Optimal Stationary Fuel Cell Integration and Control (Energy Dispatch Controller)

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Project ID # ta020

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Overview

Timeline and Budget

- Project start date: June 2016
- Project end date: Sept. 2019
- Total project budget: $2.26M
  - Total recipient share: $1.74M (NREL), $520K (PNNL)
  - Total federal share: $2.26M
  - Total DOE funds spent*: $1.8M
    * As of 3/01/19

Partners

- Pacific Northwest National Laboratory (PNNL), Washington State University (WSU), University of Colorado Boulder (collaborators)
- Humboldt University, Doosan, Plug Power, Ballard, Fuel Cell Energy (review)

Barriers

- 4.2.3: Utilize open standards and middleware software approaches to enable integration of EMS, DMS, and BMS. (GMI [1])
- 4.3.3: Develop efficient linear, mixed-integer, and nonlinear mixed-integer optimization solution techniques customized for stochastic power system models, novel bounding schemes to use in branch and bound, and structure exploiting algorithms. Demonstrate the cost-benefit achieved by these techniques relative to existing ones. (GMI [1])

[1] GMI: Grid Modernization Initiative
https://energy.gov/sites/prod/files/2016/01/f28/Grid Modernization Multi-Year Program Plan.pdf

Relevance

Project part of DOE's Grid Modernization Initiative (GMI)

- Funded by the Fuel Cell Technologies Office

Project goal: Create an open-source tool set to foster growth in fuel cell integrated buildings with emphasis on optimal control dispatch

- Stationary fuel cells can be used for combined heat and power (CHP) to meet a building's electrical and thermal loads
- Integrated building controls can be used to minimize operating costs
- Forecasts of load and resources can aid in grid ancillary market participation

Project directly addresses GMI barriers:

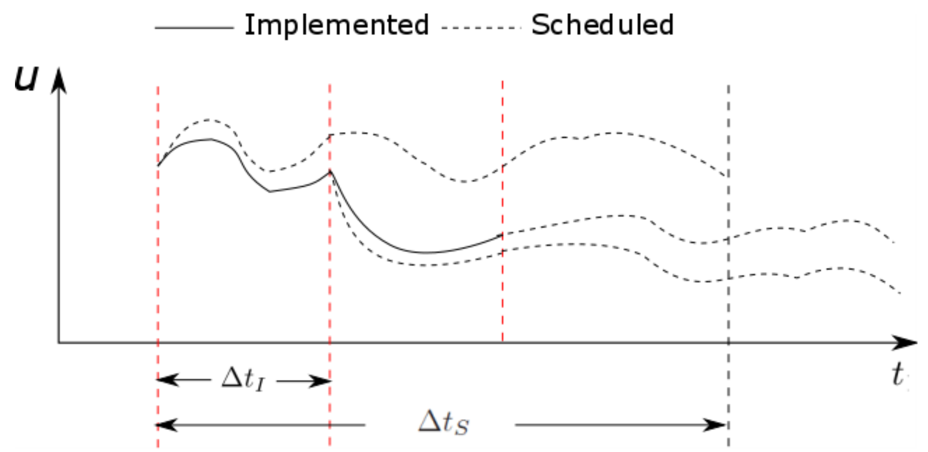
- Creating open source tools for use with energy management systems (EMS), distribution management systems (DMS), and building management systems (BMS)
- Developing efficient optimizations for system modeling and cost benefit analysis with comparisons to existing techniques

Approach

Initial formulation of the optimization problem is complete and iterative improvements through testing have begun

What is the Energy Dispatch Controller (EDC)?

- The EDC manages building operation in real time
- It uses model predictive control (MPC) to forecast 24 h moving windows and implement for 1 h



What is the objective?

- Minimize building operation costs
- Electricity bill + natural gas bill – ancillary service payment

What are the decision variables?

- The EDC can make decisions (operational set points) for building variables
- Temperature set point, fuel cell, battery thermal storage, and building HVAC system

What constraints does it have?

- Model prediction (reduced order model, forecasting), comfortable temperature bounds, equipment limits

$$
\begin{aligned}
\min_{x,u} \quad & J(x,u,d) \\
s.t. \quad & x_{k+1} = f(x_k, u_k, d_k) \\
& h(x_k, u_k, d_k) \le 0 \\
& g(x_k, u_k, d_k) = 0
\end{aligned}
$$

Accomplishments and Progress: Multi-Zone Buildings

Extended EDC to multi-zone buildings through reduced-order building model (ROM) development and optimization revisions

