AI-Driven Smart Community Control for Accelerating PV Adoption and Enhancing Grid Resilience

NREL/PR-5500-85283
Connected Communities Kickoff
November 2nd, 2022

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National Renewable Energy Lab

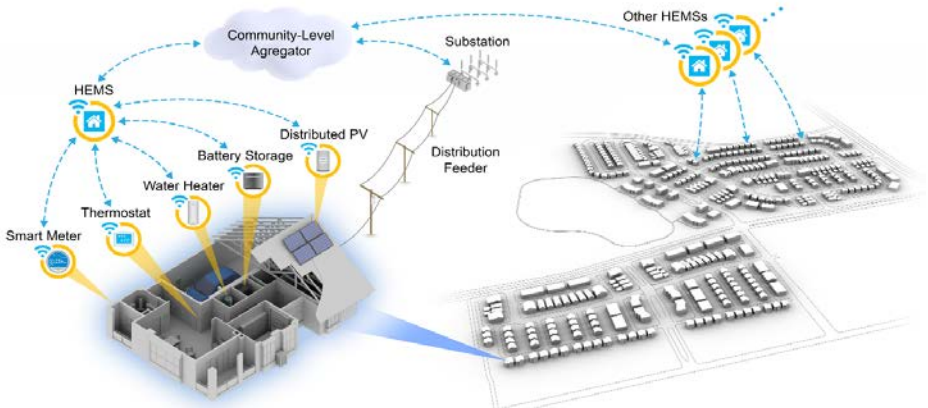
Photo credit: Anna Stonehouse
Habitat for Humanity Roaring Fork Valley

Project Overview

Challenges:

- High-penetration PV in net zero energy communities may cause grid issues.
- Existing solutions may have insufficient understanding of behind-the-meter assets or are not able to manage large-scale heterogeneous assets.
- Many municipal/rural utilities do not have resources to explore new solutions.
- Low-income families may not benefit from latest control technologies.

NREL developed a streamlined, replicable process to support connected community design and demonstrated a scalable control solution to enhance grid reliability and resilience while ensuring comfort in Colorado communities.



Technical Approach:

- Artificial Intelligence (AI)
- Home Energy Management System
- Community Aggregator

Use Cases:

- PV Self-Consumption
- Demand Flexibility
- Grid Reliability
- Grid Resilience

Motivation

- **Electric utilities**: Municipal/rural electric utilities would like to understand the benefits of integrating IoT-based technologies vs traditional, utility-owned direct load control.
- **Homeowner**: Homeowners would like to find ways to reduce utility bills while maintaining comfort and improving resiliency. Low-income families may not have knowledge of or access to those technologies.
- **Developer**: Affordable housing developers seek technical support and replicable template for building all-electric, net zero energy homes to address the affordable housing challenge and support decarbonization.
- **Equipment Manufacturer**: Manufacturers would like to support utility programs and explore integration in energy ecosystems.

Photo credit: Anna Stonehouse
https://habitatroaringfork.org/pages/basalt-vista

Team

Funding Source

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Solar Energy Technologies Office
Building Technologies Office

Project Team

NREL Transforming ENERGY

- Habitat for Humanity Roaring Fork Valley
- Holy Cross Energy
- Conservation Labs
- Copper Labs
- Thrive Home Builders
- City of Fort Collins
- A.O. Smith

Technical Advisory Group

Electric Utilities
- Duke Energy
- Xcel Energy
- Southern Company

Research Institute
- Rocky Mountain Institute
- Electric Power Research Institute

Academia
- University of Texas at San Antonio
- Colorado State University
- Penn State University
- University of Oklahoma

Technology Vendor / Manufacturer
- Itron
- Minsait Advanced Control Systems
- Leaptran
- Smarter Grid Solutions
- Quanta

Project Timeline

10/2018	Project started
12/2019	Modeling and energy efficiency design for the 498-home, net zero energy Waterfield community in Fort Collins
3/2020	The Waterfield development was delayed; identified the Basalt Vista community as the alternative field pilot site
3/2021	Hardware-in-loop laboratory experiment completed
7/2021	Recruited field pilot participants at Basalt Vista
10/2021	Field deployment completed; field demonstration started
4/2022	Project ended, equipment decommissioning

