Object-Oriented Controllable High-Resolution Residential Energy (OCHRE™) Model

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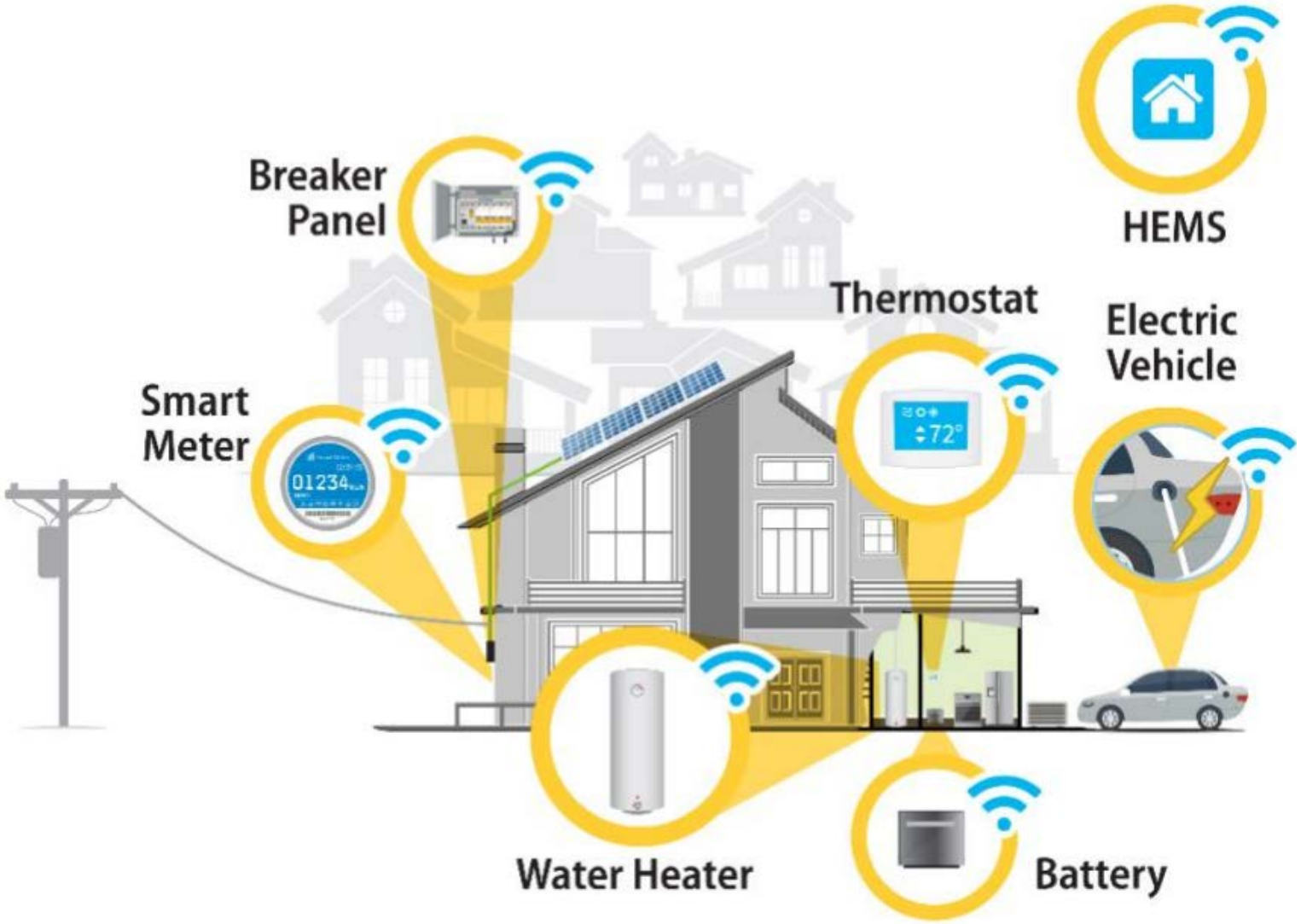
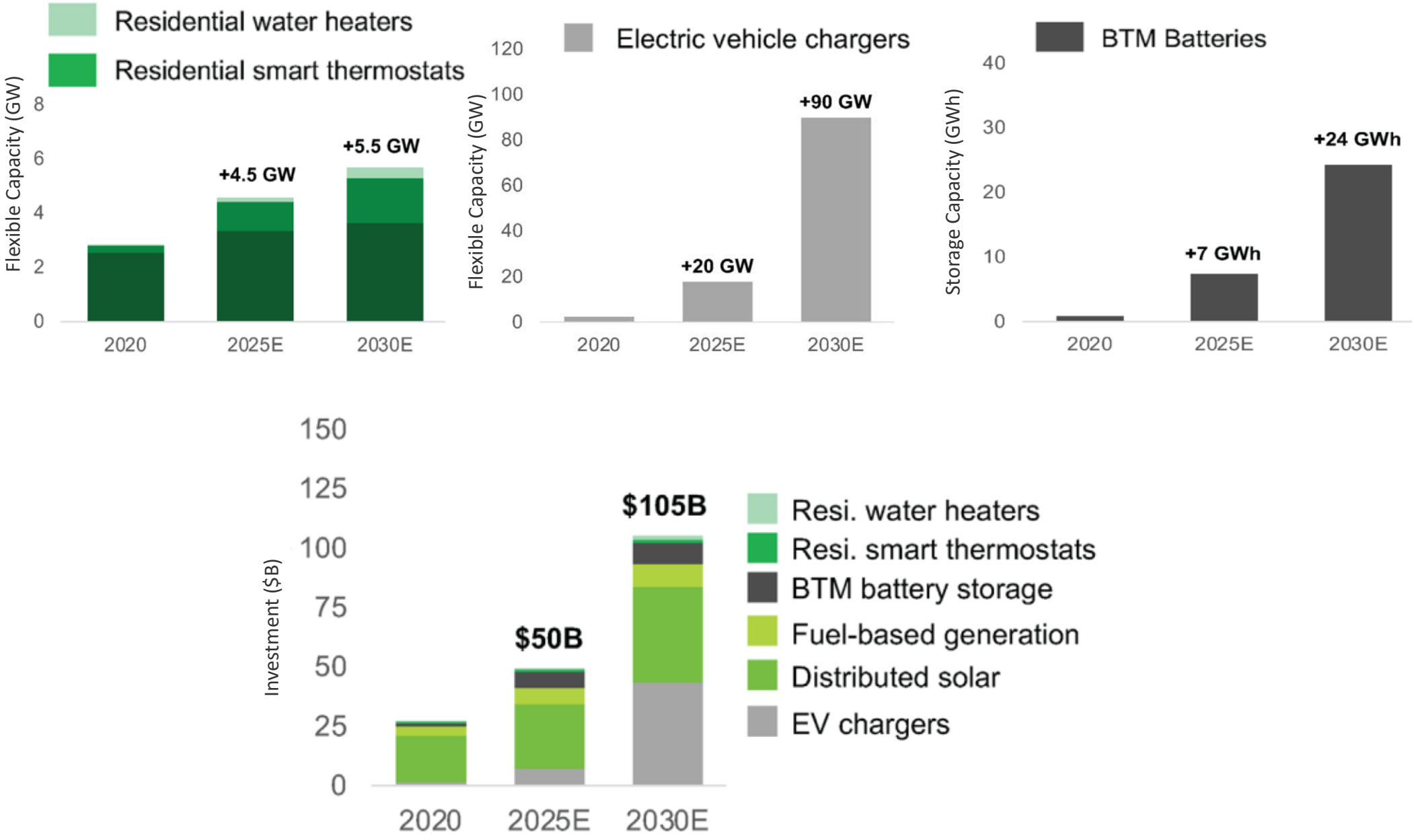
National Renewable Energy Laboratory
Nov. 12, 2024

Home energy use is becoming more controllable and flexible.

