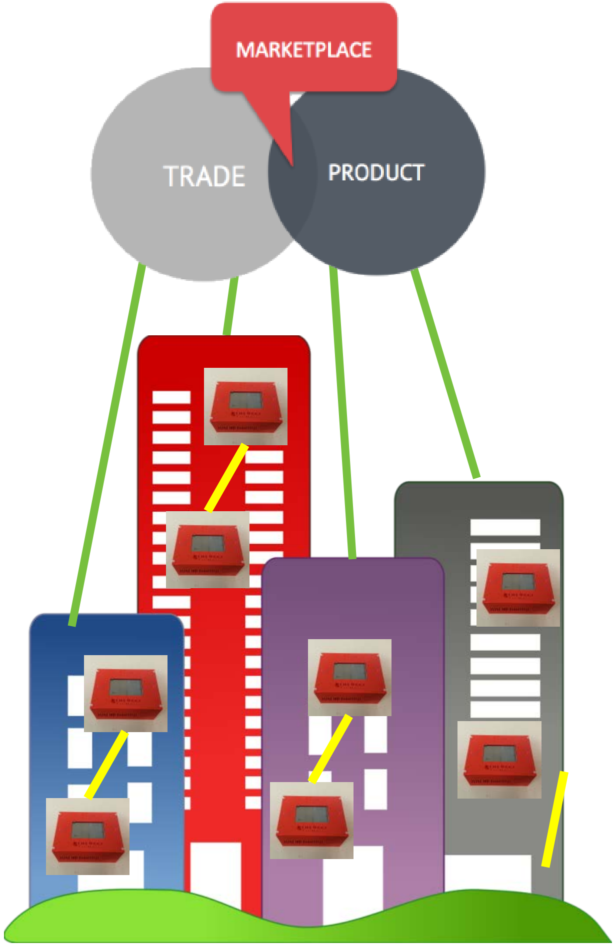
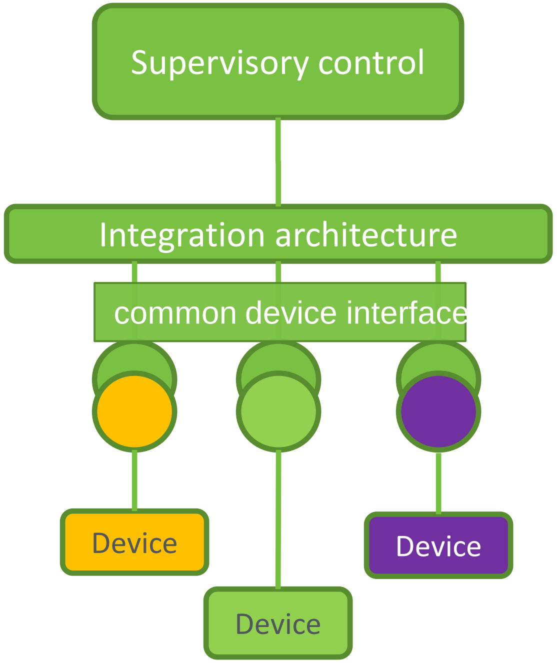
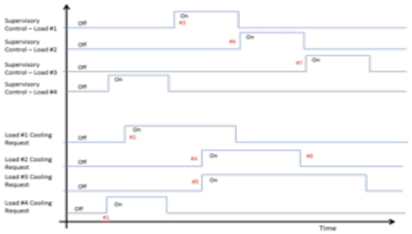
Unified Control of Connected Loads

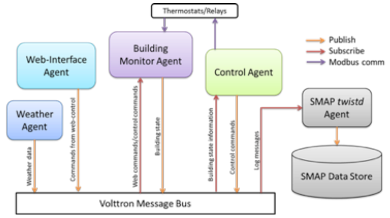
2017 Building Technologies Office Peer Review







Supervisory Control Example for Multiple Load Case



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Project Summary

Timeline:

Start date: 3/1/2016

Planned end date: 9/30/2018

Key Milestones

1. Document detailed economic benefit analysis opportunity for small- and medium-sized buildings (12/31/2016)
2. Extend control to enable dynamic load shaping and document testing of control with dynamic load (3/31/2017)
3. Integrate utility DR signal into the prototypical control systems to perform adaptive load shaping response (6/30/2017)
4. Deployment site selection in collaboration with Emerson and Southern and document field deployment site selection (9/30/2017)

Key Partners:

Emerson	Southern Company

Budget:

Total Project $ to Date:

- DOE: $750,000
- Cost Share: $150,000

Total Project: $2,500,000

- DOE: $2,000,000
- Cost Share: $300,000

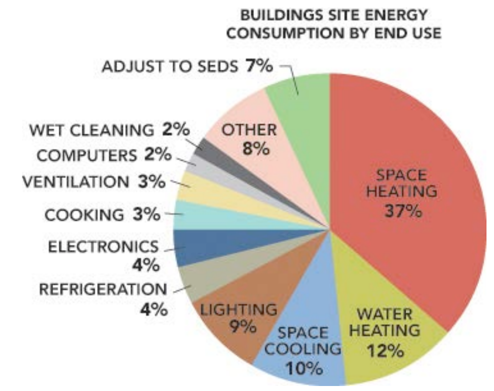
Project Outcome:

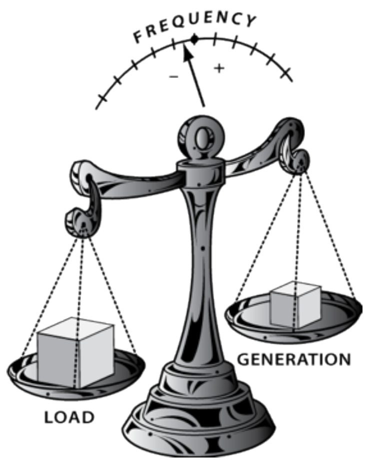
The outcome of the project is retrofit-compatible control technology to connect loads within buildings to enable information exchange and demonstrate applications that reduce energy costs and enable grid-response capability. The technology will target MYPP goals of 33% decrease in cost of reserve margins while maintaining reliability by 2025 and demonstrate reliable building load dispatch to achieve 50% decrease in the net integration cost of distributed energy resources by 2025.

Purpose

Problem Statement:

- Buildings consume up to 40% of energy produced in the US
- Sensors and controls have demonstrated potential to reduce building energy consumption by 20-30%
- Savings can be realized only by retrofit solutions: 1-2 year payback to facilitate adoption
- Seamless self-aggregation technologies are needed to exploit potential
- Small Footprint Supermarkets
  - 37,000 supermarkets in the US
    - 2,000,000 kWh per year per store
    - 1,000,000 kWh per year for refrigeration
  - Substantial opportunities for energy savings, demand reduction, and to provide energy services
    - Supermarkets and grocery Stores
    - Convenience stores
    - Restaurants and food services





Project Focus: Develop a retrofit system for coordinating the operation of multiple loads to - reduce peak demand, reduce energy consumption, and providing transactive energy services to the electric grid.

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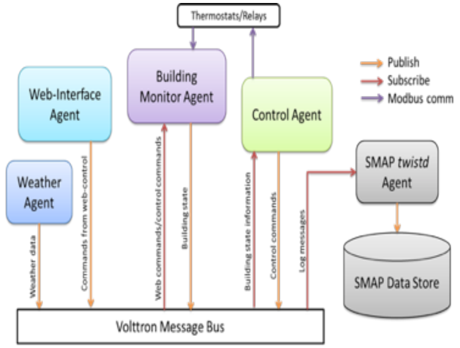
Objectives

- Develop whole-building, retrofit-**supervisory load control** for improving energy efficiency and reducing peak demand by coordinating various building loads
  - Heating Ventilation and Air Conditioning (HVAC)
  - Commercial Refrigeration
- Develop **grid responsive load control** technology that can be deployed at large-scale to provide novel grid services (namely, ancillary services and renewable penetration)
- Deploy platform-driven technology for **seamless self-aggregation** of building-level loads for providing grid services
- **Partnership** with a building equipment **manufacturer** and an electric utility to demonstrate algorithms and techniques developed on an open-source control platform in real building sites