Efficiency Reduces Energy Bills and Peak Demand

Single-family detached

Cottage

Two-story townhomes

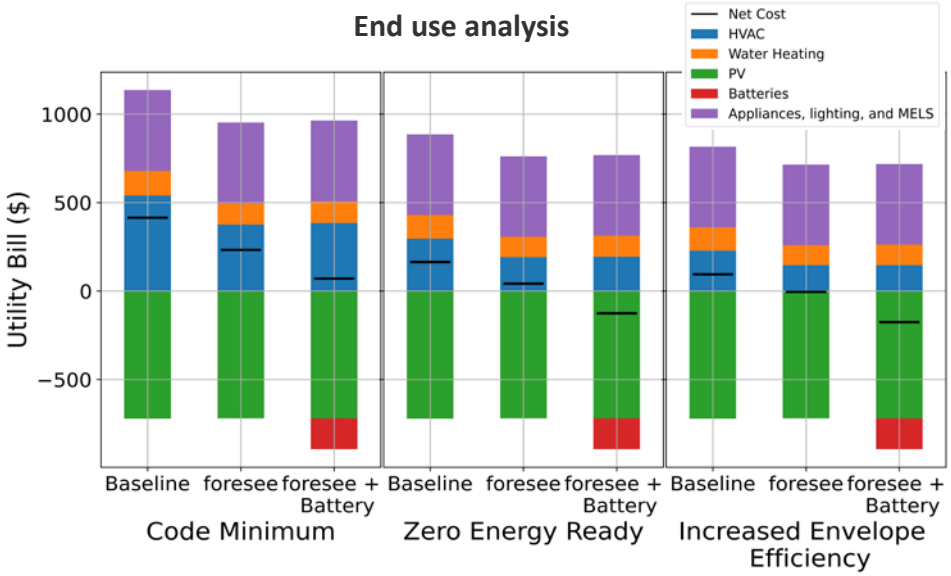
Three-story townhomes

Duplex

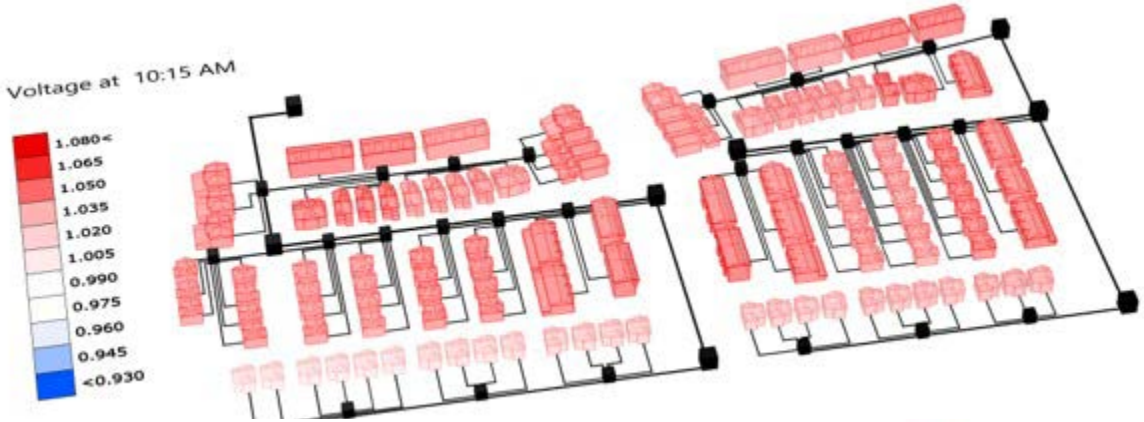
Physics-based modeling and optimization in BEopt generate cost-optimal energy efficiency measures for various building types. It also informs the control-oriented models for enabling large-scale building-to-grid co-simulation.

