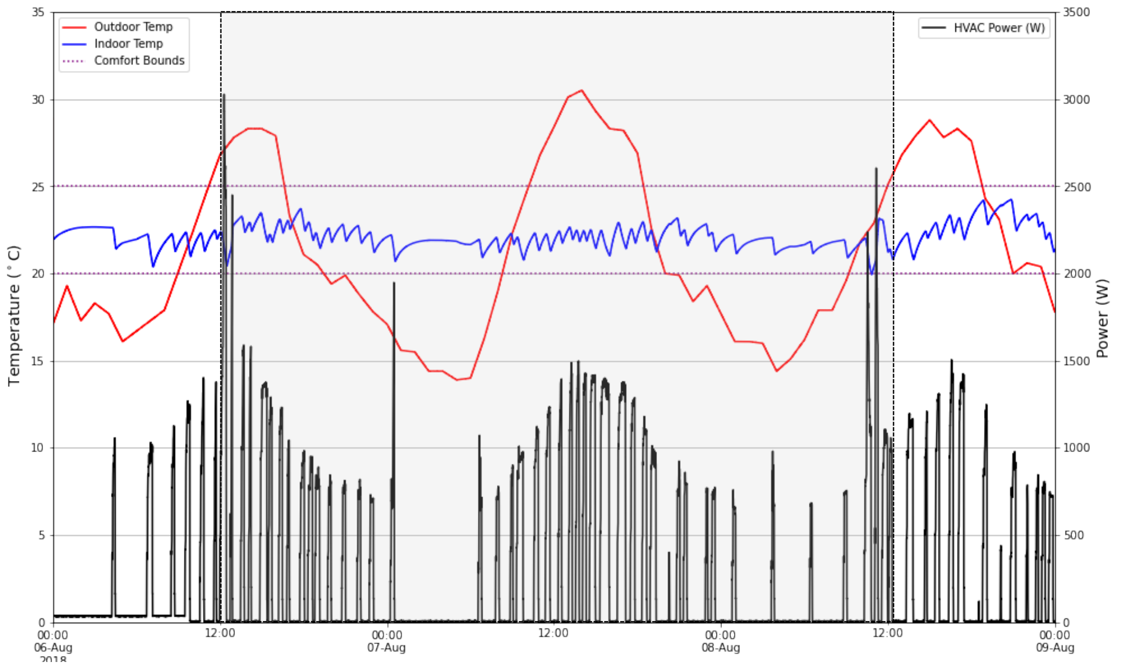

**Lab home power data of the Resilience Scenario. Normal operation for half day, followed by two days of resilience mode, and back to normal mode for half day.**
**This work has not been published in a peer-reviewed format.*




**Battery power data of the Resilience Scenario. Positive power indicates charging, negative power indicates discharging.**
**This work has not been published in a peer-reviewed format.*

- The lab home was operated by HEMS following the reference signal from the aggregator. The home exported the excess power to the grid during the day and powered the critical loads with battery during the evening to minimize power import from the grid.
- All the critical loads were supported during the resilience operation.

# Detailed Results for Lab Home Under Resilience Controls




**Resilience Controls: HVAC Power and Temperature Data**
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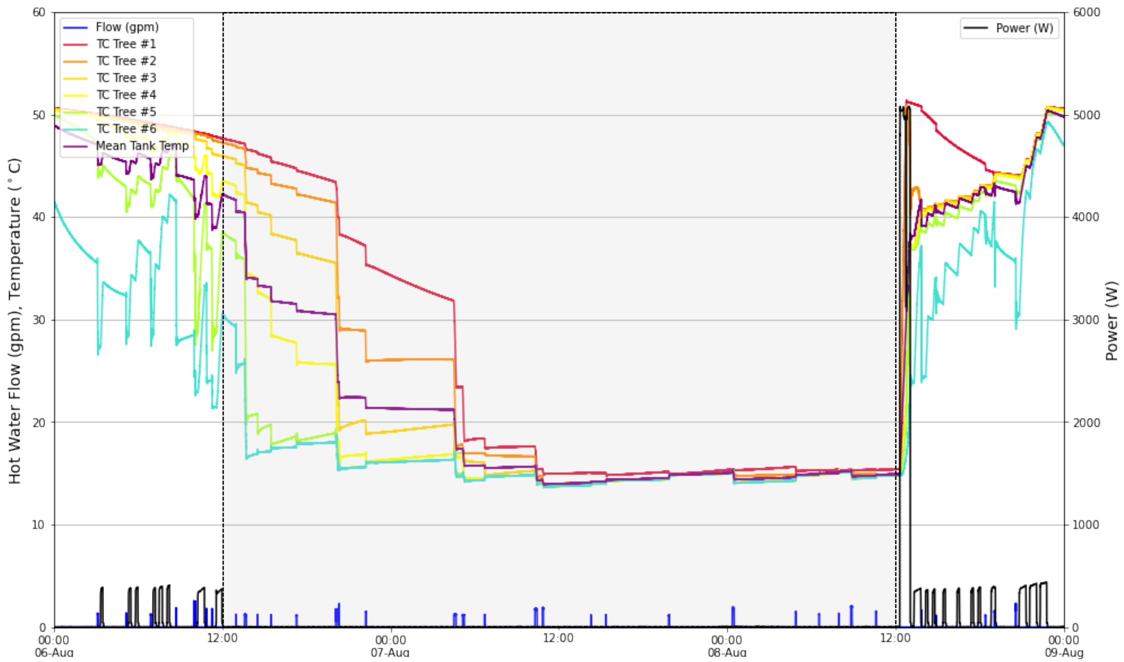