- Key challenge: develop a ROM to predict the behavior of the building
  - Balance model accuracy and complexity
  - **For use in practice, the model should use inputs commonly available from building measurements, and the model should also be calibrated from commonly available measurements**
- ROM development for multi-zone buildings
  - Large office and large hotel
  - Consider Energy+ prototype building as “real building” and use E+ simulation data to calibrate ROM
  - Each zone is modeled as:

$$T_i^{k+1} = T_i^k + c_i^0(T_o^k - T_i^k) + c_i^1(\dot{Q}_{int,i}^k + \dot{Q}_{ret,i}^k) + c_i^2\dot{m}_i^k(T_{dis,i}^k - T_i^k)$$

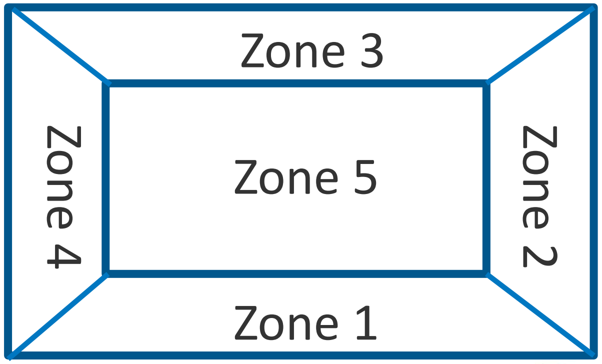
  - The inputs are outside air temperature, internal heat gain, reheat from HVAC, supply air temperature

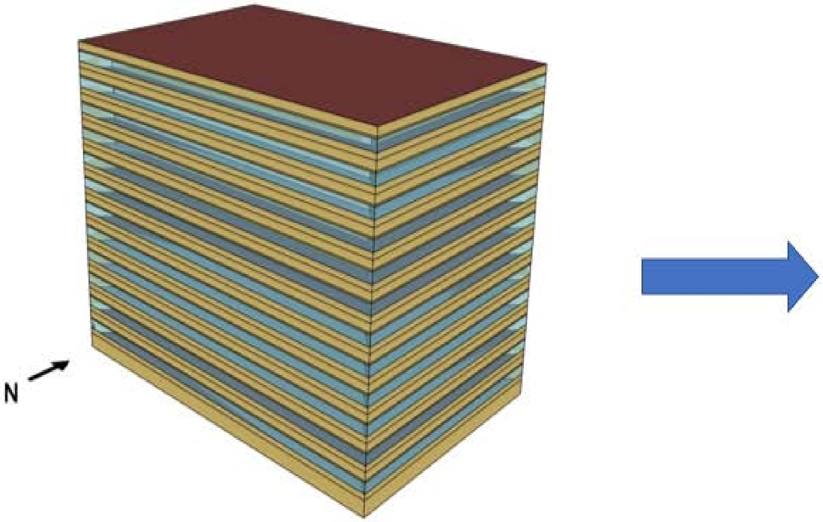
ROM development a collaboration between NREL and PNNL

Accomplishments and Progress: Multi-Zone Buildings

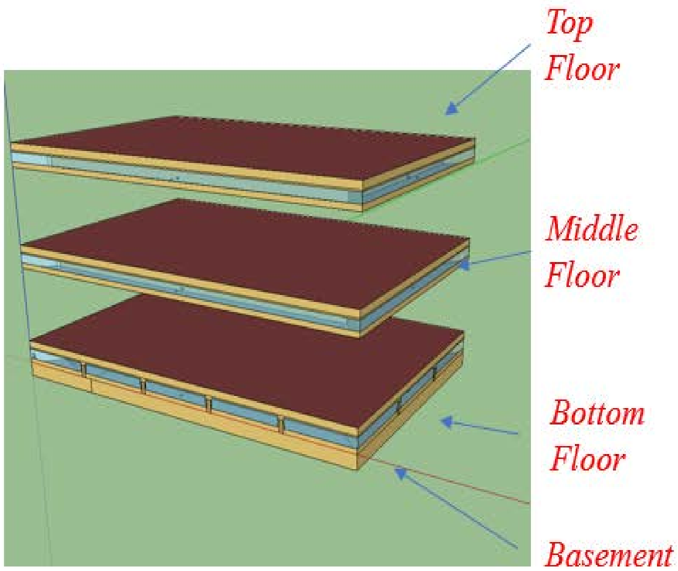
A large office is modeled by four floors with five zones each

- DOE prototype large office building
  - Modeled by four floors: basement, bottom, middle, top
  - Each floor is modeled by five zones