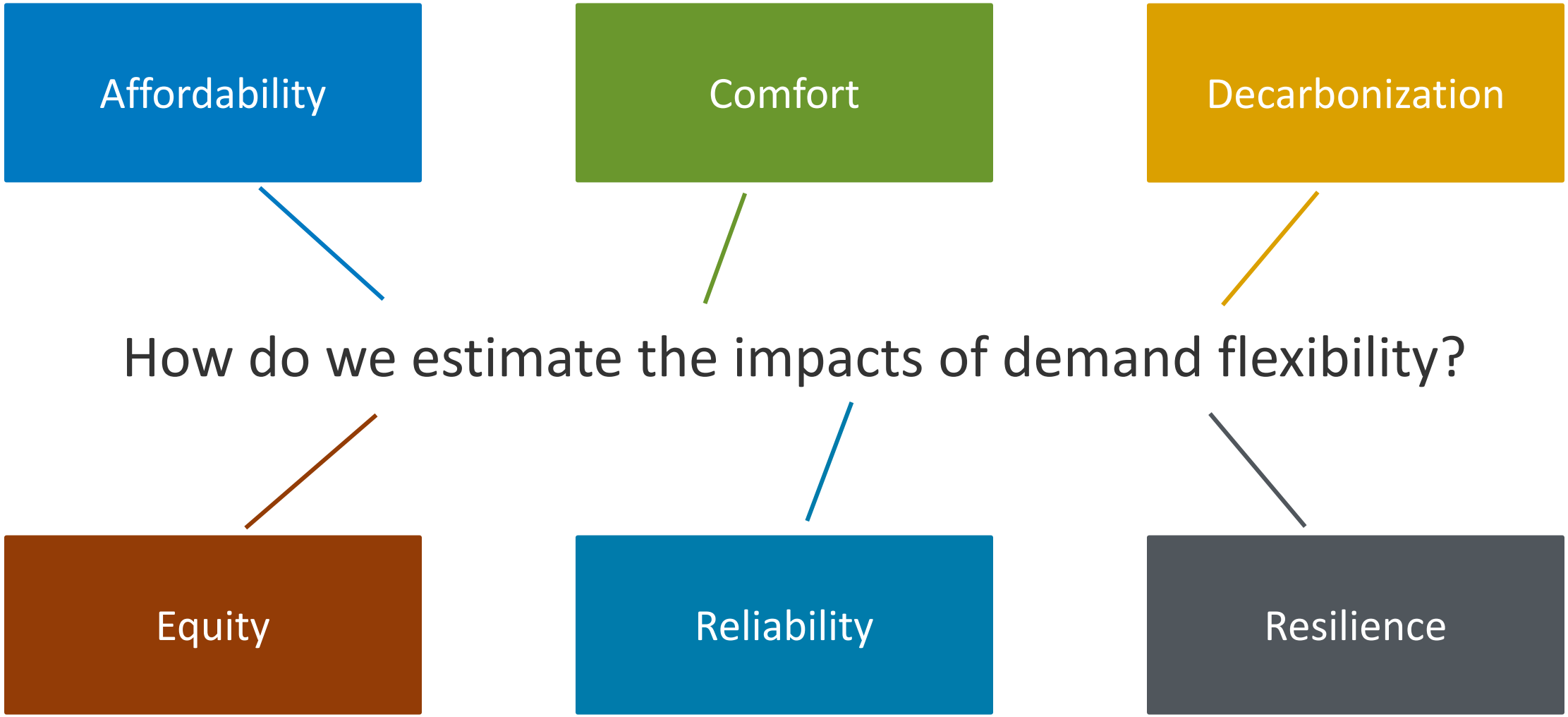


HEMS = Home Energy Management Systems
Image from Sparn and Werling (2021): https://www.osti.gov/servlets/purl/1810537

Significant growth in available flexibility is expected across many residential technologies.



BTM = Behind-the-meter, EV = Electric Vehicle
Images from Downing et al. (2023) https://liftoff.energy.gov/wp-content/uploads/2023/09/20230911-Pathways-to-Commercial-Liftoff-Virtual-Power-Plants_update.pdf


Affordability
Comfort
Decarbonization
How do we estimate the impacts of demand flexibility?
Equity
Reliability
Resilience

Bridge Between **Buildings/Vehicles Tools** and **Grid** Tools

Building/Vehicles Tools

- ✓ Customer impacts
- ✓ Load diversity
- ✓ Accurate modeling.

Grid Tools

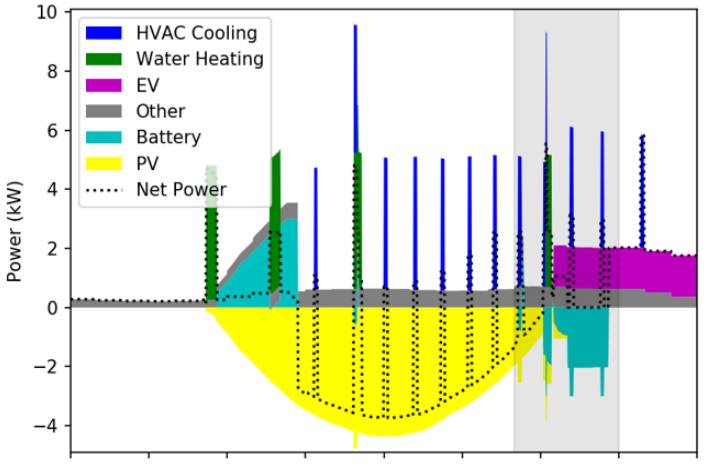
- ✓ Dynamic controls
- ✓ System integration
- ✓ Resilience and reliability.

OCHRE Capabilities

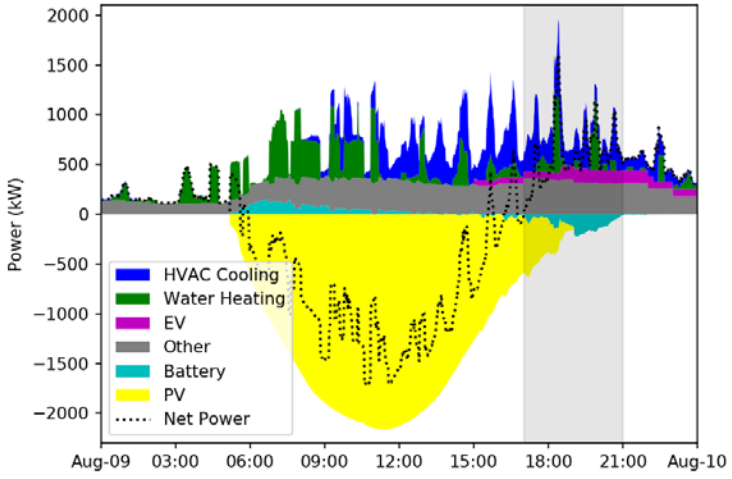
What Is OCHRE?