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Target Market and Audience and Impact of the Project

Target Market and Audience:

- Commercial buildings.
  - **Small and medium commercial buildings** – improved control of energy providing opportunity for 6-8 quads of energy savings potential
  - **Small-footprint supermarkets** – improved control of energy use optimization, and grid integration
- Building automation system and equipment manufacturers for OEM integration

Impact of Project: The project envisions reducing the cost barriers to deploying advanced controls to enable optimization of energy usage. The project will develop and demonstrate retrofit control technology along with path towards deployment.

- <u>Near Term</u>: Demonstrate end-to-end technology and identify path towards low-cost deployment through industrial partnerships
- <u>Intermediate Term</u>: Identify building equipment and automation manufacturing partner(s) for commercialization and deployment tailored to specific building applications
- <u>Long Term</u>: Demonstrate energy savings and grid responsiveness realized by widespread adoption of the technology within buildings

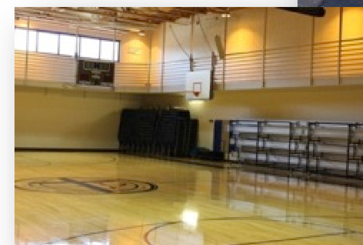
Impact on Buildings Technology: Advanced sensor, control technology brings big growth to building energy management market: <u>$2.14 billion industry by 2020</u> (Lux Research)

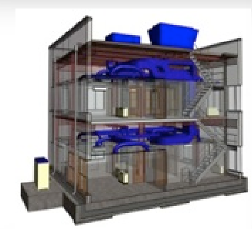
Approach

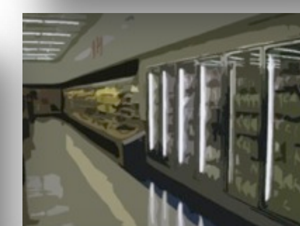
- Develop control techniques for reducing peak demand and improving energy efficiency of rooftop units and supermarket refrigeration systems and integrate photovoltaic sources

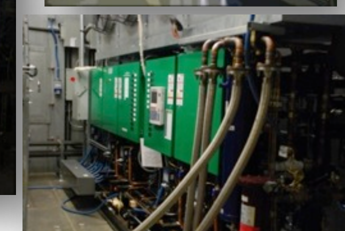
Key Issues: Low-cost, “low-touch” retrofit of control technology into buildings and refrigeration systems to facilitate transactive opportunities for energy efficiency and with the electric grid

Distinctive Characteristics: Our approach integrates control technologies into buildings to reduce peak demand with minimal retrofit cost