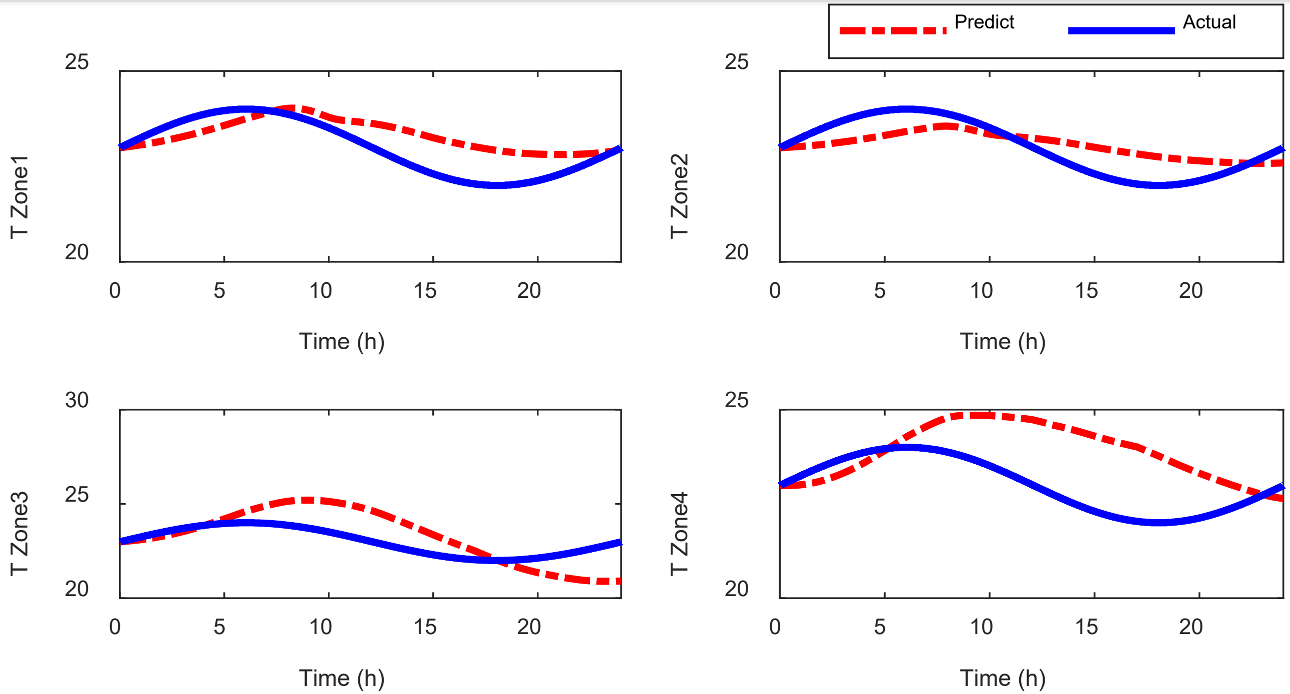
Original Building:
12 Floors + basement

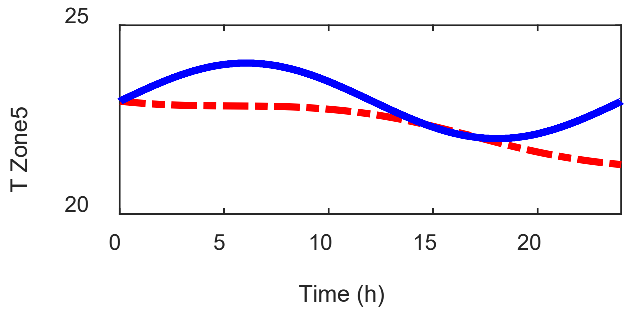


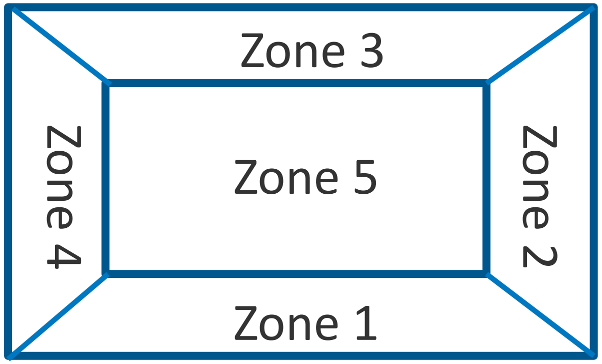
Simplified Building in models

Accomplishments and Progress: Multi-Zone Buildings

Large office building: Top floor prediction results example



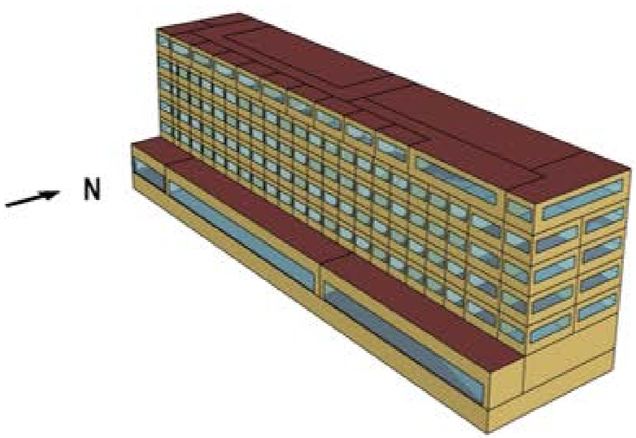




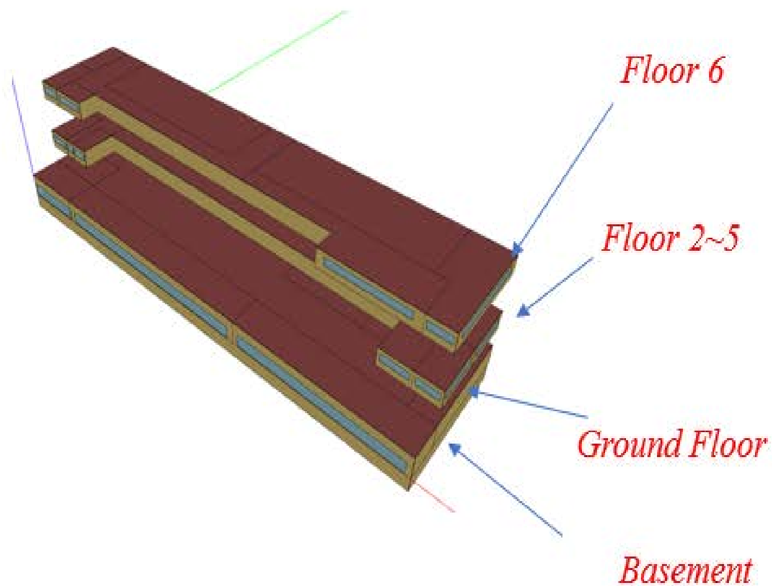
Accomplishments and Progress: Multi-Zone Buildings

A large hotel is modeled by four floors with five zones each

- DOE prototype large hotel building
  - Modeled by four floors: basement, bottom, middle, top
  - Each floor has different layout
  - Individual zones on each floor model lobby, retail, kitchens, guest rooms, and other areas in a hotel