- The **O**bject-oriented **C**ontrollable **H**igh-resolution **R**esidential **E**nergy model:
  - Enables **flexibility** for heating, ventilating, air-conditioning (HVAC); water heating, EVs, photovoltaics (PV), and batteries
  - Measures occupant **comfort** and **resilience**
  - Scales from single device to **community-scale analysis**
  - **Integrates in co-simulation** with controllers, HEMS, and distribution grid models.

Single Building



Multiple Buildings



Images from Blonsky et al. (2021) https://www.sciencedirect.com/science/article/pii/S0306261921002464

OCHRE Simulation Workflow

Building and Occupant Characteristics

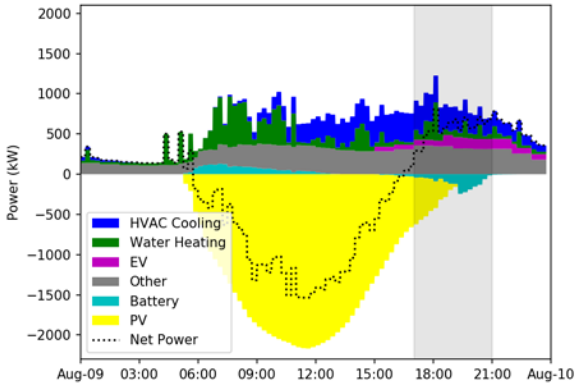
Weather Data

OCHRE

DER and Flexible Load Controller

Distribution Grid Model

Load Profiles



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Occupant Comfort and Resilience Metrics

Images from Sengupta et al. (2019) https://www.nrel.gov/docs/fy19osti/73667.pdf
and Blonsky et al. (2021) https://www.sciencedirect.com/science/article/pii/S0306261921002464

OCHRE Integrates With Many Datasets and Tools

Model Inputs

ResStock

BEopt Building Energy Optimization

EVI-Pro

OCHRE

Integrations

REopt

GridAPPS-D

foresee™

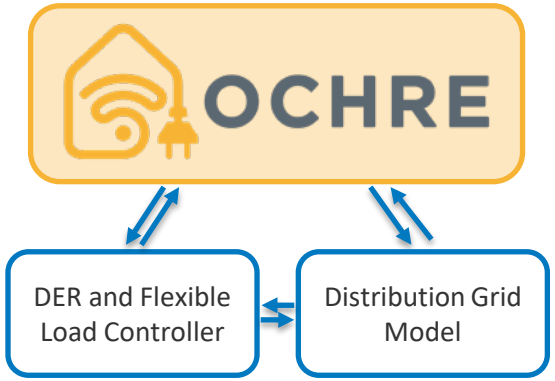
DSS

DER controllers and aggregators

- Home Performance XML (HPXML) for building properties
- Many weather formats
- Device-specific data and tools.

- Co-simulation frameworks
- Device controllers
- Grid models
- Planning tools.

OCHRE Control and Communication



End Uses	Control Options (inputs to OCHRE)	Status Variables (outputs from OCHRE)
HVAC Water Heating	• Thermostat setpoint • Duty cycle • Direct load control • Disabling high speeds (for 2-speed HVAC).	• Indoor temperature and humidity • Hot water draws and outlet temperature • Ambient conditions • Device capacity and efficiency.
Electric Vehicle Battery PV	• Real and reactive power setpoints • Battery modes: daily schedule, self-consumption, target net load • Delayed charge for EV.	• State of charge • Power constraints • Battery degradation • EV parking status.
Other Loads	• Direct load control.	• Power consumption.
Grid/Whole Home	• Islanded mode • Grid voltage (impacts real and reactive power of some loads).	• Whole home power (real, reactive, and natural gas power).

OCHRE Building Envelope

- Detailed, dynamically generated envelope model
  - Up to 4 zones
  - Up to 13 boundaries.
- Simplified, linear model for heat transfer pathways
  - Faster computation speed
  - Nonlinear calculations for radiation and infiltration.
- Considers:
  - Ambient and ground temperature
  - Solar irradiance and wind speed
  - Internal heat gains from equipment and occupants
  - Humidity (for HVAC performance).

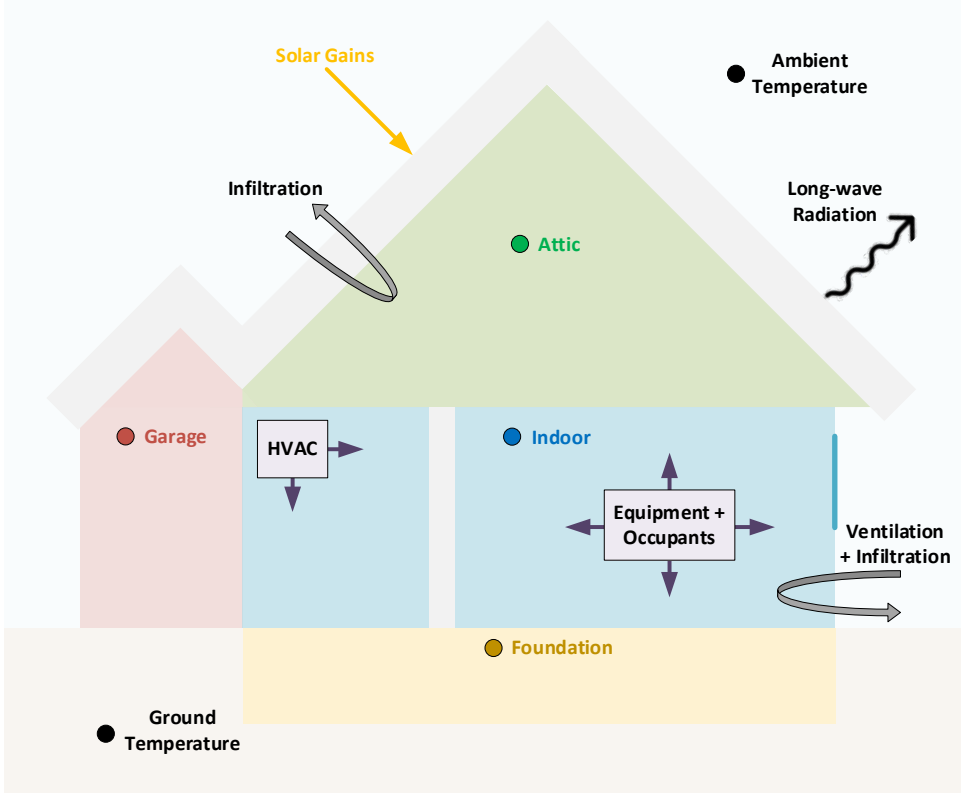
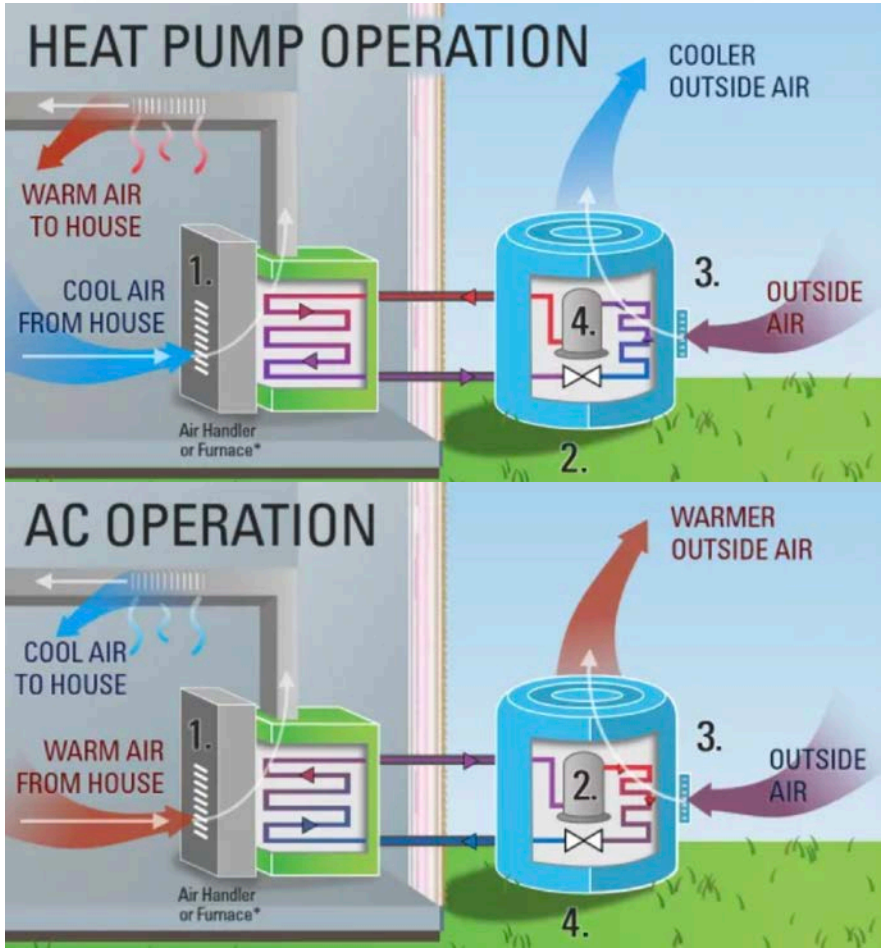


