U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Virtual Battery-based Characterization

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Project Summary

Timeline:

Start date: 6/1/2016

Planned end date: 3/31/2019

Key Milestones

1. Develop control applications to provide grid services: 3/31/2018
2. Develop online characterization methods: 6/30/2018

Key Partners:

Pacific Northwest National Laboratory

University of Florida

Budget:

Total Project $ to Date:

- DOE: $938K
- Cost Share: $0

Total Project $:

- DOE: $988K
- Cost Share: $

Project Outcome:

Enable utilities to use flexible building loads as virtual storage resources to provide grid services, integrate more renewable generation such as wind and photovoltaics (PV) into the grid, and improve building operational efficiency.

Team

ORNL

- Develop commercial HVAC RTU/VAV modeling and control methods.
- Develop commercial refrigeration model.
- Develop residential building/HVAC models and control methods.
- Provide experimental data from test sites and regional building load parameters to PNNL.
- Assist PNNL on testing and validation.

PNNL

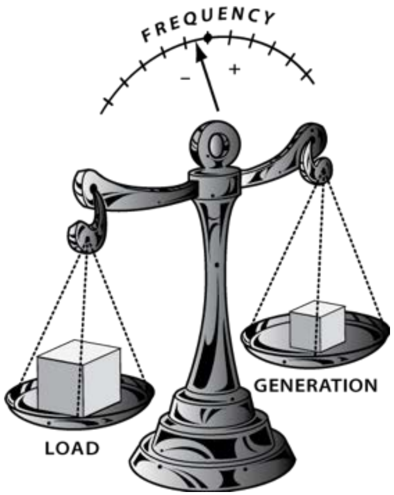
- Develop VB characterization, optimal schedule and device control method.
- Develop VB Assessment Tool (VBAT).
- Perform testing and validation.

University of Florida

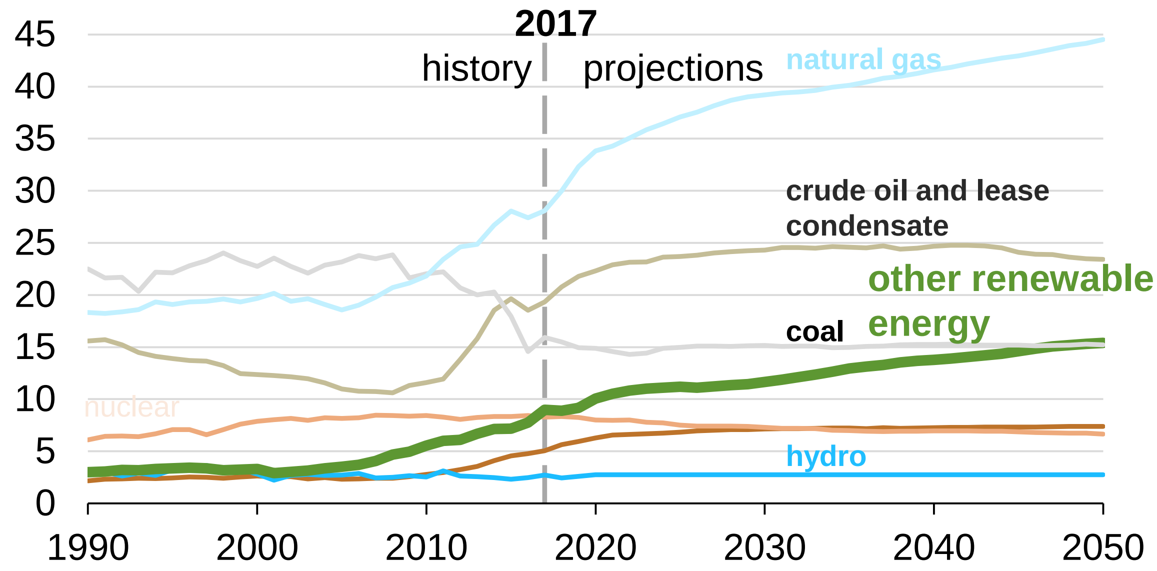
- Develop models for medium-scale commercial buildings and assist validation.