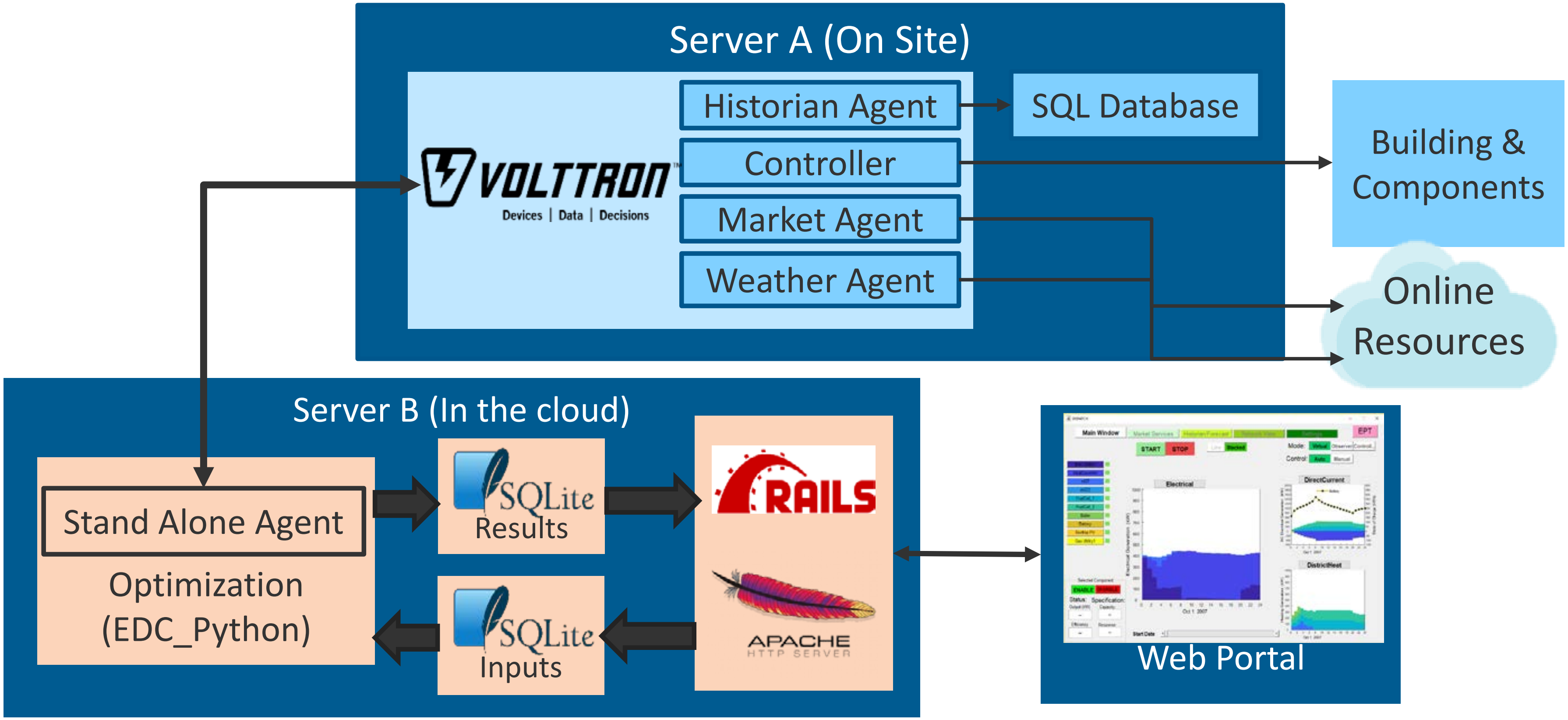


DOE prototype hotel
6 floors + basement



Simplified representation for ROM

Accomplishments and Progress: Washington State University

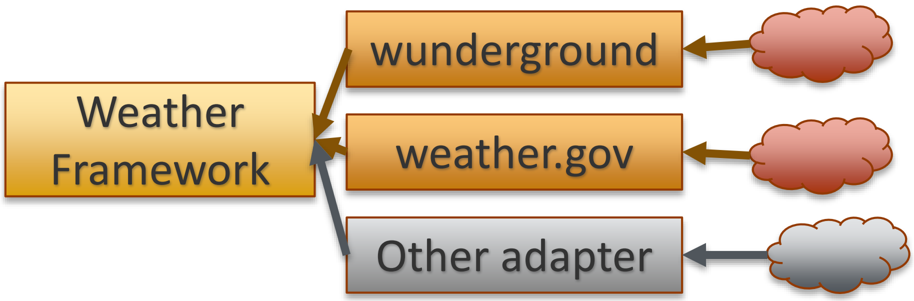


- Completed conversion of generalized micro-grid control optimization to open-source platform (Python) (alternative WSU version of the EDC)
  – Converted multi-zone EnergyPlus building models to a dynamic control framework that facilitates local linearization for optimal zone temperature management
- Demonstrated communication connections with VOLTTRON

Accomplishments and Progress: PNNL Support

Significant VOLTTRON work for functionality and simplified setup

- WeatherAgent
  - Original WeatherAgent based on WeatherUnderground, which stopped providing free access
  - Agent has been re-implemented as a framework following the pattern of the drivers and historians
  - Simpler to create multiple implementations for different weather services



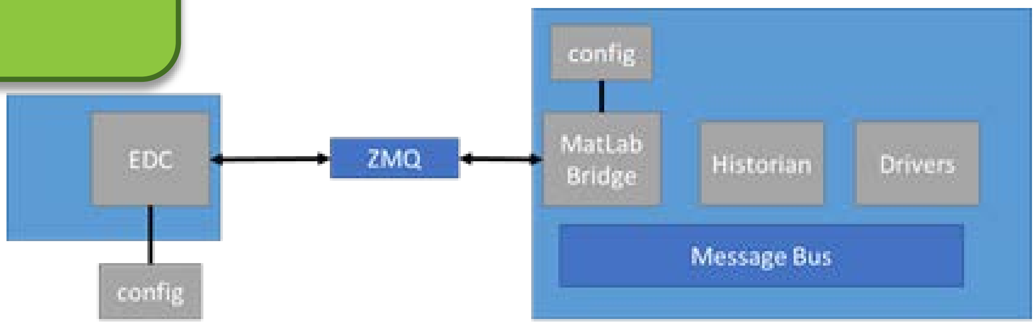
- OpenADR
  - OpenADR contribution incorporated into platform for potential use by EDC
- Hardware integration
- Simplified setup
  - Docker container and VirtualBox VM created to simplify deployment
- Ancillary services study and agent design