Image from Blonsky et al. (2021)
https://www.sciencedirect.com/science/article/abs/pii/S0306261921002464

Heating, Ventilating, and Air Conditioning (HVAC) Model

- Current technology coverage:
  - Air source heat pump (ASHP)
  - Minisplit heat pump
  - Air conditioner (central and window unit)
  - Furnace (gas and electric)
  - Boiler (gas and electric)
  - Electric baseboard.
- Options for single-speed, two-speed, and variable speed equipment
- Using EnergyPlus™ approach for dynamic modeling
  - Direct expansion (DX) coil performance curves taken from BEopt™
  - ASHP includes defrost
  - Ducts modeled with distribution system efficiency (ASHRAE 152).
- Default control options:
  - Thermostat with deadband (with equipment cycling)
  - "Ideal" control to maintain temperature setpoint.



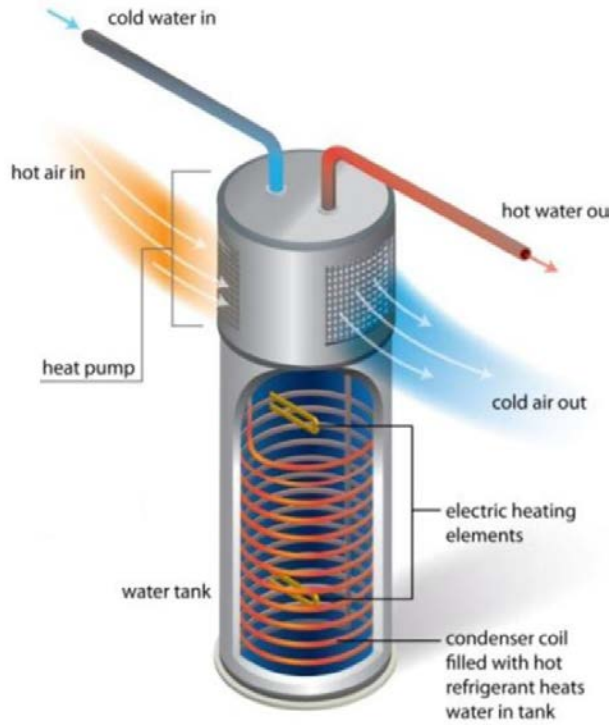
Images from
https://www.energystar.gov/products/air_source_heat_pumps

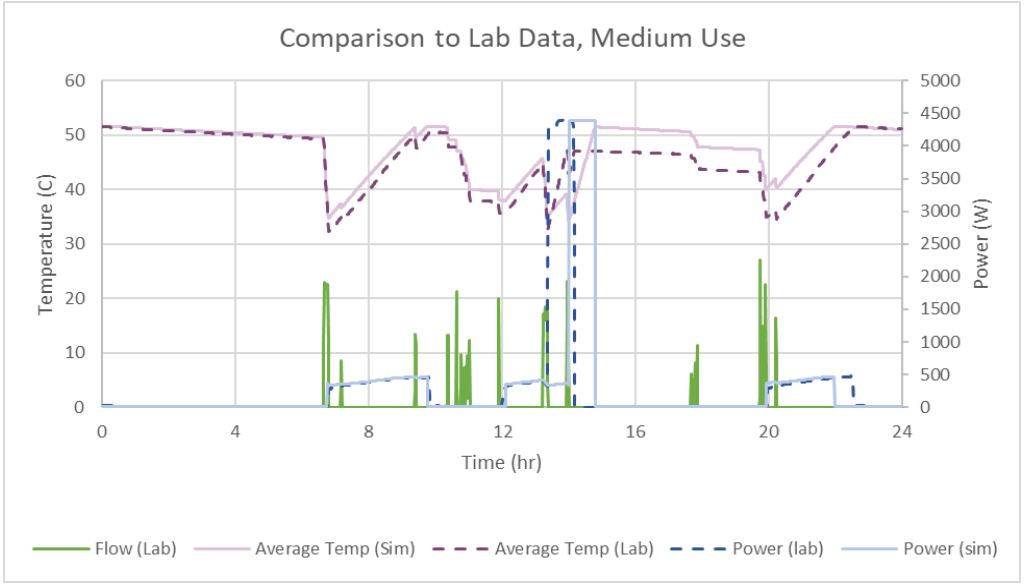
Water Heater Model

- Current technology coverage:
  - Electric resistance water heater (WH)
  - Gas WH
  - Heat pump water heater (HPWH)
  - Tankless (gas and electric).

- Thermal tank models
  - Are available in 1-node, 2-node, and 12-node models
  - Are validated with lab data
  - Account for heat transfer, water draws, and inversion mixing.

- Default control options:
  - Thermostat with deadband (with equipment cycling)
  - “Ideal” control to maintain temperature setpoint.





Images from https://www.energystar.gov/partner-resources/residential_new/educational_resources/sup_program_guidance/heat_pump_water_heater_guide

Photovoltaic Model

- Uses PySAM and PVWatts® for PV model
  - Accounts for PV capacity, tilt, orientation, and weather data
  - Includes standard PV module and inverter specifications.