Challenge

- Traditionally, electricity generation has been modulated to meet the load and maintain balance between supply and demand.
- Renewable energy sources, whose generation varies with the weather, pose a challenge for balancing supply and demand. Excess generation of renewables must be used, stored, or lost to maintain balance.
- How do we increase renewable energy generation, while maintaining grid reliability and efficiency?



- Batteries/pumped hydro
  - High first cost
- Modulate load to meet generation = Virtual Batteries
  - What are the resources?
  - How much is available? Power/Energy
  - How can it be controlled?



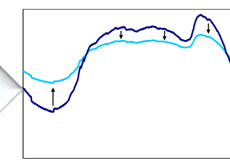
Source: EIA, Annual Energy Outlook 2018

Approach

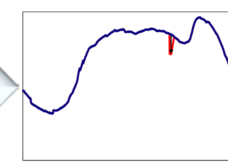
- Identify building resources with largest flexibility/storage potential.
- Develop simplified models for evaluating the flexibility/storage potential based on measured data.
- Identify which grid services building assets are capable of providing.
- Utilize models in PNNL VB assessment and control methods.
- Develop online characterization methods.
- Develop and demonstrate control strategies.
- Implement using open source architecture.

VOLTRON™
Devices | Data | Decisions

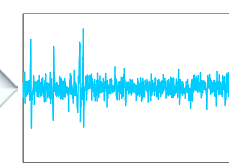
Peak shaving/shifting



Reliability response



Regulation response



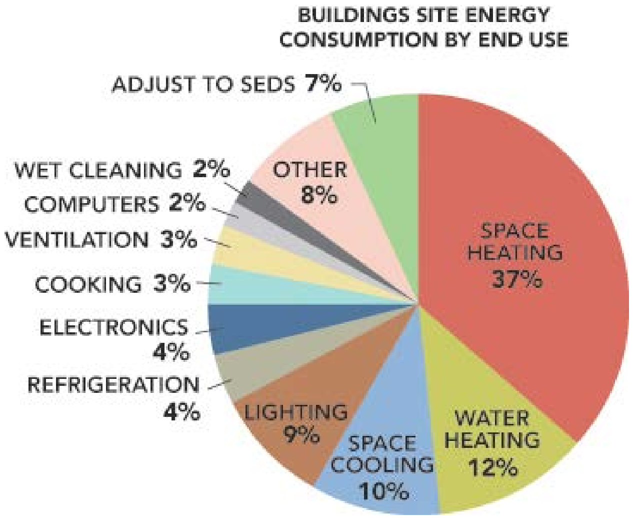
Approach - Risks

- **Reliability**
  - Develop control methodologies that maintain the temperature within the typical operating bounds → conservative control.
  - Evaluate impact on equipment cycling.
  - Developing learning algorithms for hot water use and building electrical use to improve forecasting.
- **Uncertainty**
  - Proposal for future work to develop methodology for calculating and quantifying uncertainty of load flexibility.
    - Weather
    - Occupant Behavior
    - Equipment/Building Model Error

VS

Impact

- Buildings consume 74% of the electricity produced in the US.
  - Thermostatically controlled loads make up the majority of building energy use (63%).
- Demand flexibility of residential sector alone can save 10-15% of potential grid costs, reduce customers utility bills by 10-40%, and reduce total US peak demand by 8% (Rocky Mountain Institute, 2015, The Economics of Demand Flexibility).
- **For the grid:**
  - Increased grid resiliency.
  - Increased ability to incorporate and utilize renewable generation.
  - Reduced primary energy use.
  - Reduced costs (avoided generation/distribution investment, grid losses).
- **For the building owner:**
  - Increased grid resiliency.
  - Reduced utility bills (demand charges/time-of-use pricing).