Accomplishments and Progress: EDC/Hardware Integration

PNNL has provided support for hardware and software integration with VOLTTRON

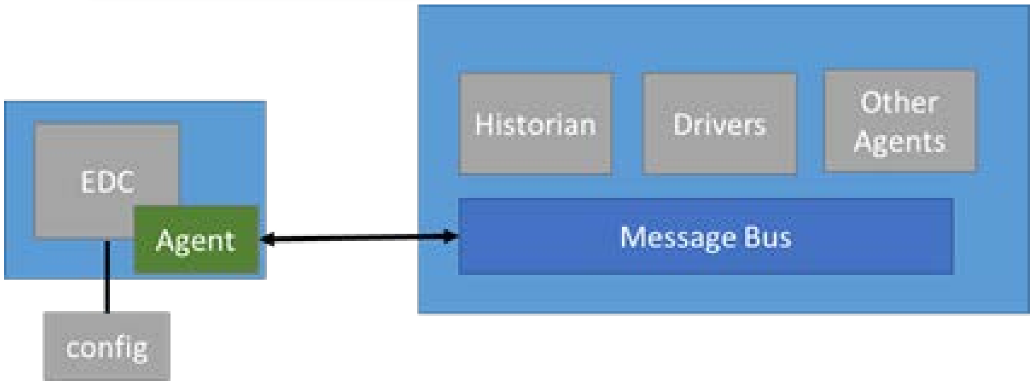
- PNNL held VOLTTRON workshops
  - WSU to assist in EDC integration with VOLTTRON and the Python EDC implementation
  - Working session at NREL to demonstrate setting up the platform and configuring drivers at the NREL lab
- Python-based EDC can connect directly to the VOLTTRON message bus without a need for a separate bridge. This allows maximum flexibility for utilizing platform resources

Previous integration



EDC communicating via a bridge that needs to explicitly expose functionality

New Python-based integration



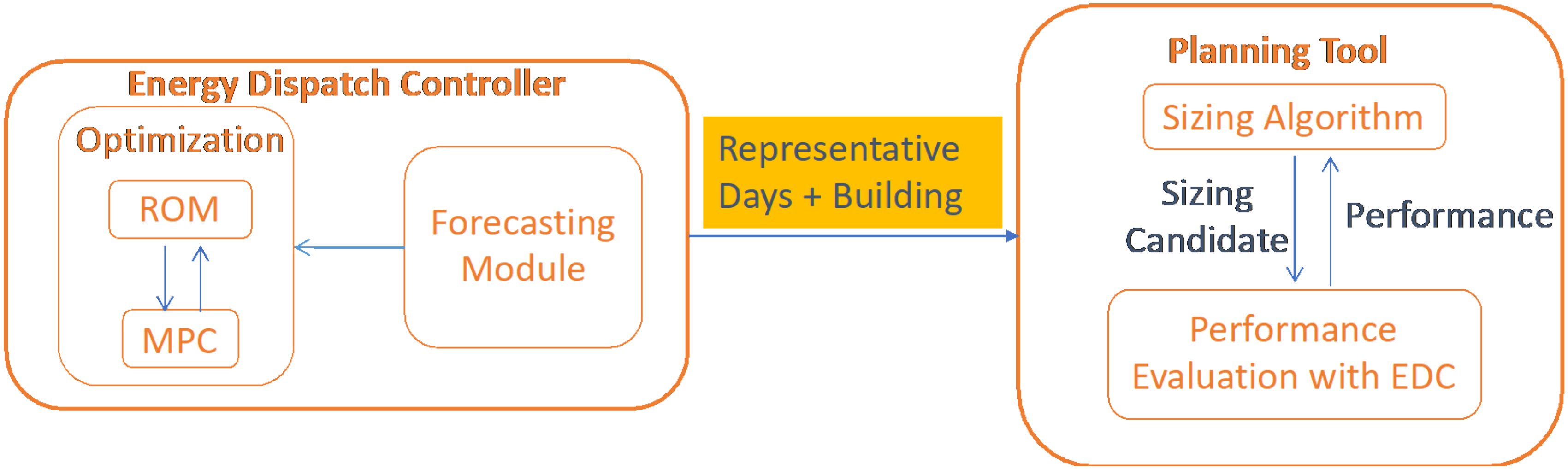
Python-based EDC communicating directly with VOLTTRON Message Bus

Accomplishments: Planning Tool

Integration has begun and underlying modules are being developed

Integration of the planning tool with EDC

- Goal is to size generation and storage equipment for best economic benefit
- Class-based approach easily creates different equipment/building configurations
- Developed web-based interface as an open source tool
- Built database to store user inputs and model outputs



Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- "This project seems to be concentrating on the development of a model, which leaves the accomplishments lost in model details, rather than demonstration of the impact of the technology. "
  - *Agreed. ROM development and some of the software decisions (conversion from MATLAB to Python) has delayed some of the analysis. We hope to complete more of this in the final year and provide more results and analysis.*

- "The project's weakness is the challenge of relying on a third party to take source code and bring a viable commercial product to market that can actually be implemented outside of the laboratory resource framework and expertise. "
  - *We are currently working on developing a open-source code that can be used to increase understanding on the topic. It will not be implemented into a product yet, but we are well-positioned to provide expertise and knowledge base on the topic.*

Collaboration and Coordination

- **NREL, Transportation and Hydrogen Systems Center**—Fuel cells, modeling, optimization, coordination, and management
- **NREL, Power Systems Engineering Center**—Buildings control optimization, ancillary markets
- **NREL, Commercial Buildings Group**—Buildings models and control optimization
- **Washington State University**—Building controls optimization, ROM, graphical user interface, ancillary markets
- **Pacific Northwest National Laboratory**—Buildings interface and communications backbone (VOLTTRON), ancillary market work, and ROM
- **University of Colorado Boulder**—Buildings controls expertise and review
- **Consulting and review**—Humboldt University, Doosan Fuel Cells America, Plug Power, Inc., Ballard, Fuel Cell Energy