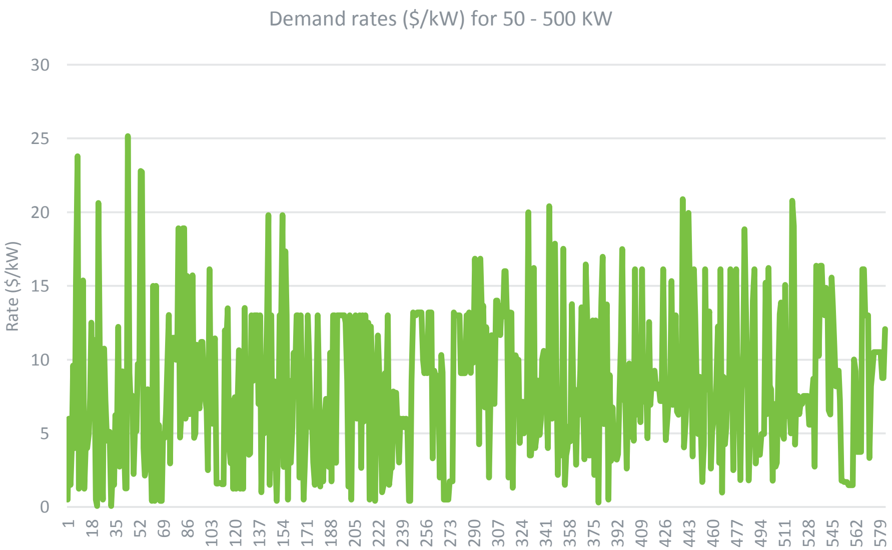


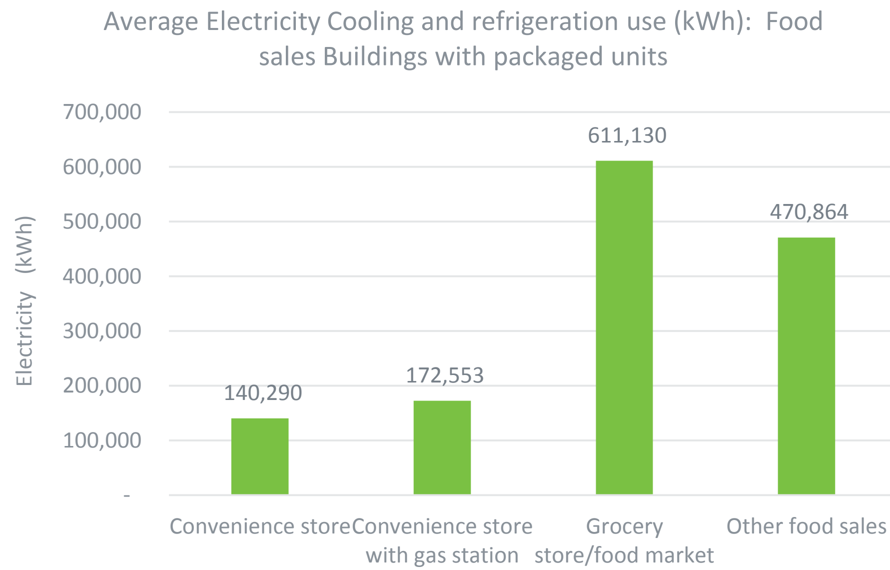






Economic Potential





Type	No of buildings	kWh/building	avg kWh/hr	Peak (kW)/building	Peak MW
Convenience store	69,564.06	140,290	16	25	1,743
Convenience store with gas station	50,190.07	172,553	20	31	1,547
Grocery store/food market	34,701.09	611,130	70	109	3,787
Other food sales	1,245.71	470,864	54	84	105

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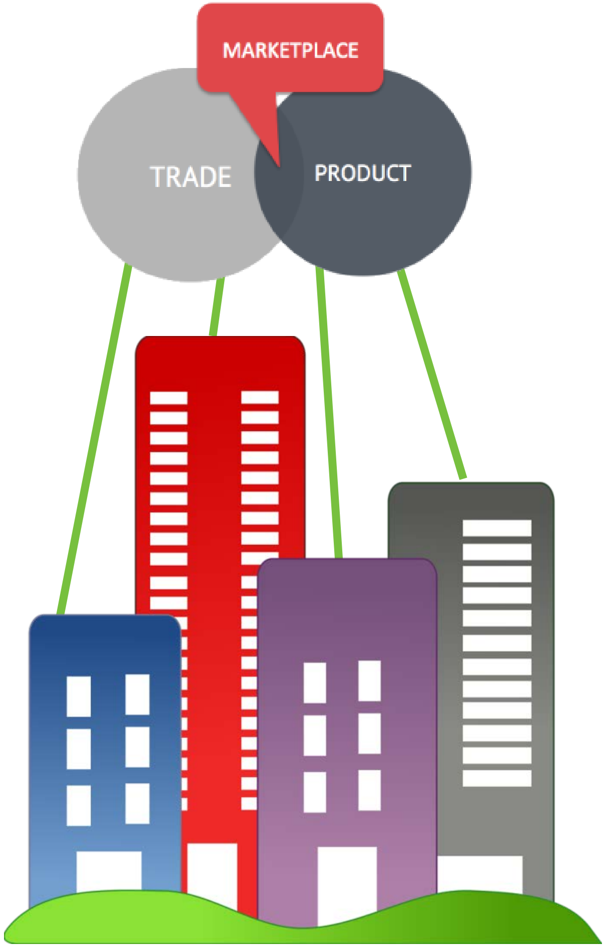
A Multi-level Strategy