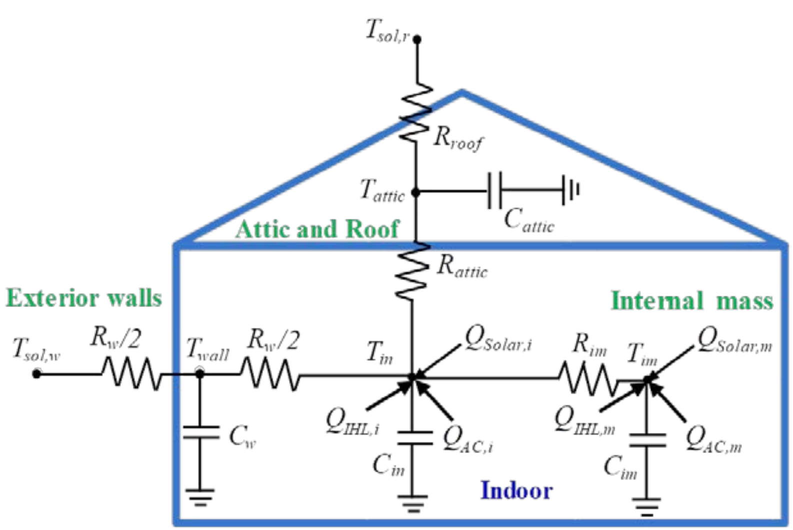


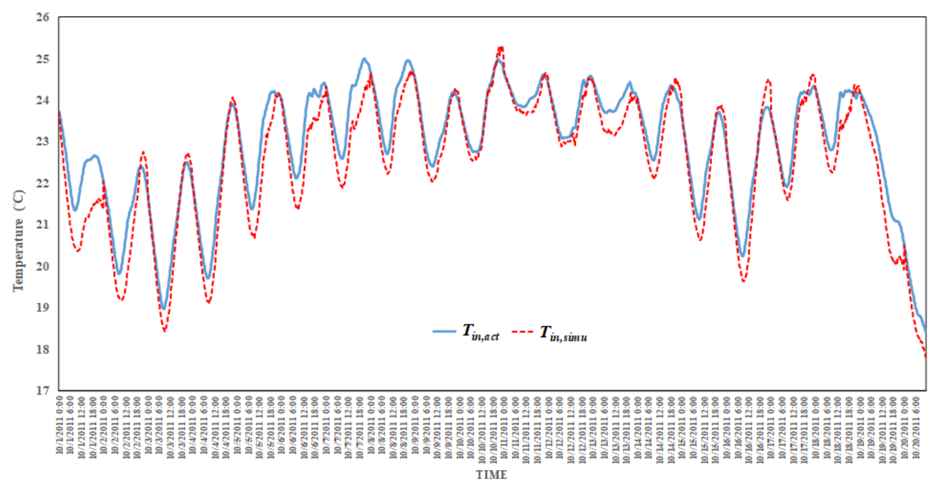
Progress – Residential HVAC/Buildings

- Simplified building model
  - Developed a simplified building model that can be used for long-term (up to 24 hours) predictions of indoor temperature or cooling/heating load.
  - Model is being used for Connected Neighborhood demonstration in conjunction with a time-of-use price signal to minimize HVAC operation cost over the course of a day.