**Resilience Controls: Water Heater Power and Temperature Data**
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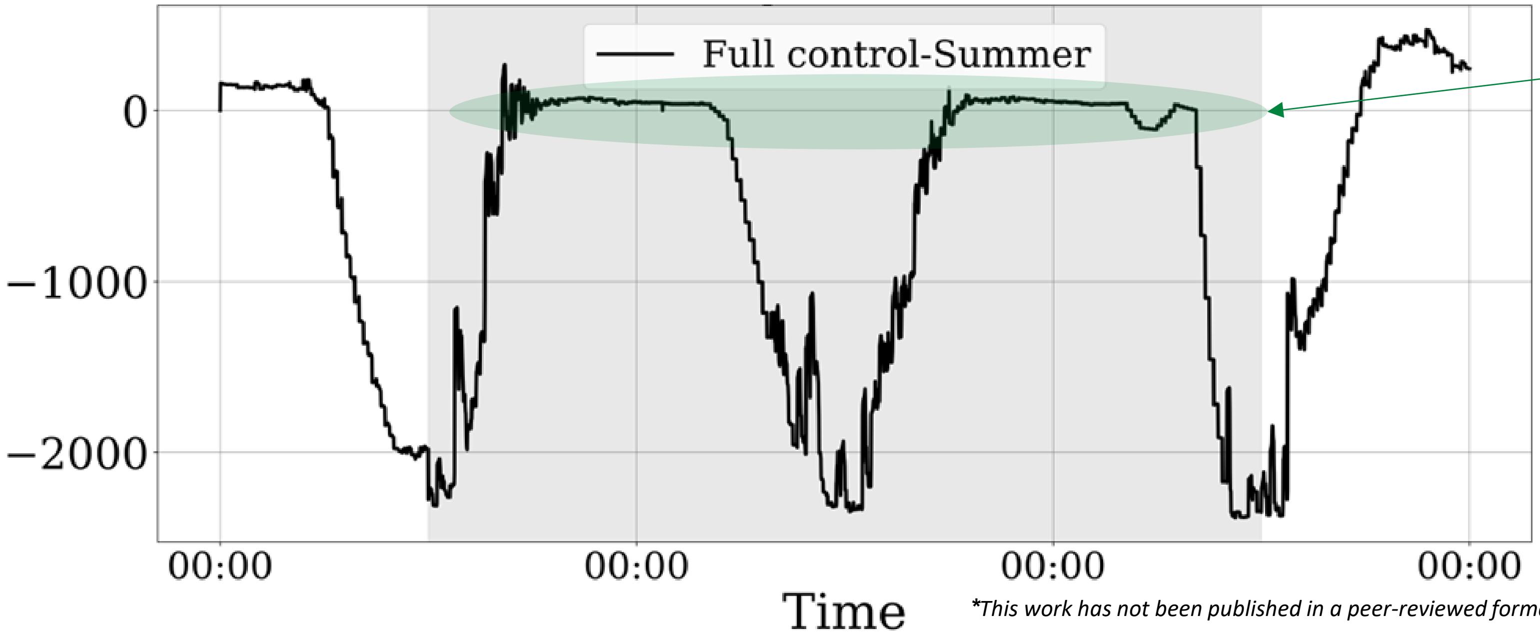
- The HVAC system was subjected to relaxed comfort band but was still allowed to operate. The indoor temperature was maintained between 20$^{o}$C and 25$^{o}$C, which was within the comfort bands.
- The water heater was not considered a critical load during the test, so it was turned off during the 2-day resilience operation. The hot water in the 50-gallon tank was depleted (too cold for showers) in the first 12 hours of resilience period (assuming no behavior change).