- Our goal is an integrated set of control strategies that realize the three main aims:
  - Peak demand reduction, on demand defrost
  - Energy efficiency
  - Provide services to the electrical grid
- A priority-based scheme for achieving peak demand reduction within a building
- A transactive approach to demand shed
  - Priorities and nominal load are communicated to a community wide demand shed "marketplace" where they serve as the "price" of supplying the service: price a function of priority and nominal load
  - When a demand shed is requested, the "market" clears at "price" that meets the request
  - Loads that are below the clearing price provide the service and receive the economic benefit
  - Price function constructed to favor shedding of active loads with lowest priority and highest nominal power (i.e., cheapest)

Connected loads participate in a larger marketplace to provide grid services



Connected loads within a building provide peak demand reduction and energy efficiency to the building owner

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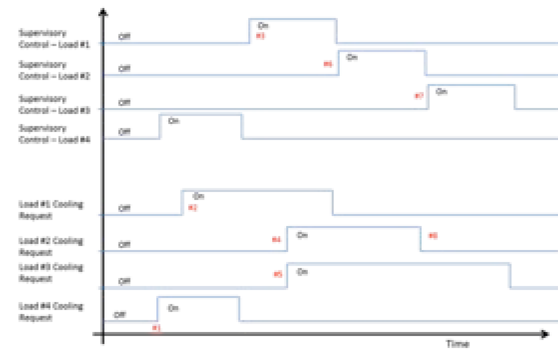
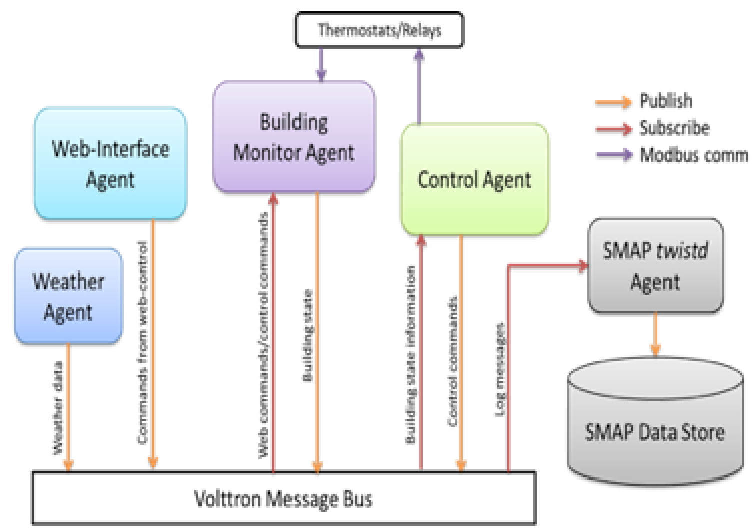
Supervisory Control of Connected Loads

- Supervisory load control for flattening or otherwise shaping the load profile
  - Peak demand reduction, on demand defrost
  - Energy efficiency
  - Provide services to the electrical grid
- Operate loads within safety constraints set by control sub-systems for individual equipment
  - e.g., by using thermal storage in refrigerated cases and room air to calculate scheduling slack
- Enable **self-aggregation** framework for loads
  - Cloud-based interfaces
  - Upgrade existing buildings
  - Information exchange
  - Transact with electric grid