Alabama Power

REYNOLDS LANDING AT ROSS BRIDGE



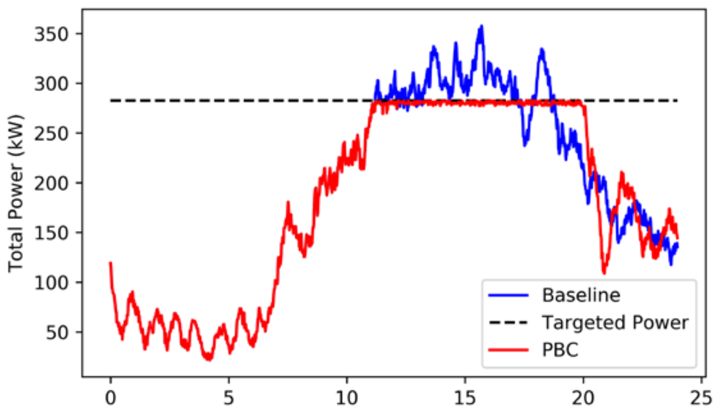


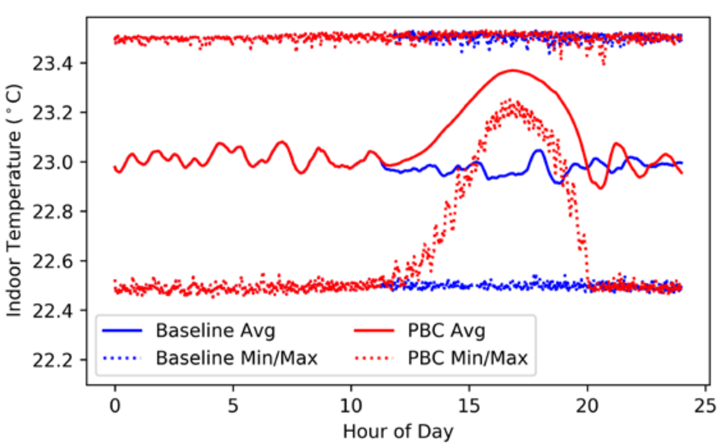
Progress – Residential HVAC

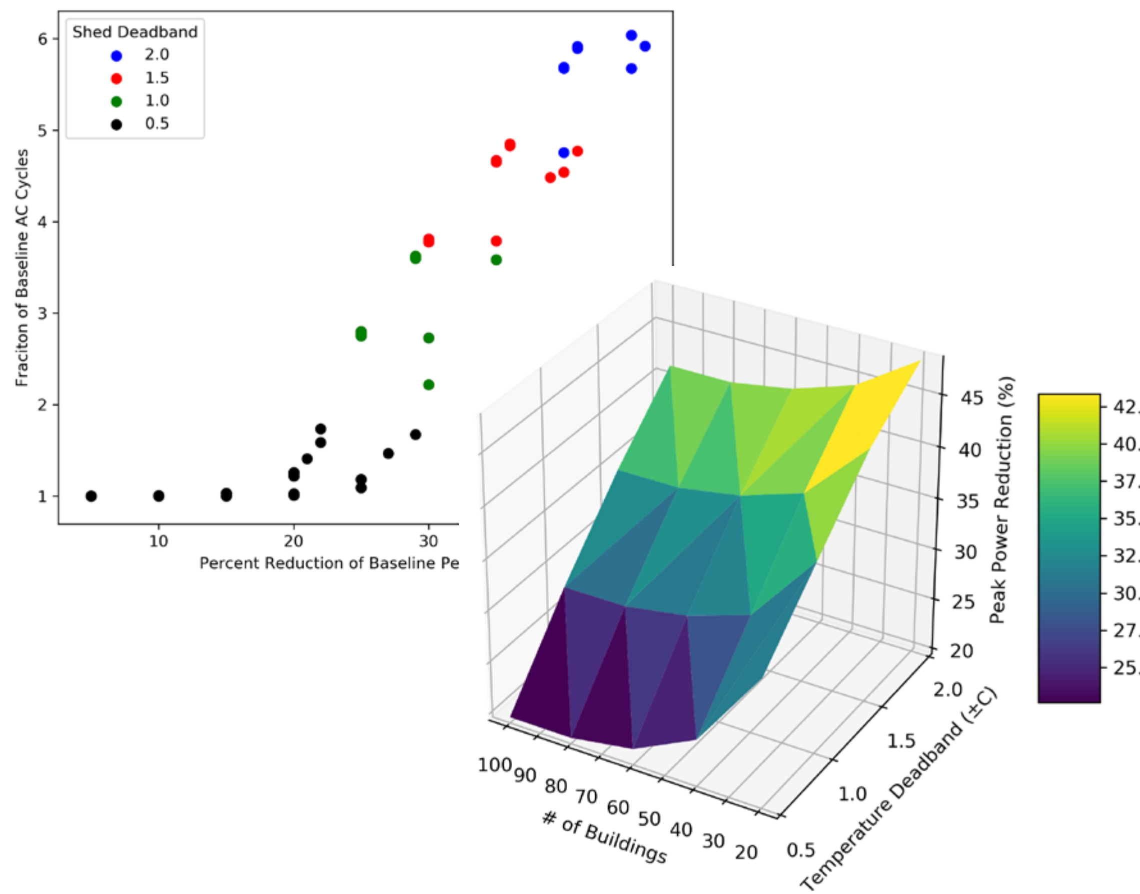
- **Priority-based control**
  - Computationally simple control.
  - Requires continuous communication between homes and aggregator/controller.
  - Homes are sorted based on temperature deviation from set point.
  - For Cooling: homes with lowest temperature are placed at the top of the "Turn Off" list. Homes with highest temperatures are at the bottom of the list.
  - Units are turned off to limit peak load → causes increase in average temperature of homes.
- **Model predictive control**
  - Use building and equipment models to predict future energy use.
  - Coordinated control of homes allows for planning of HVAC on/off schedules to limit peak load while maintaining comfort.
  - Ability to forecast allows for pre-cooling.