Munankarmi et al. "Community-scale interaction of energy efficiency and dema flexibility in residential buildings". **Applied Energy**. Vol 298. Sep 2021, 117149.

- Efficiency upgrades can save 58% energy savings or $312/year utility bill savings on HVAC.
- Adding HEMS + battery increases savings to $590/year.
- Higher efficiency home has lower peak power.
- HEMS+battery further reduces peak load under TOU rate structure by energy arbitrage.

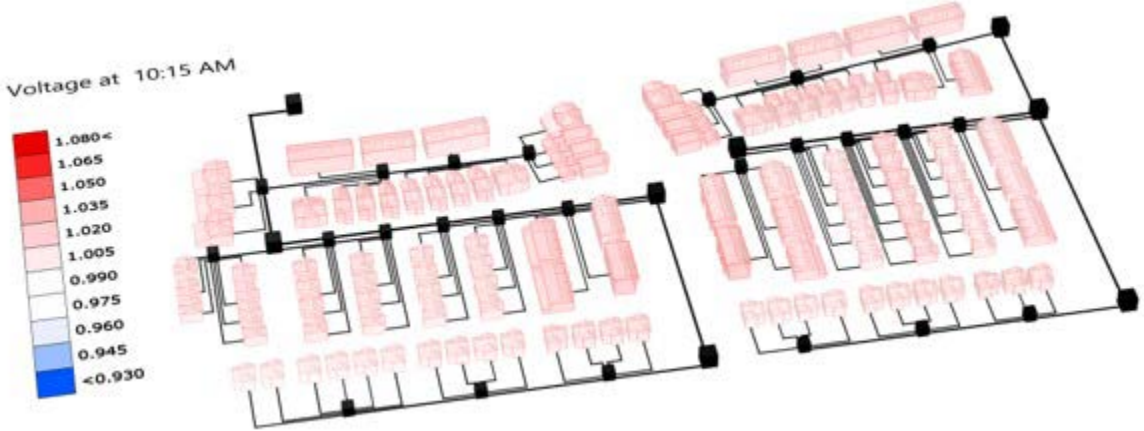


PV Self-consumption Mitigates Overvoltage Issues



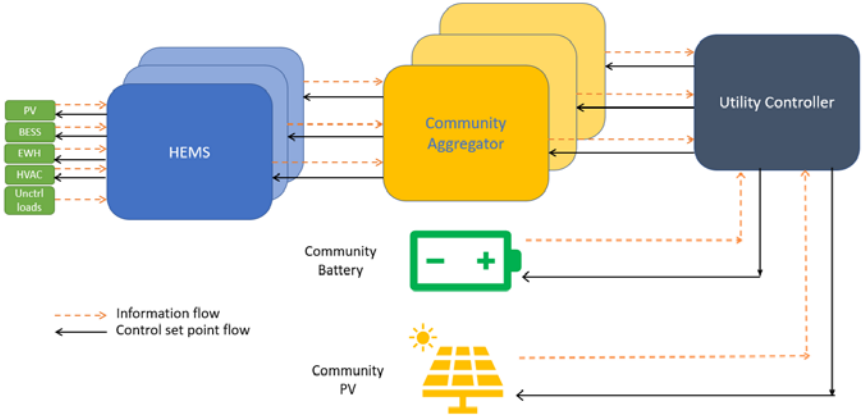
No HEMS or Battery

15-minute interval voltage result from 10 am to 2 pm on a day in the shoulder season