- Is a smart inverter model for reactive power
  - Real and reactive setpoints
  - Maximum inverter power constraint
  - Watt-priority and volt-ampere-reactive (VAR)-priority modes.

- Can also accept PV schedule from a player file.

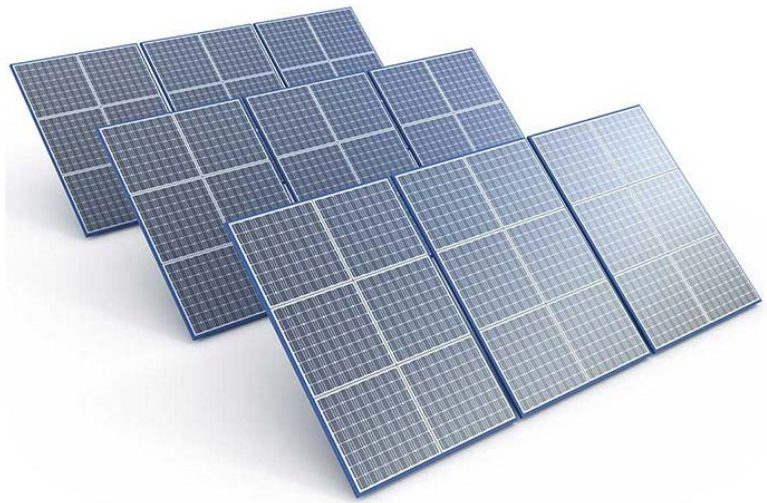


Image from https://today.ucsd.edu/story/moving-perovskite-solar-cell-advancements-from-the-lab-to-the-manufacturing-floor

Battery Model

- Similar to SAM battery model
  - Tracks battery power and state-of-charge
  - Tracks capacity degradation
  - Is a 1-node thermal model (for degradation).

- Control options
  - Daily charge/discharge schedule
  - Target net load (e.g., self-consumption)
  - Power setpoint from external controller.

- Islanded mode option (for resilience use cases)
  - Uses battery or generator to power other equipment
  - Models thermal dynamics in an outage.

Image from https://www.wagner-renewables.com/advice/battery-storage-your-questions-answered/

Electric Vehicle Model

- Generates charging events per simulation day
  - Uses a stochastic event-based model
  - Accounts for parking start time, duration, and initial state of charge
- Uses data from the Electric Vehicle Infrastructure-Projection (EVI-Pro) tool
  - Level 1 and Level 2 charging options
  - Plug-in hybrid electric vehicles and battery electric vehicles with 20- to 250-mile range
  - Weekday/weekend variability
  - Ambient temperature variability.
- Control strategies
  - Immediate charging (i.e., no control)
  - Delayed charging
  - Direct setpoint control.

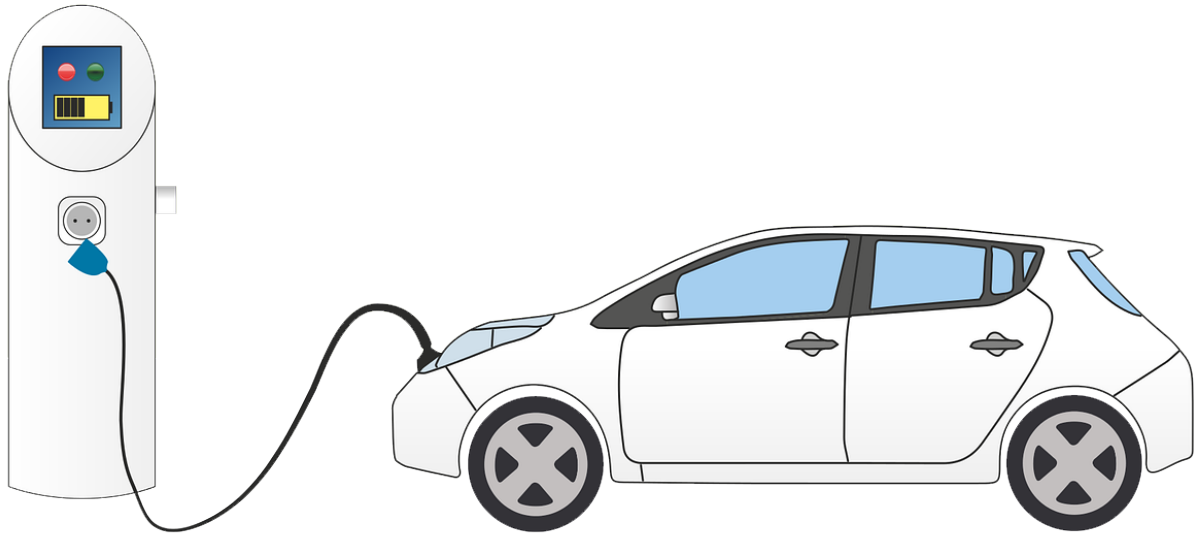


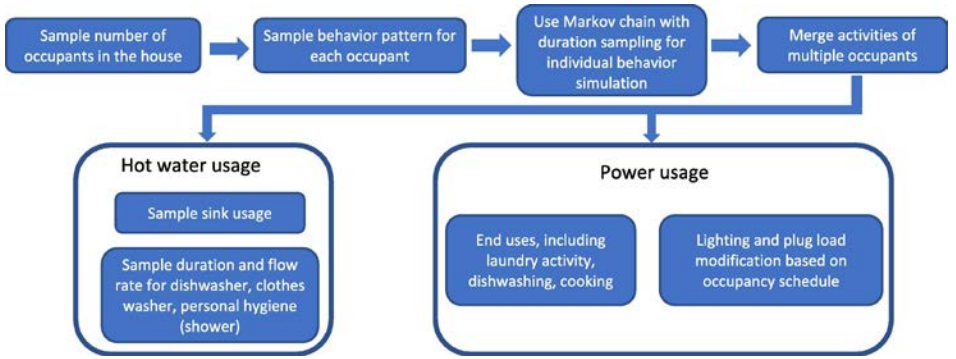
Image from https://calgreenenergyservices.com/wp/wp-content/uploads/EV-750x330.png

Other Loads

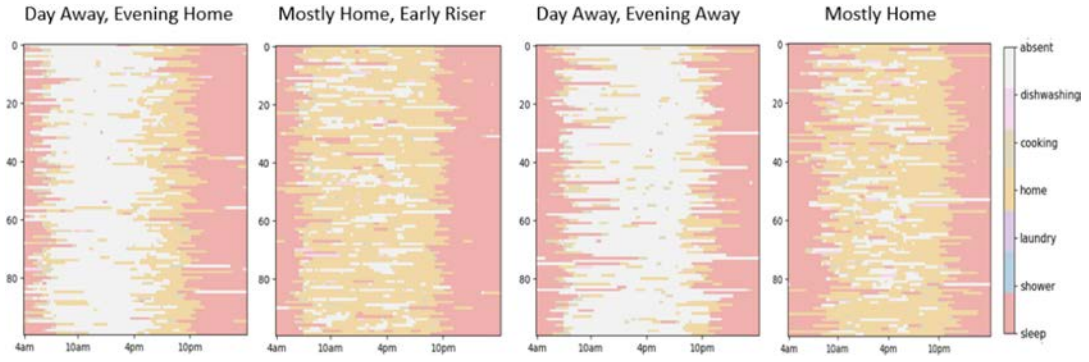
- Other modeled loads include:
  - Lighting by zone
    - Lighting schedule affected by location and local sunrise/sunset
  - Major appliances
    - Refrigerator, cooking range, dishwasher, clothes washer, clothes dryer
  - Miscellaneous electric and gas loads