Progress – Residential HVAC

- **Priority-based control of HVAC systems for peak load limiting/load shaping**
  - Used simplified building models to simulate peak load limiting for a hot day in Las Vegas.
  - At least **20% peak reduction** of 1-minute peak available with **no impact on comfort** and less than 50% increase in equipment cycling.







Progress – Commercial RTU/VAV System

- **Modulate supply fan airflow/power to provide frequency regulation**
  - VAV damper control adjusts to try and maintain airflow to zone.
  - Used Flexible Research Platform light commercial building data to validate RTU fan and VAV damper model.

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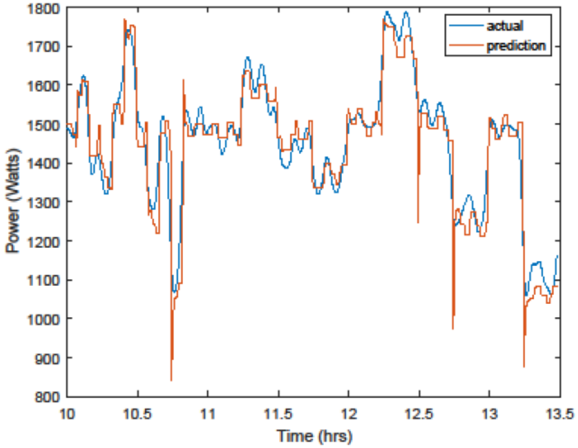
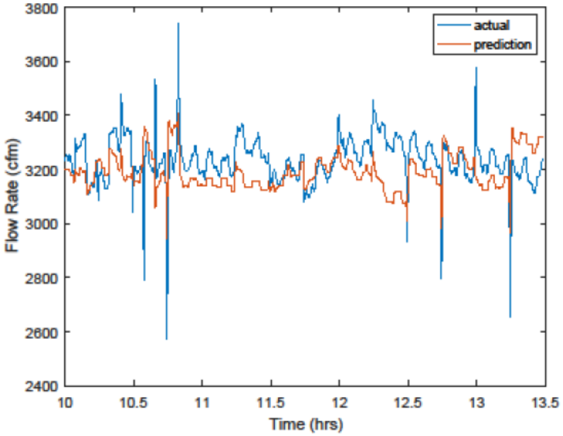
2-story Flexible Research Platform (FRP) at ORNL