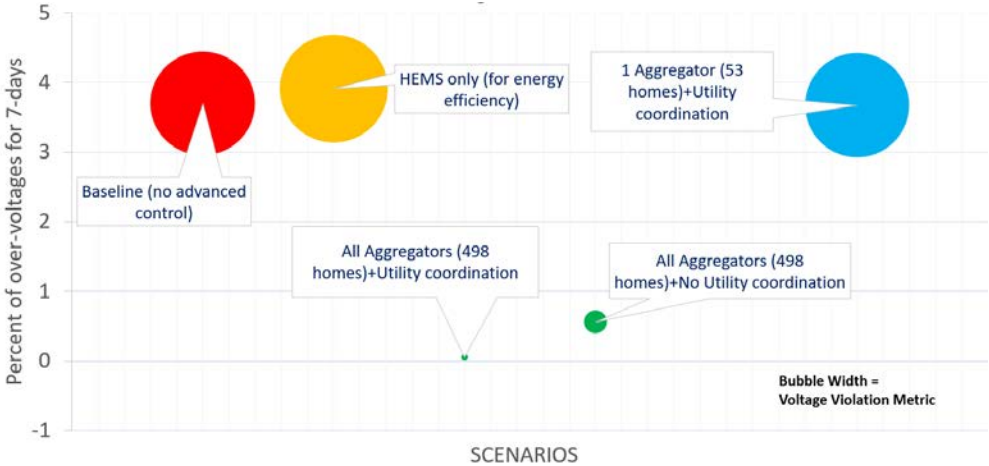
HEMS + Battery (PV self-consumption)

Hierarchical Control Improves Grid Reliability



Modular, hierarchical controller design ensures control performance and scalability to large-scale applications.

Hierarchical control effectively mitigates the overvoltage issues in the net zero energy community with high PV penetration.

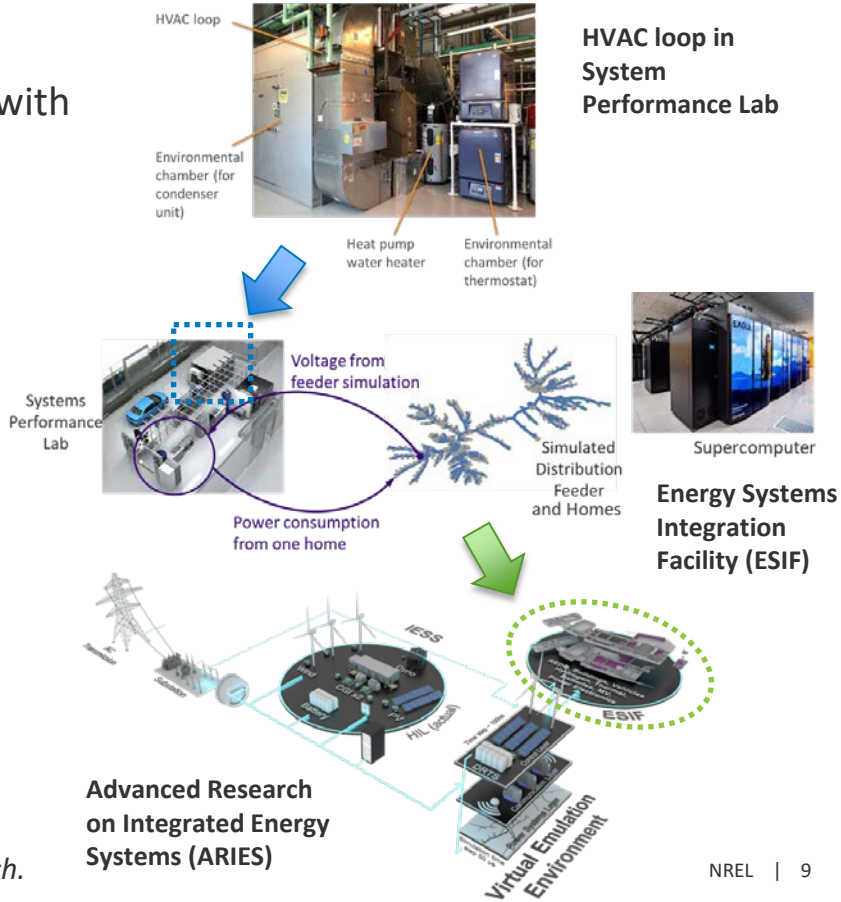


Hardware-in-Loop Experiments Derisk Field Deployment

Equipment in the loop: Physical equipment in the lab home verifies control performance at the device level with emulated ambient conditions and load profiles.