- Stochastic occupant model used to determine load profile
  - Based on number of building occupants
  - Data from the American Time of Use Survey
  - Included in OS-HPXML based tools

Schedule generation procedure



Example occupant schedules

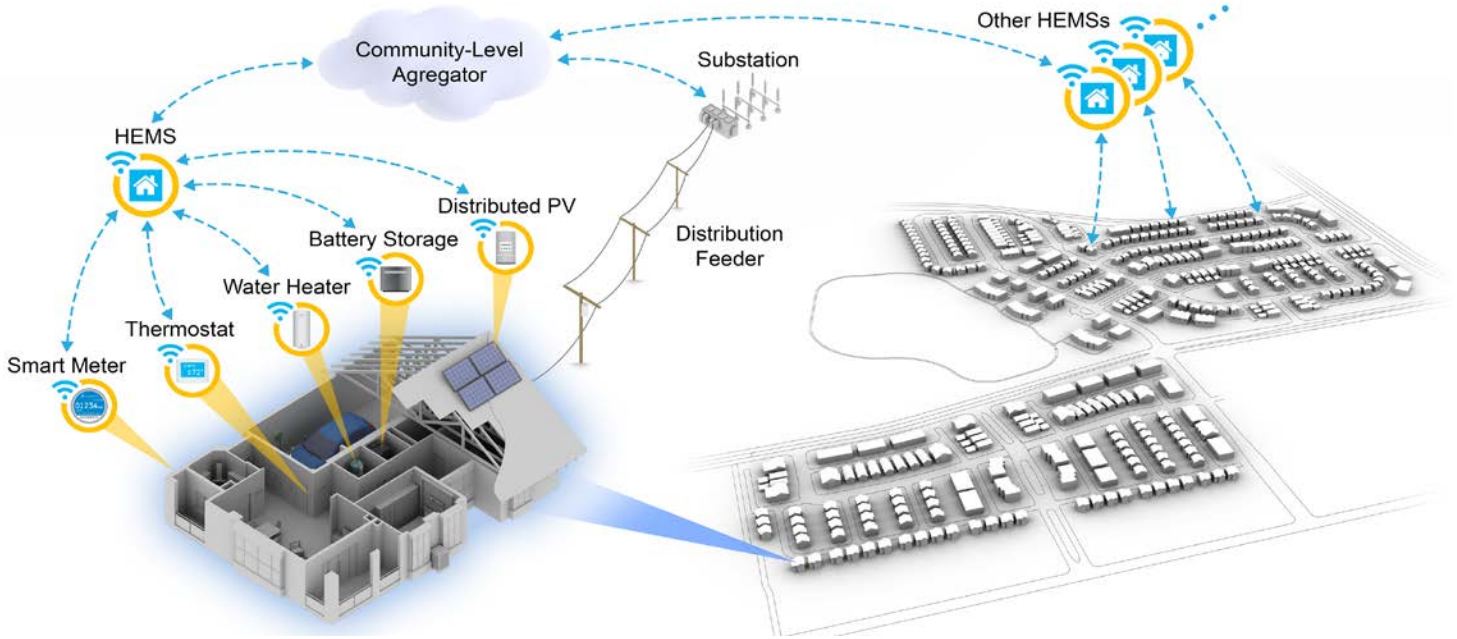


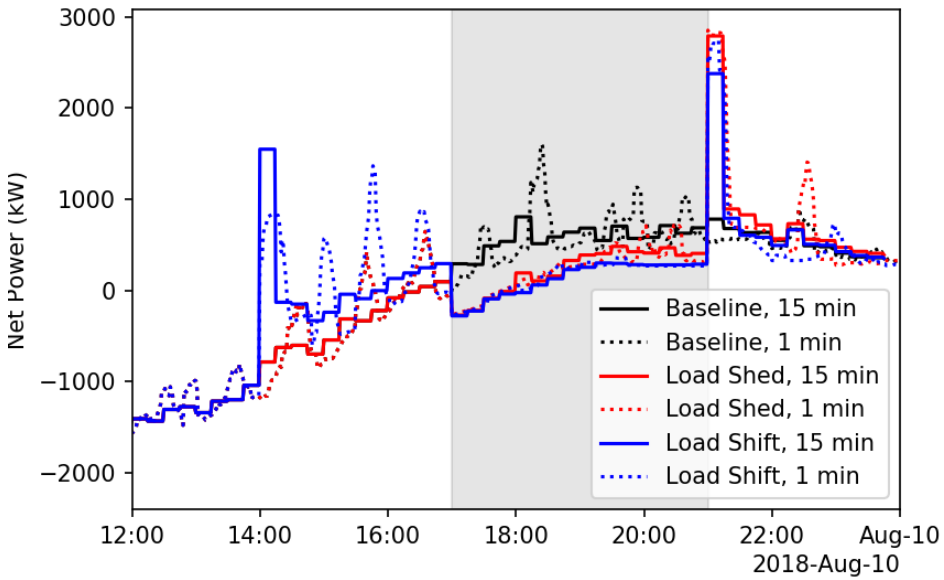
Images from Chen et al. (2022)
https://www.sciencedirect.com/science/article/pii/S0306261922011540

OCHRE Use Cases

Net-Zero Smart Community

- Evaluated HEMS and a community aggregator in a net-zero energy community
- Improved grid operations, reliability, and energy costs.





Images from Ding (2019) https://www.nrel.gov/docs/fy19osti/74511.pdf
and Blonsky et al. (2021) https://www.sciencedirect.com/science/article/pii/S0306261921002464

Field Demonstration of Flex Load Operation

Project Goal:

- Build a 1.4-megawatt flex load resource in the study area consisting of energy efficiency (EE), connected devices, solar, storage, and EVs.
- Demonstrate bulk services (energy, capacity, and frequency response) and distribution services (capacity relief, power quality, and voltage regulation).

Additional Project Learning:

- Program design
- Customer engagement
- New partnership models
- ADMS/DERMS assessment
- DER/EE value and co-benefits
- Building on regional sharing.

Image from https://connectedcommunities.lbl.gov/smartgrid-advanced-load-management-optimized-neighborhood-salmon

Advanced Clean Communities Collaborative (AC3)

Project Goal:

- Develop and enroll new and existing communities with flexible loads to participate in providing grid services.
- Use EnergyHub's distributed energy resource management platform to serve Duke utility peak capacity and resource adequacy needs in North Carolina.

Additional Project Learning:

- Program design
- Customer engagement
- Builder engagement
- Distribution grid impacts of flexing ASHP and HPWH loads.