Thanks to our team:
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Remaining Challenges and Barriers

- Python conversion
  - Originally developed in MATLAB; we are working on a conversion to Python with a web (HTML)-based interface
- Software integration
  - We are working through the integration of several code modules that were developed by separate sub-teams
  - Includes two alternate versions of the control optimization as developed by NREL and WSU and working on the common interface
- Hardware-in-the-loop testing

Proposed Future Work

This project is ending at the end of FY19. Future work is for the remainder of FY19.

- Software integration with web interface
- Hardware-in-the-loop and co-simulation results and analysis
- Publication results, analysis, and lessons learned for project

Technology Transfer Activities

- Objective is to release all code as open source by end of project
  - The target audience includes building managers and building control companies, ancillary service aggregators
- Benefits
  - Reduce building energy cost with better integrated controls
  - Position building participation in the changing ancillary market environment

Summary

FY18

- ROM development and refinement of NREL's control optimization
- WSU development of alternative approach to the control optimization
- VOLTTRON development and strategy for testing/deployment
- Software development
  - Python conversion (previously MATLAB)
  - Integration of code modules
  - Planning tool development
  - HTML-based graphical user interface development
- Test plan development for hardware-in-the-loop

Remainder of FY19

- Results, analysis, publications

Thank You

www.nrel.gov

Publication Number

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NREL Transforming ENERGY

Technical Back-Up Slides

Relevance: Impact

Modernize energy management and control of buildings

- Reduce energy bills and emissions
- Maximize benefits of CHP, storage, and renewable generation

Support grid modernization

- Characterize ancillary service opportunities
- Increase grid reliability and security using flexible, dispatchable energy resource

Support fuel cell market development

- Quantify economic benefit of integrated CHP
- Inform the industry of favorable characteristics