Smart home in the loop: Control physical devices in a lab home, interact with the emulated community and distribution feeder hosted on the supercomputer, update lab home's voltage from feeder simulation.

Communities in the loop*: *NREL's ARIES research platform supports coordinated control of physical and emulated equipment in ESIF (up to 2MW) with utility-scale assets at NREL's Flatiron campus.*



** Not used in our project. Available to support Connected Communities research.*

Live Learning Lab

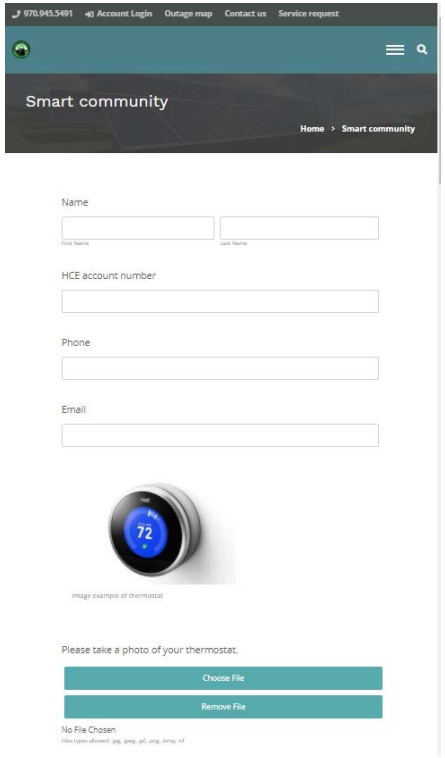
Basalt Vista Affordable Housing Partnership

- Holy Cross Energy, Habitat for Humanity, Pitkin County, Basalt School District
- 27 homes for teachers and local workforces.
- 4 selected for field deployment
- Designed to all-electric, zero net energy homes
- Adjacent to Basalt High School

Photo credit: Holy Cross Energy

Field Pilot Participant Recruitment

Recruitment flyer

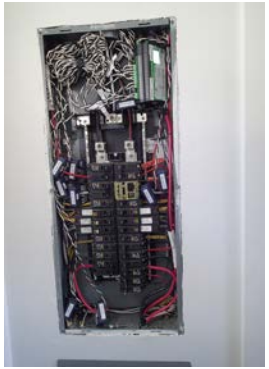


Sign-up webpage

- NREL worked closely with Habitat for Humanity and Holy Cross Energy to recruit field pilot participants.
- NREL presented the field deployment plan at the Basalt Vista HOA Board meeting in June 2021, and the recording was shared with homeowners on YouTube.
- The Habitat staff met with homeowners in person and sent out reminder emails to encourage them to sign up.
- Holy Cross Energy received six applications, and four submitted final written confirmation.