SOUTHERN COMPANY | Pacific Northwest NATIONAL LABORATORY | EMERSON



Supervisory Control Example for Multiple Load Case



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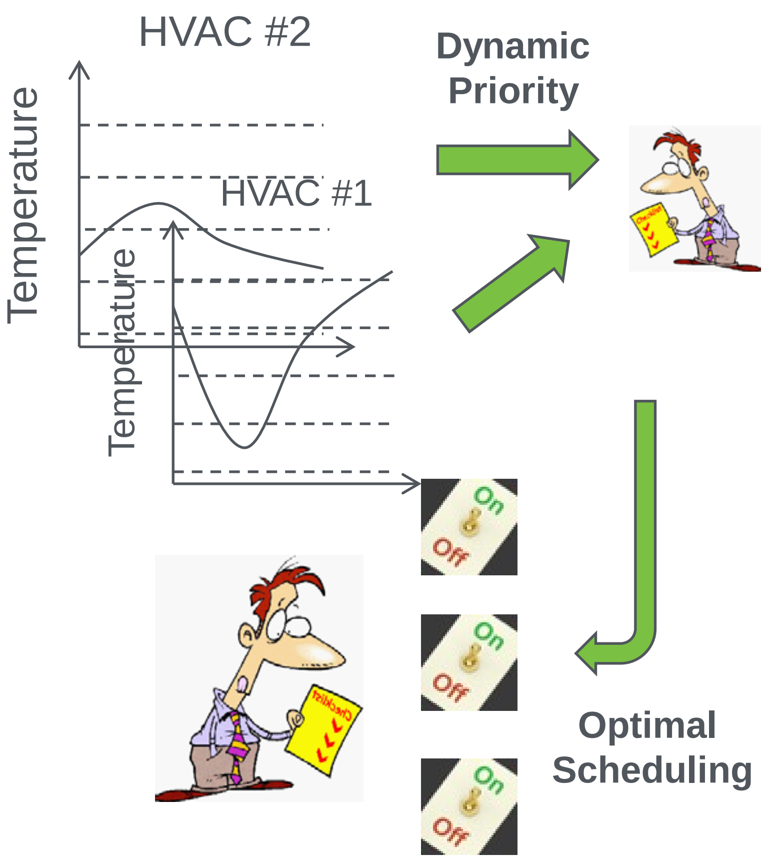
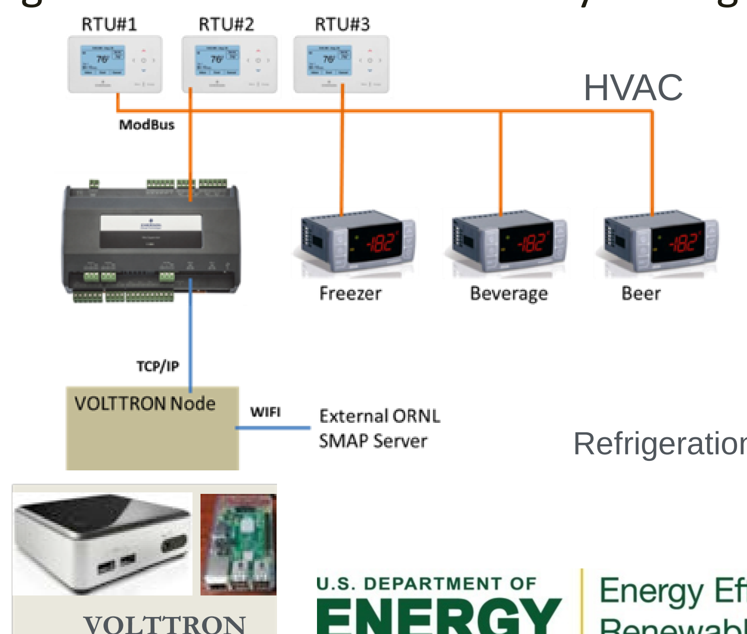
Control Formulation Priority-based Control – 2-step Implementation