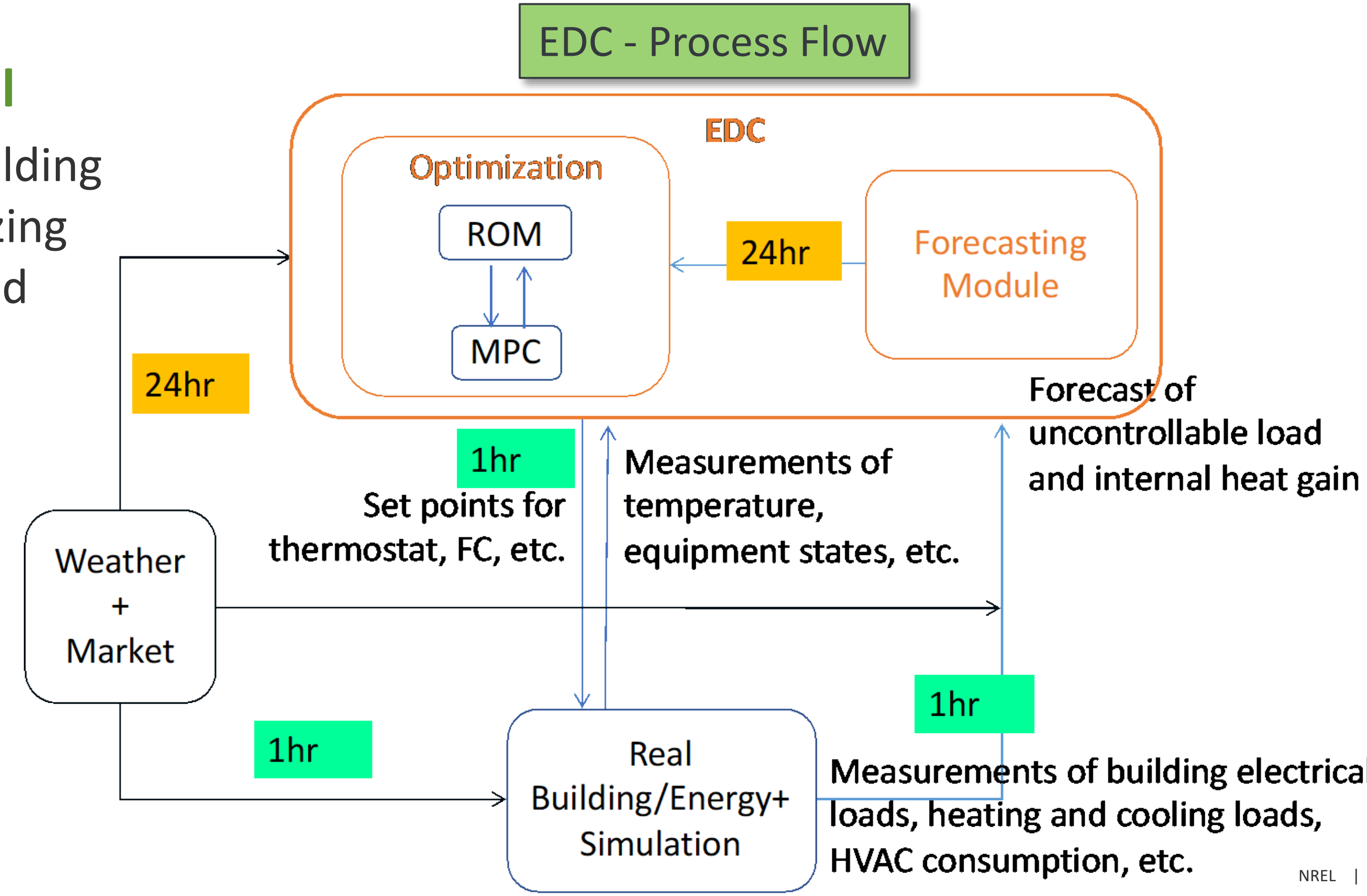
Relevance: Tools Objectives

Energy Dispatch Controller (EDC)

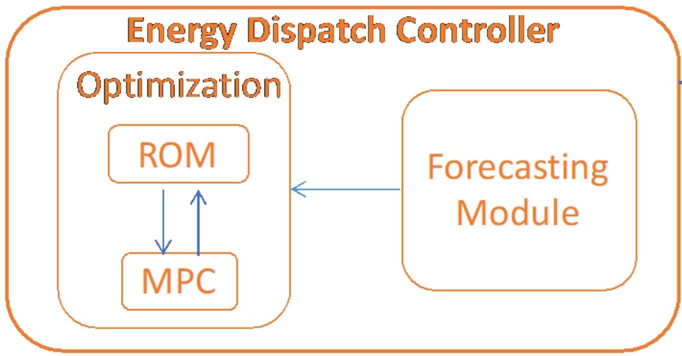
- Minimize building operating costs while maintaining occupant comfort
- Allow participation in grid ancillary services using load and equipment forecasts from model predictive control approach

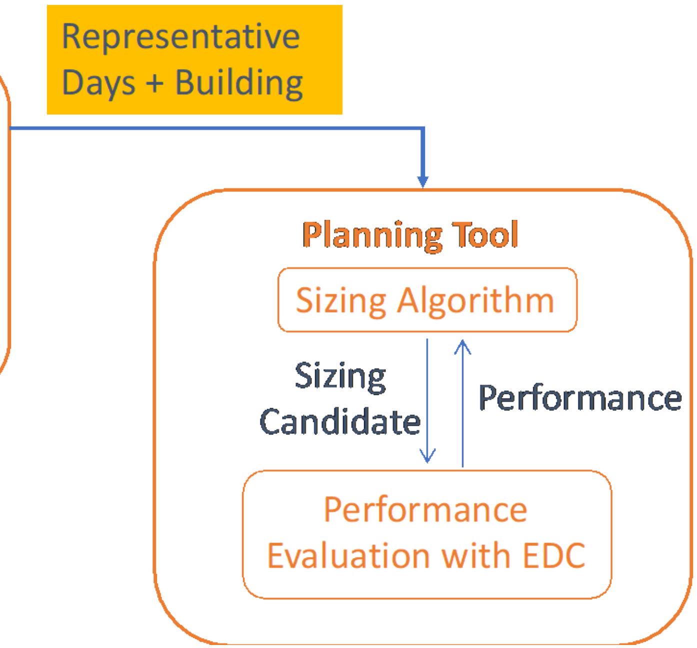
Planning Tool

Determine building component sizing using simulated dispatch and economic evaluation



Approach: Cross-Functional Approach





Team expertise

- Fuel cells (NREL, WSU)
- Power systems (NREL, WSU)
- Optimization techniques (NREL, WSU, PNNL)
- Commercial buildings (NREL, PNNL)
- Building communication networks (PNNL)

We are leveraging tools and skills across several different groups both intra- and inter-lab at NREL and PNNL and with academia

- Developing modules for this project that have extensible applications

Approach: Reduced Order Building Model

The ROM is a RC model to represent the building

Why is a ROM needed?

- Model predictive control (MPC): at each time step, calculate the optimal operation of the next 24-hour
  - Need a model to predict the building behavior
  - Need to know how power consumption and temperature evolves under the controllable inputs (thermostat set points, fuel-cell operation set points, battery charging/discharging, etc.) and uncontrollable inputs (weather, building occupancy loads, etc.)
  - The model needs to be "simple" for the optimization problem to be tractable