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

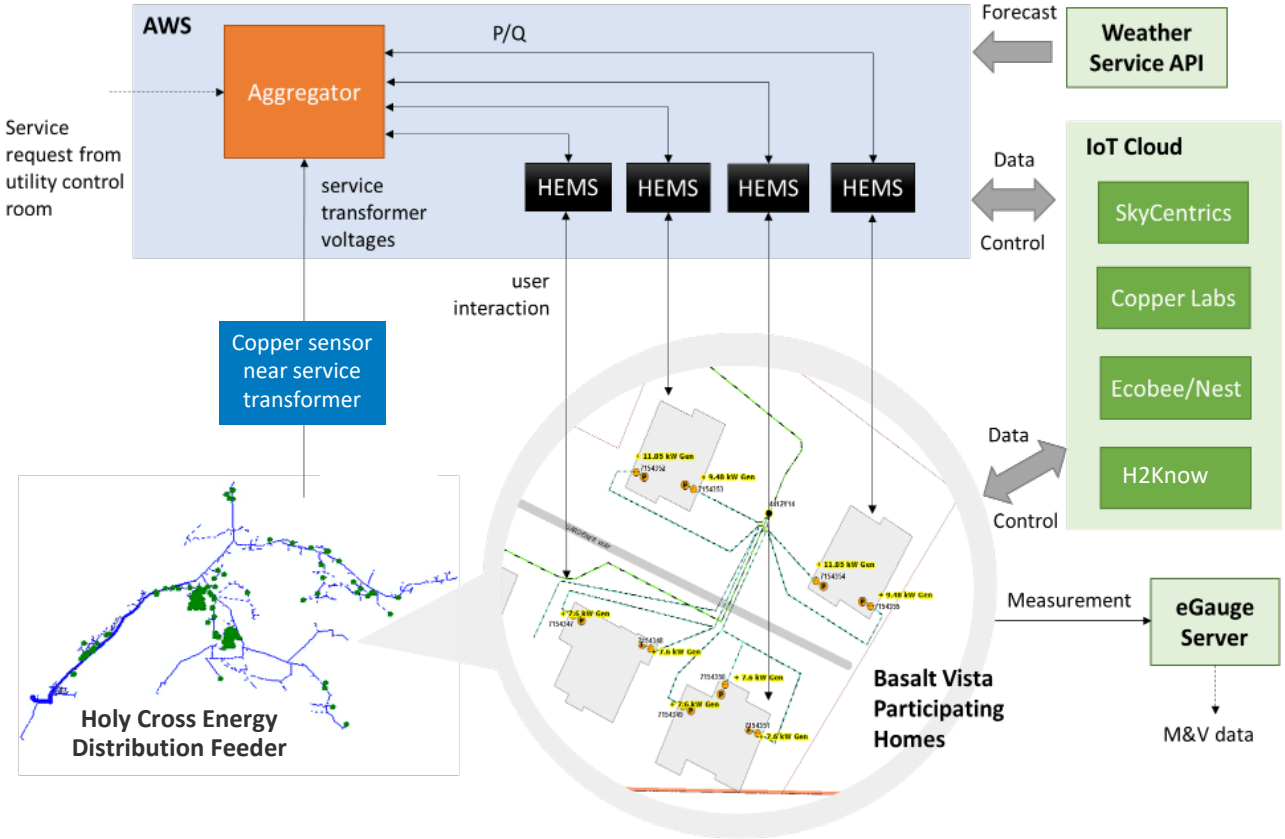
SMA Sunny Boy PV inverters

SMA Sunny Island battery inverter

H_2know water flow sensor

Communication box and service transformer

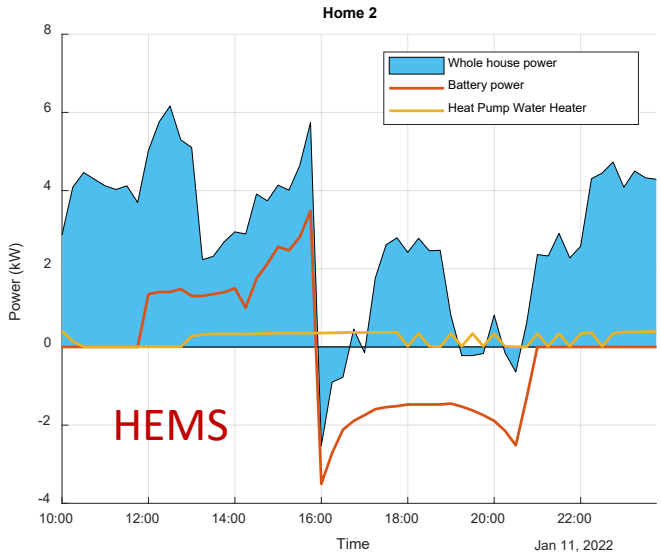
Cloud-based Control for the Field Pilot Study