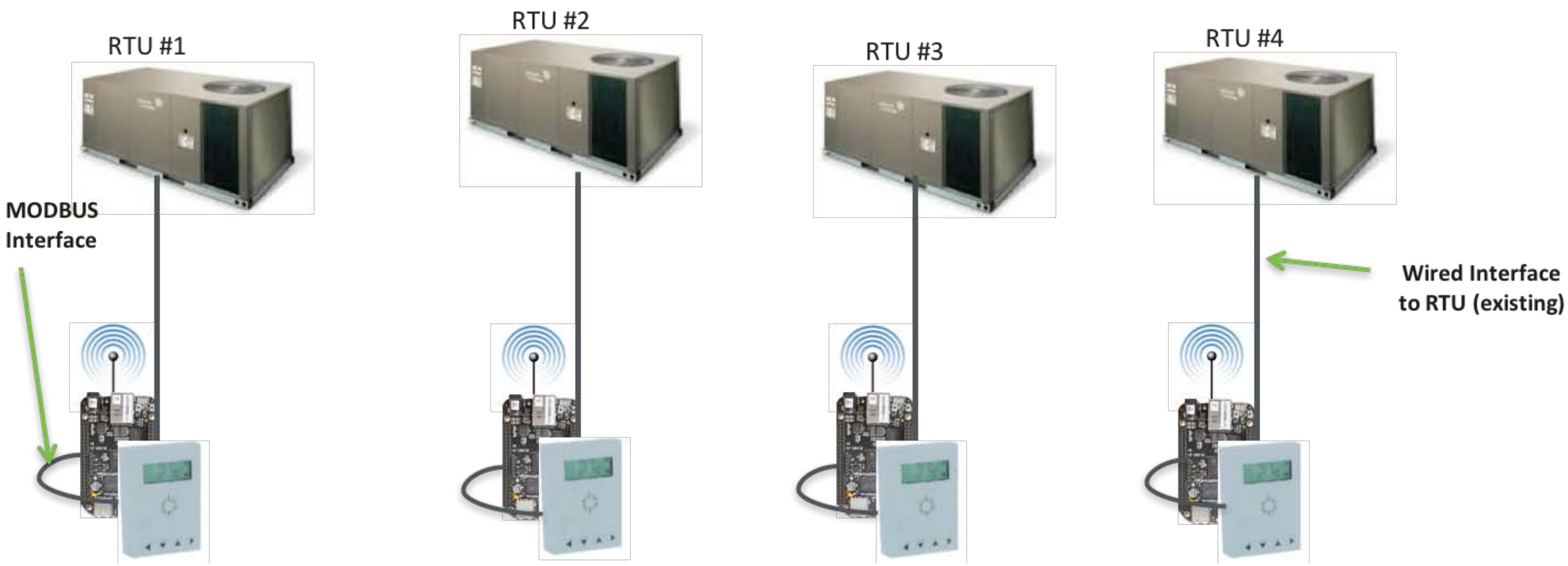


$$p = \begin{cases} \text{ceil}\left(\frac{T-S}{0.1}\right) & \text{if } 0 < T - S < 1 \\ 0 & T \leq S \\ 10 & T - S \geq 1 \end{cases}$$

- Earliest Deadline First (EDF) scheduling utilized
  - Dynamic scheduling algorithm based on priority queue
  - HVAC Constraints imposed into optimal selection
    - Both for activation and deactivation
    - Requests to deactivate may be ignored to avoid, e.g., short cycling a compressor
- Simultaneously track equipment status - past activity
- Activate HVACs according to priority and desired limit N on number of simultaneously active units
- Algorithm is tested for arbitrary scaling



V-Stat Development



- Peer-to-peer communication to share state of each RTU and estimation of future states
- Small form factor and plug compatible with Thermostat interface but provide “app loading” functionality
- Different agents are distinct entities and interact through messages on the bus
- Remote Protocol Calls can allow direct interaction between agents
- Agents can publish/subscribe to external VOLTTRON™ platforms via TCP/IP

Iterative Development

- Develop and demonstrate controls that meet individual objectives
  - Peak demand, on demand defrost, energy efficiency
- Integrate proven strategies into the multi-level system