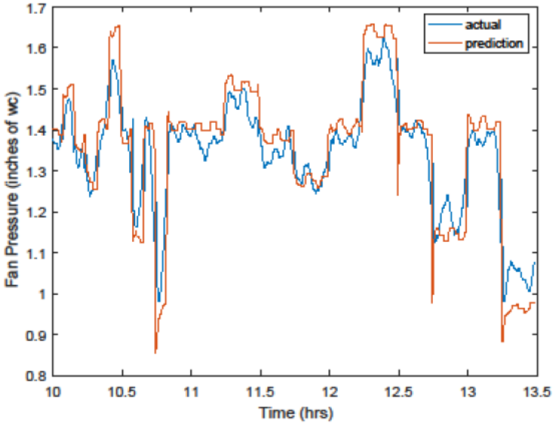
Power
rmse = 62



Flow rate
rmse = 112

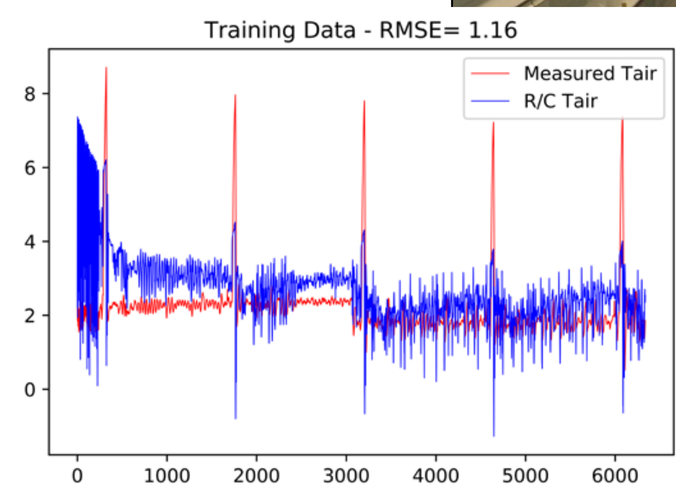


Fan pressure
rmse = 0.08



Progress – Commercial Refrigeration

- **Utilize thermal mass of product to allow for variation of cooling supply air/refrigeration power.**
- **Medium-temperature case model developed based on lab testing.**
  - Working on additional refinements



$$\frac{dT_{air}}{dt}C_{air} = -(C_1)Q_{evaporator} + \frac{(T_{product} - T_{air})}{R_{product}} + \frac{(T_{ambient} - T_{air})}{R_{case}} + Q_{lights+fans} + (455.8)(C_{infil})(T_{ambient} - T_{air})$$

$$\frac{dT_{product}}{dt}C_{product} = \frac{(T_{air} - T_{product})}{R_{product}}$$

Stakeholder Engagement

- Partnership with Southern Company (Alabama Power and Georgia Power) for connected neighborhood demonstrations provides a direct path towards utility adoption and demonstration of model and control performance.
- Building and equipment models implemented in PNNL regional flexibility screening tool (VBAT).

Alabama Power

Georgia Power

Remaining Project Work

- Residential HVAC/Buildings
  - Evaluate model predictive control for peak load limiting or load shaping using group of homes. Need to balance computational requirements with model complexity/accuracy, timestep interval, and forecast horizon.
- Commercial RTU/VAV System
  - Develop online characterization method.
  - Simulate RTU/VAV frequency regulation capability.
  - If feasible to integrate VOLTTRON™-based control agents with Johnson Controls system in FRP, demonstrate load following capability of RTU supply fan power.
- Commercial Refrigeration
  - Develop and validate models for low-temperature refrigerated cases.
  - Simulate peak load limiting using PBC and MPC for medium-temperature and low-temperature cases.

Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: 335K (FY16), 503K(FY17), 100K (FY18)
Variances: None
Cost to Date: 622k
Additional Funding: None

Budget History					
FY 2017 (past)		FY 2018 (current)		FY 2019 – 3/2019 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
503K	0	100K	0		

Project Plan and Schedule

Project Start: 6/2016
Project End: 3/2019

Projected End: 3/2019												
		Active Task (in progress work)										
	◆	Milestone/Deliverable (Originally Planned) use for missed										
	◆	Milestone/Deliverable (Actual) use when met on time										
	FY2017				FY2018				FY2019			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Q1 Milestone: Load flexibility characterization	◆											
Q2 Milestone: Utlization of load flexibility for grid services		◆										
Q3 Milestone: Prototypical control application			◆									
Q1 Milestone: Develop control application						◆						
Current/Future Work												
Q3 Milestone: Online characterization app							◆					