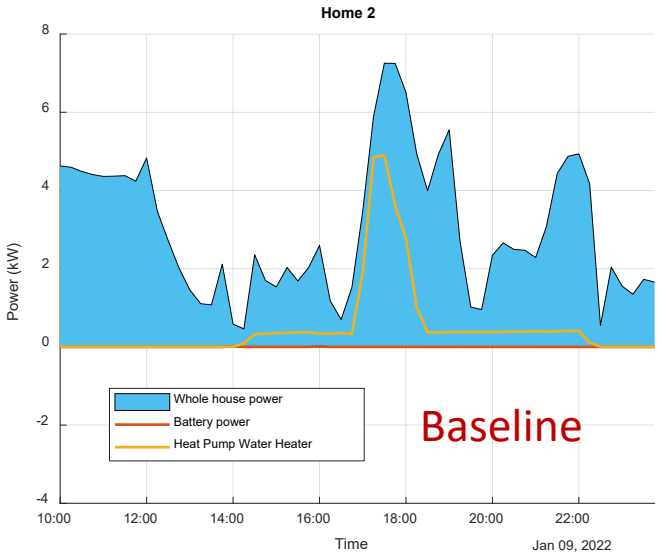


Homeowner-facing User Interface

- A homeowner-facing user interface allowed homeowners to monitor the home status and control certain devices.
- Homeowners can access the web-based user interface on https://foresee.nrel.gov/ with their log in credentials.
- Homeowners were able to override the control or temporarily disable the HEMS, but no override or disable events were recorded during the field deployment.

Field Experiments – Load and Peak Demand Reduction





- A series of field experiments were implemented to demonstrate the PV self consumption, load shifting, and coordinated control capabilities.
- Holy Cross Energy's time-of-use rate with 4 pm–9 pm peak period was used in the experiment.
- A 3.1 kW average load reduction and 4.5 kW peak demand reduction were achieved during the 5-hour peak period.
- The home battery provided significant load reduction along with the heat pump water heater.

Lessons Learned

1. Community partnership is key to successful recruitment
   - Utility/developer-led initiative is more effective in recruiting participant
   - Contractual obligation guarantees better participation rate than volunteer-based participation
2. Dedicated personnel with site access is crucial for fixing unexpected issues
   - Certain issues were difficult for the engineering team to resolve remotely
   - Local staff with site access is crucial for debugging and fixing those issues
3. A reconnaissance trip would help derisk the field deployment
   - A reconnaissance trip would help identify difficulties in retrofitting the minisplit thermostat
   - Future projects should plan such trips if budget/schedule allows for derisking field deployment
4. Early engagement in community design and instrumentation simplifies deployment
   - Early engagement provides better understanding of the home design and equipment
   - Instrumentation during construction can also reduce the measurement & verification costs

Lessons Learned

5. Homeowner's internet was reliable for cloud communication most of the time
   - Hardwired connection is the most reliable solution if available.
   - Homeowner's internet was very reliable, and we didn't need to use backup cellular modems.
6. Anticipate the need for occasional power cycling – smart plugs can help
   - Field equipment may occasionally freeze and need power cycling to reset.
   - Smart plugs are a cost-effective alternative to reaching out to homeowner or field crew for help
7. Snow covering on the solar panels greatly affects the PV generation
   - Snow covering made PV panels in some homes not able to generate for weeks after snowfalls.
   - Future projects should consider more steep roof pitches or find ways to remove snow promptly.
8. Tradeoff between grid control and homeowner satisfaction
   - Delivering grid services and minimizing thermal discomfort are conflicting objectives.
   - Future projects should develop better understanding of occupant's preference on thermal discomfort and explore larger setpoint change if the occupants are willing to save on utility bills/reduce carbon footprint at the cost of thermal comfort.