# Grid Resilience – Community-Level Results

## Community Homes Power (kW)




Power imported from the grid (anything above zero) was minimized during Grid Resilience Experiment

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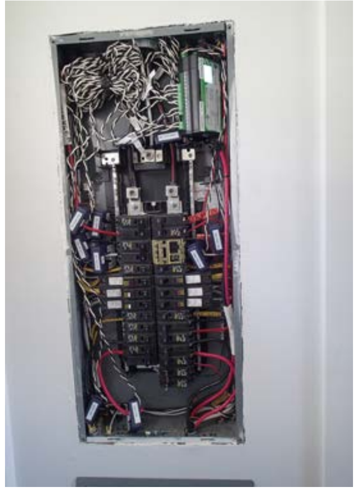
- The grid resilience case was run for a hot summer day to investigate the ability to reduce stress on the grid on days when high air conditioning loads are present.
- In the baseline scenario, the homes cannot intelligently control their HVAC systems or batteries to utilize the generated energy efficiently and to self-sustain during the emergency period
- However, in the Full control scenario, the Aggregators and HEMS controllers aim to minimize and stagger critical power requirement for the homes as much as possible by utilizing home batteries along with intelligent HVAC control

# Field Deployment at Basalt Vista


Exterior



Electrical panel with current transformers


Utility meters and Copper gateway

A.O Smith heat pump water heater


Ecobee thermostat

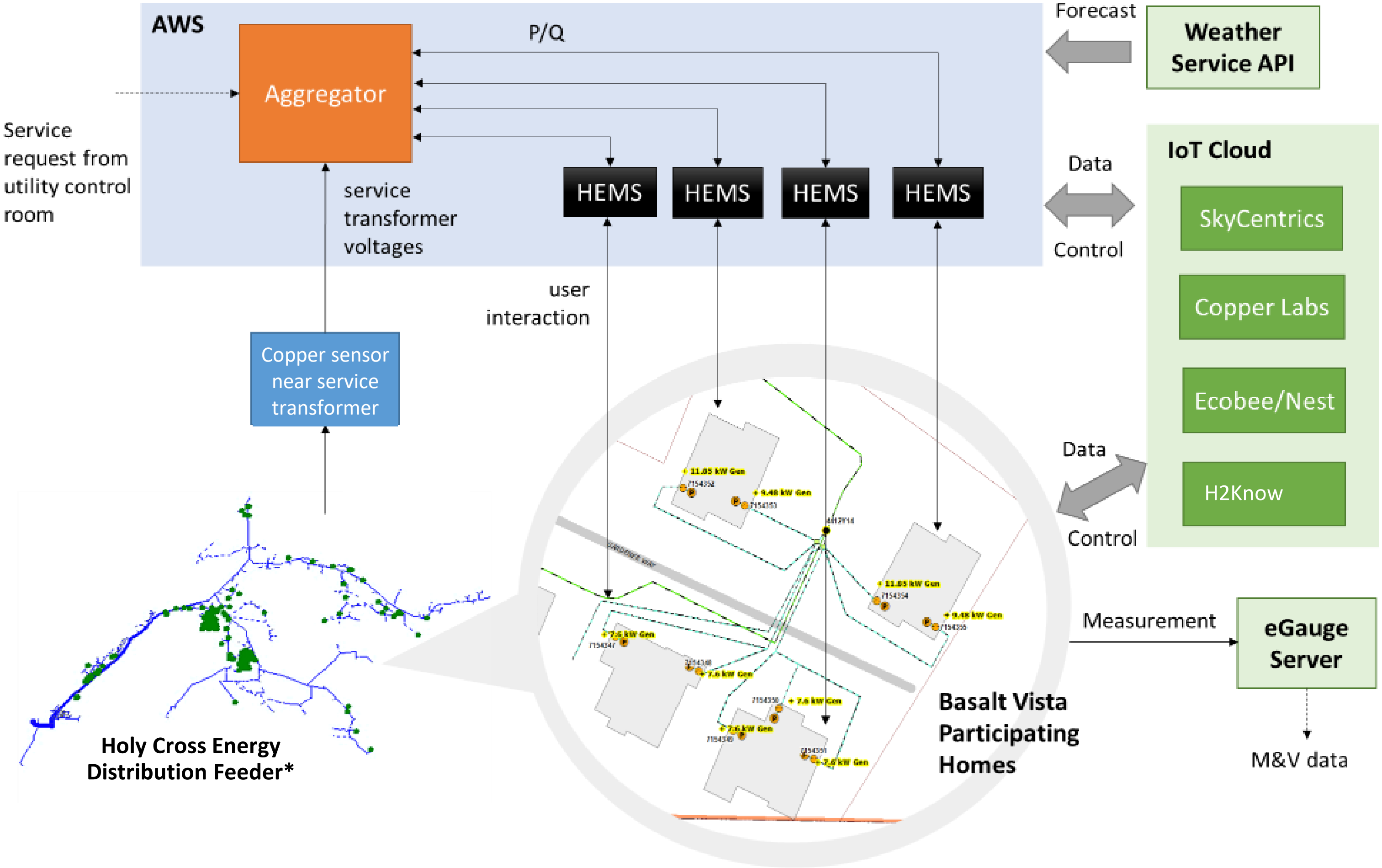

SMA Sunny Boy PV inverters

SMA Sunny Island battery inverter

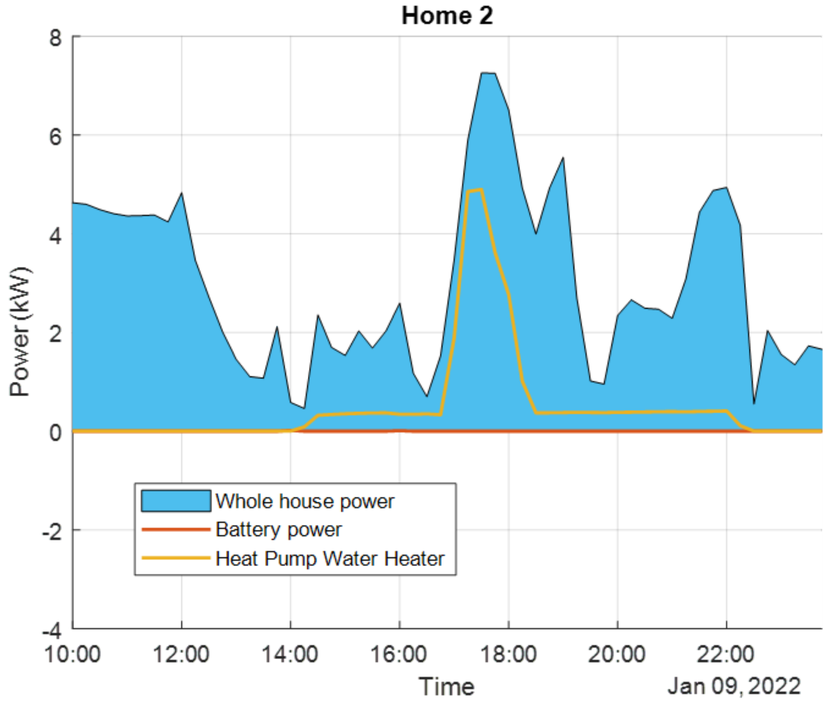

$H_2$know water flow sensor

Communication box and service transformer

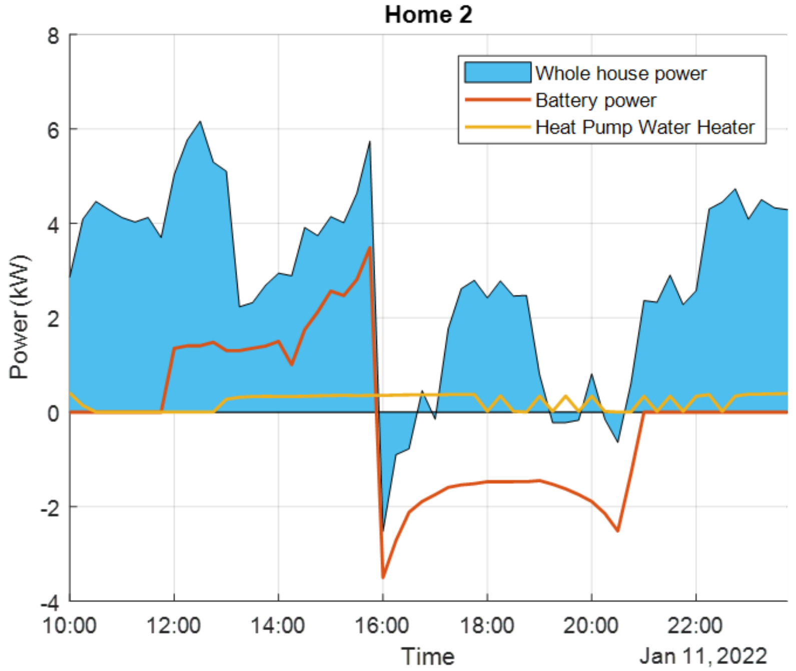
# Key Components of the Field Deployment



# Results from Field Experiments




**Baseline Winter Load Profile**




**HEMS Control Winter Load Profile**

- Experiments were implemented to demonstrate the load shifting capabilities, following Holy Cross Energy's Time-of-Use rate with 4 pm—9 pm peak period.
- An average of 3.07 kW load and 4.46 kW peak demand were reduced during the peak period.
- The home battery provided significant load reduction along with the heat pump water heater.

# Thank you!

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