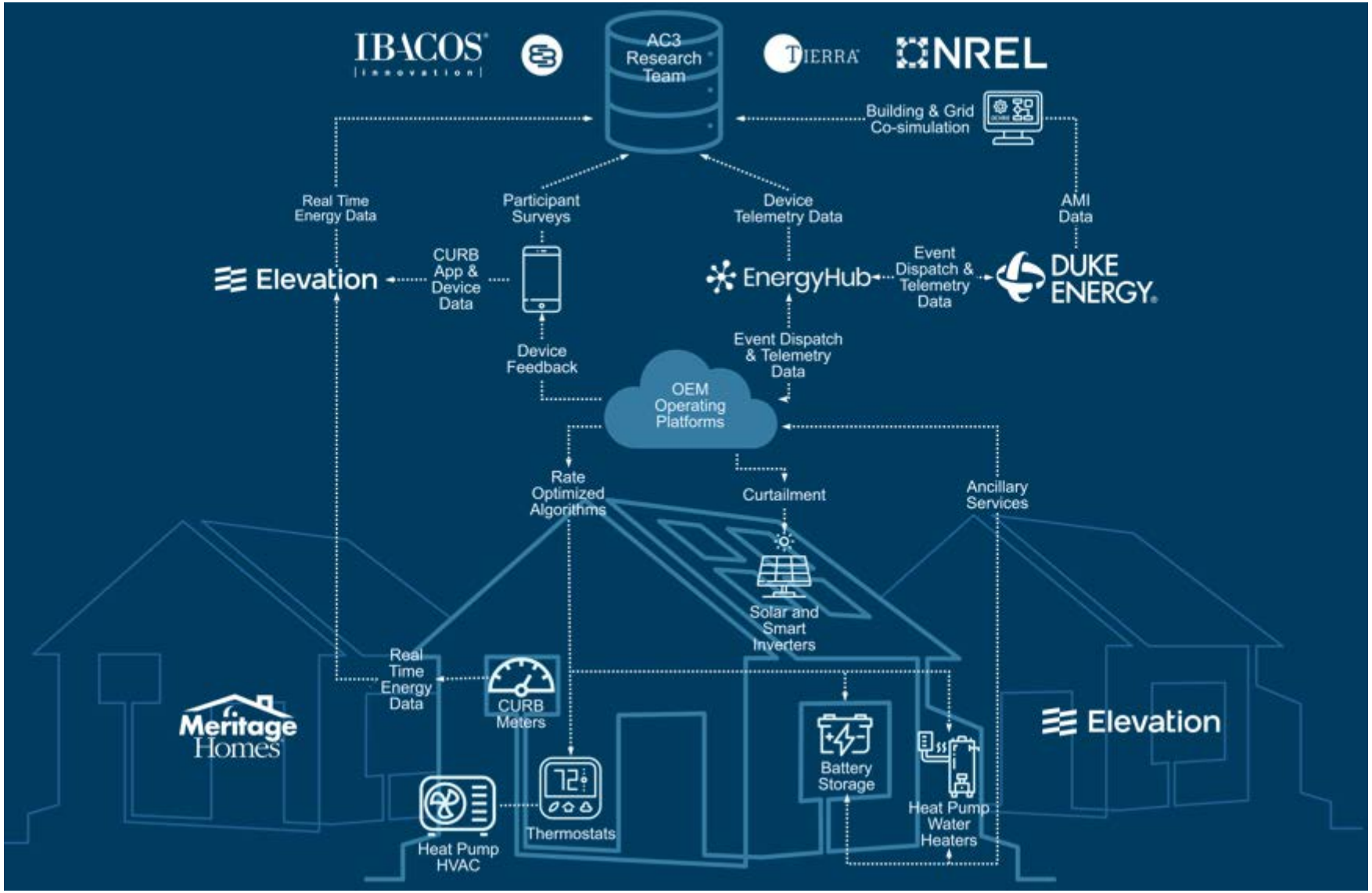


Image from https://connectedcommunities.lbl.gov/advanced-clean-communities-collaborative-ac3

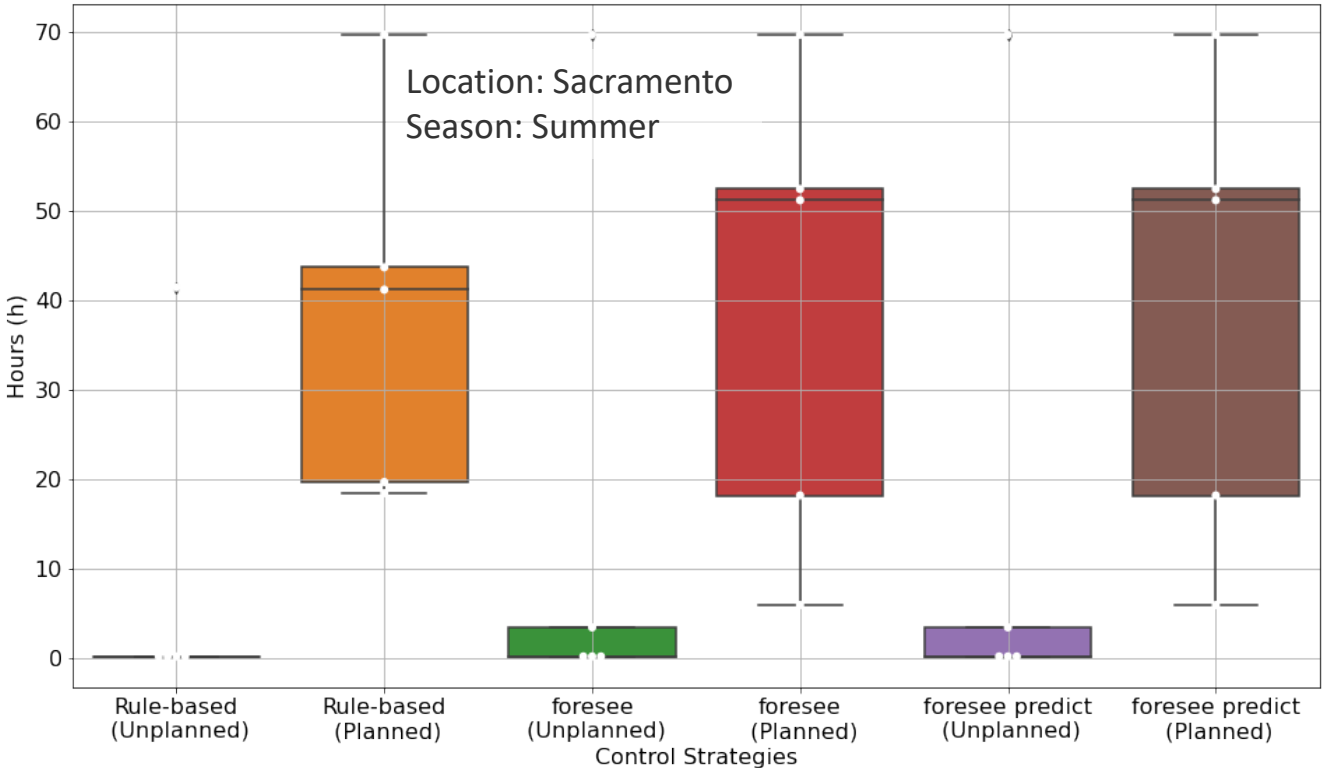
Smart Panel Evaluation

Project Goals:

- Understand potential benefits of circuit level control for a HEMS system.
- Use OCHRE to look at potential benefits during a power outage (planned or unplanned).

Additional Project Learning:

- Evaluated the Span smart panel in NREL's Systems Performance Laboratory.
- Analyzed real-world performance of circuit level HEMS in a field pilot.