Achievements

Journal Articles

1. El Kontar, R., & Jin, X. (2020). A framework for optimal placement of rooftop photovoltaic: Maximizing solar production and operational cost savings in residential communities. ***ASME Journal of Engineering for Sustainable Buildings and Cities***, *1*(4), pg. 041006.
2. Blonsky, M., Maguire, J., McKenna, K., Cutler, D., Balamurugan, S. P., & Jin, X. (2021). OCHRE: The Object-Oriented, Controllable, High-Resolution Residential Energy Model for Dynamic Integration Studies. ***Applied Energy***, *290*, 116732.
3. Munankarmi, P., Maguire, J., Balamurugan, S. P., Blonsky, M., Roberts, D., & Jin, X. (2021). Community-scale interaction of energy efficiency and demand flexibility in residential buildings. ***Applied Energy***, *298*, 117149.
4. Utkarsh, K., Ding, F., Jin, X., Blonsky, M., Padullaparti, H., & Balamurugan, S. P. (2021). A Network-Aware Distributed Energy Resource Aggregation Framework for Flexible, Cost-Optimal, and Resilient Operation. ***IEEE Transactions on Smart Grid***.
5. Wang, J., Munankarmi, P., Maguire, J., Shi, C., Zuo, W., Roberts, D., & Jin, X. (2022). Carbon emission responsive building control: A case study with an all-electric residential community in a cold climate. ***Applied Energy***, *314*, 118910.

Conference Papers

1. El Kontar, R., Maguire, J. B., Chen, J., & Jin, X. (2019). ”Seminar 13-Advanced Methods for Grid Integration of High-Performance Residential Communities”. ***2019 ASHRAE Building Performance Analysis Conference***. Available as NREL Tech. Report No. NREL/PR-5500-74946.
2. Park, J. Y., Chen, J., Jin, X., & Nagy, Z. (2019). Investigating occupancy profiles using convolutional neural networks. In ***Proceedings of the 6th ACM International Conference on Systems for Energy-Efficient Buildings, Cities, and Transportation*** (pp. 338-339).
3. Utkarsh, K., Ding, F., Zhao, C., Padullaparti, H., & Jin, X. (2020, February). A model-predictive hierarchical-control framework for aggregating residential DERs to provide grid regulation services. In ***2020 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT).***
4. Munankarmi, P., Jin, X., Ding, F., & Zhao, C., “Quantification of Load Flexibility in Residential Buildings Using Home Energy Management Systems”, In ***Proceedings of the 2020 American Control Conference***, pp. 1311-1316.
5. El Kontar, R., & Jin, X. (2020, October). Optimal efficiency and operational cost savings: A framework for automated rooftop PV placement. In ***Proceedings of 2020 Building Performance Analysis Conference and SimBuild****, ASHRAE and IBPSA-USA*.
6. Pattawi, K., Munankarmi, P., Blonsky, M., Maguire, J., Balamurugan, S. P., Jin, X., & Lee, H. (2021, June). Sensitivity Analysis of Occupant Preferences on Energy Usage in Residential Buildings. In ***15th International Conference on Energy Sustainability*** (Vol. 84881, p. V001T08A004). American Society of Mechanical Engineers.

Achievements

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To
Kaleb Pattawi

FOR THE OUTSTANDING PAPER TITLED
"Sensitivity Analysis of Occupant Preferences on Energy Usage in Residential Buildings"

Presented at the
15th INTERNATIONAL CONFERENCE
ON ENERGY SUSTAINABILITY
JUNE 16-18, 2021

Award

- Best Technical Presentation Award**,** 15th International Conference on Energy Sustainablility (ES 2021), June 2021.

News Release/Media Report

- Colorado Mountain Homes Prepare To Pilot Autonomous Energy Management, NREL News, Nov 1, 2021.
- NREL to evaluate AI energy management system for solar microgrid, PV Magazine, Nov 11, 2021.
- NREL pilots new AI-enabled Smart Community concept in Colorado, Smart Energy International, Nov 4, 2021.
- Virtual Power Plants And The Future Ubiquity Of Energy Creation, Forbes, Nov 24, 2020.

Technology Transition

- A cooperative research and development agreement (CRADA) with an electrical panel manufacturer
- A technical service agreement (TSA) with a major utility company for designing a new residential community
- Two software records: opensource software for control-oriented buliding energy modeling (OCHRE™) and co-simulation framework for community-scale building grid integration
- Active discussions with equipment manufacturers and technology vendors to license and commercialize the home energy management software (foresee™)
- Continued working with Habitat to address the unique challenges in multifamily housing

Thank You

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