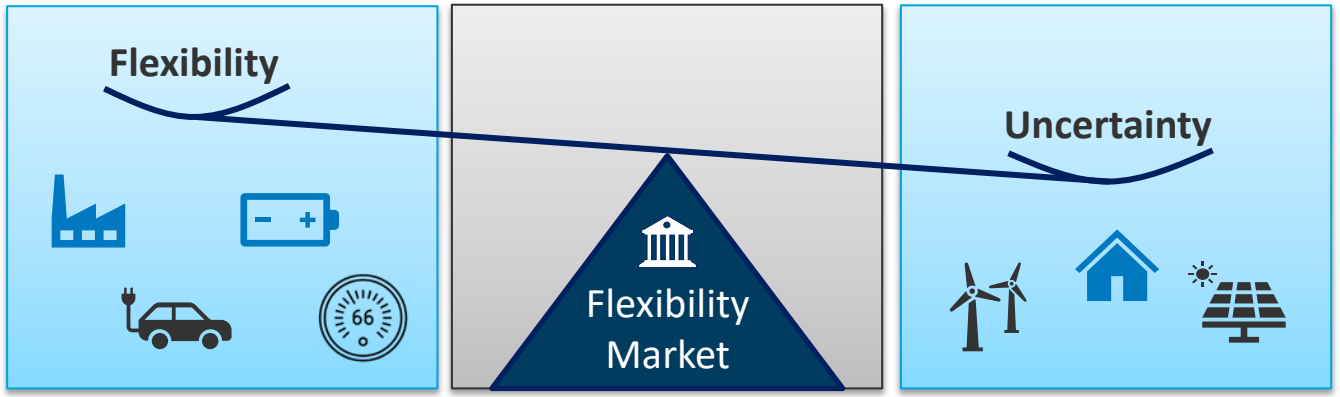


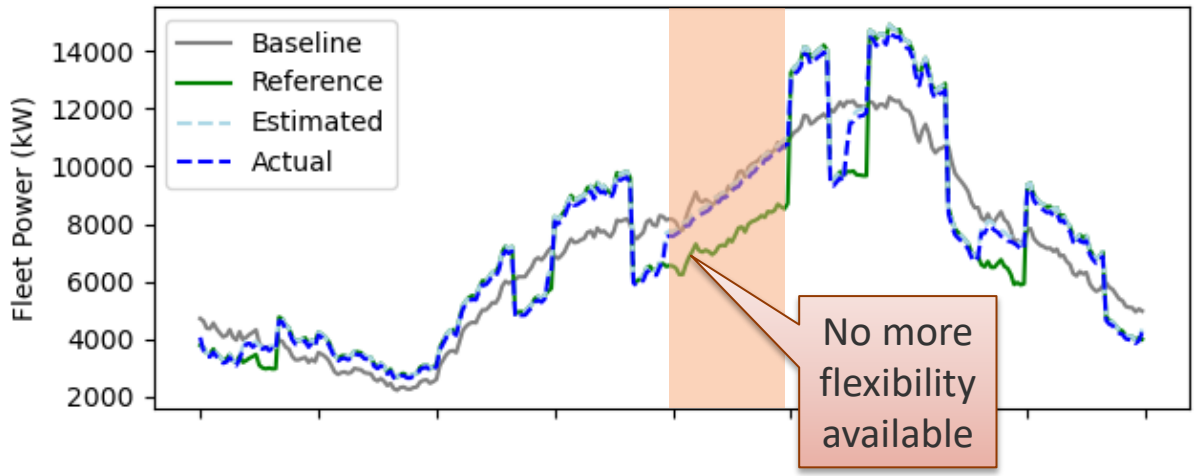
Images from Munankarmi et al. (2023) https://www.osti.gov/biblio/2221860 and https://support.span.io/hc/en-us/articles/4411673294743-System-Design-Specifications-for-SPAN-Panels

Virtual Power Plant (VPP) Optimization

- Modeled a virtual power plant (VPP) to:
  - Aggregate flexible loads
  - Bid into wholesale markets
  - Dispatch loads to minimize discomfort.

- Modeled 2000 devices in OCHRE:
  - Smart thermostats
  - Water heaters
  - In co-simulation with VPP and market.



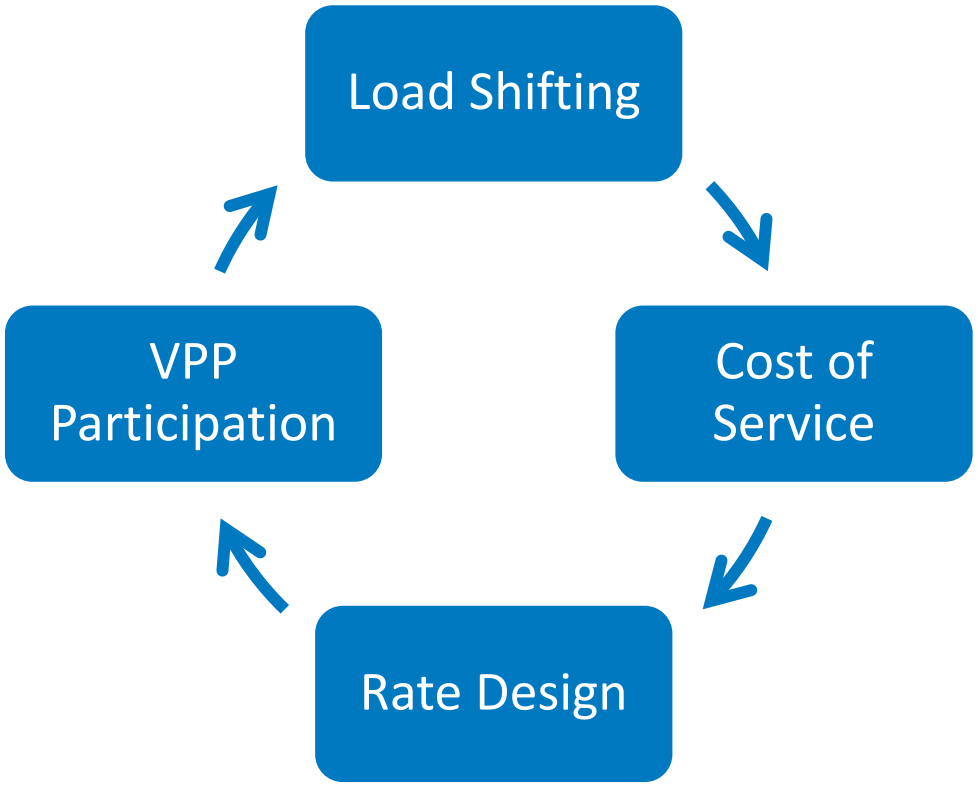


Images from Blonsky (2023)
https://www.esig.energy/event/2023-meteorology-and-market-design-for-grid-services-workshop/

Demand Flexibility and Retail Rate Interactions

- How can time-varying and dynamic rates impact demand and system costs?
  - Retail rates impact DER adoption and demand flexibility.
  - Changing loads impact utility costs and customer bills.

- Framework quantifies trade-offs between:
  - Affordability
  - Equity
  - Customer comfort.



How To Access OCHRE

More info: https://www.nrel.gov/grid/ochre.html

Open-source code:

- GitHub repository: https://github.com/NREL/ochre
- Documentation: https://ochre-nrel.readthedocs.io/en/latest/

Please reach out with questions or ideas!

Questions?

www.nrel.gov **NREL/PR-6A40-92031**

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