V-Stat

Demand defrost

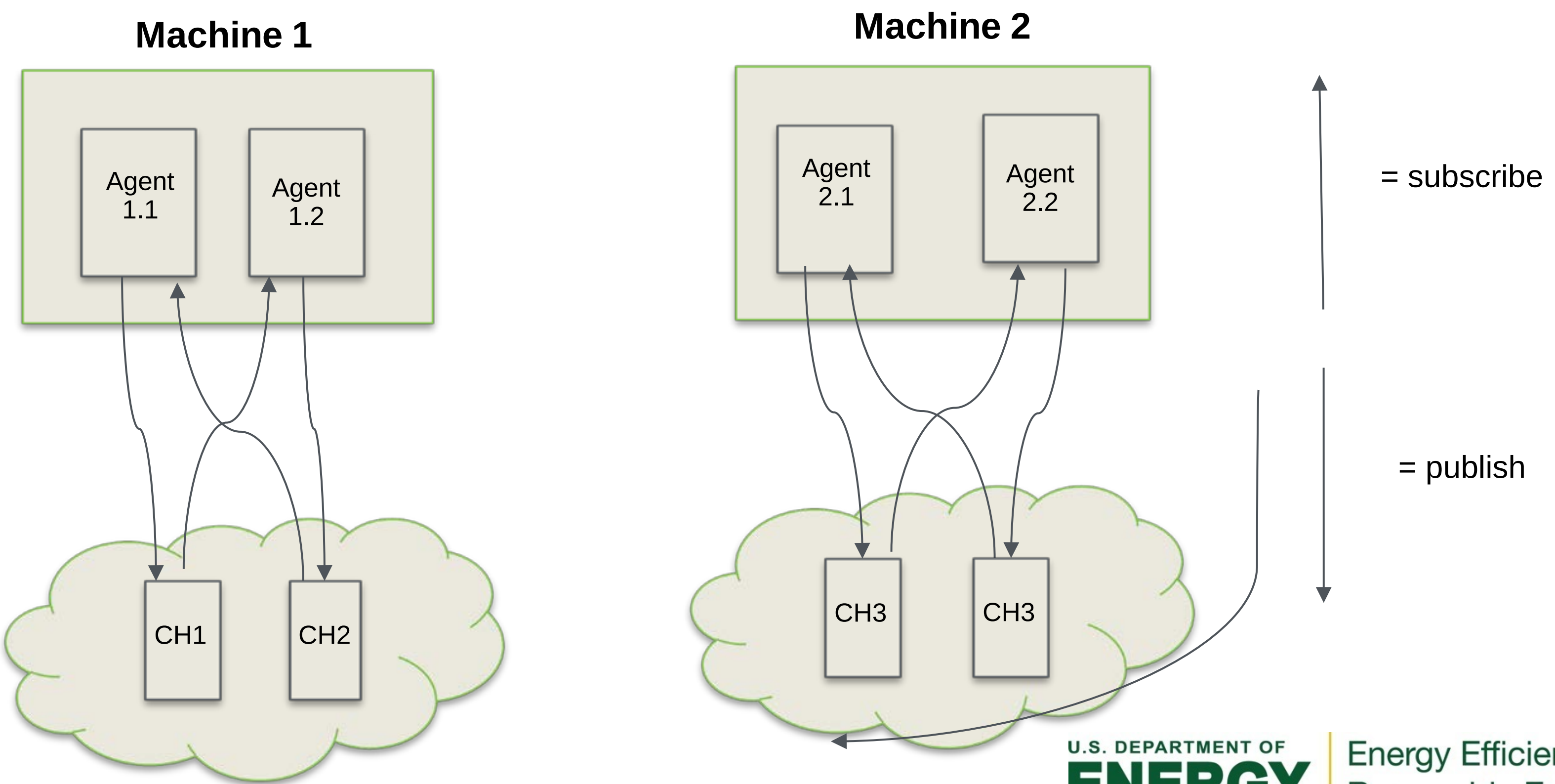
DR “marketplace”

Supervisory control for peak demand reduction

Integrated PDR, dynamic demand shed control

VOLTTRON™ – Architecture

- Different agents are distinct entities and interact through messages on the bus
  - Remote Protocol Calls can allow direct interaction between agents
  - Agents can publish/subscribe to external VOLTTRON™ platforms via TCP/IP



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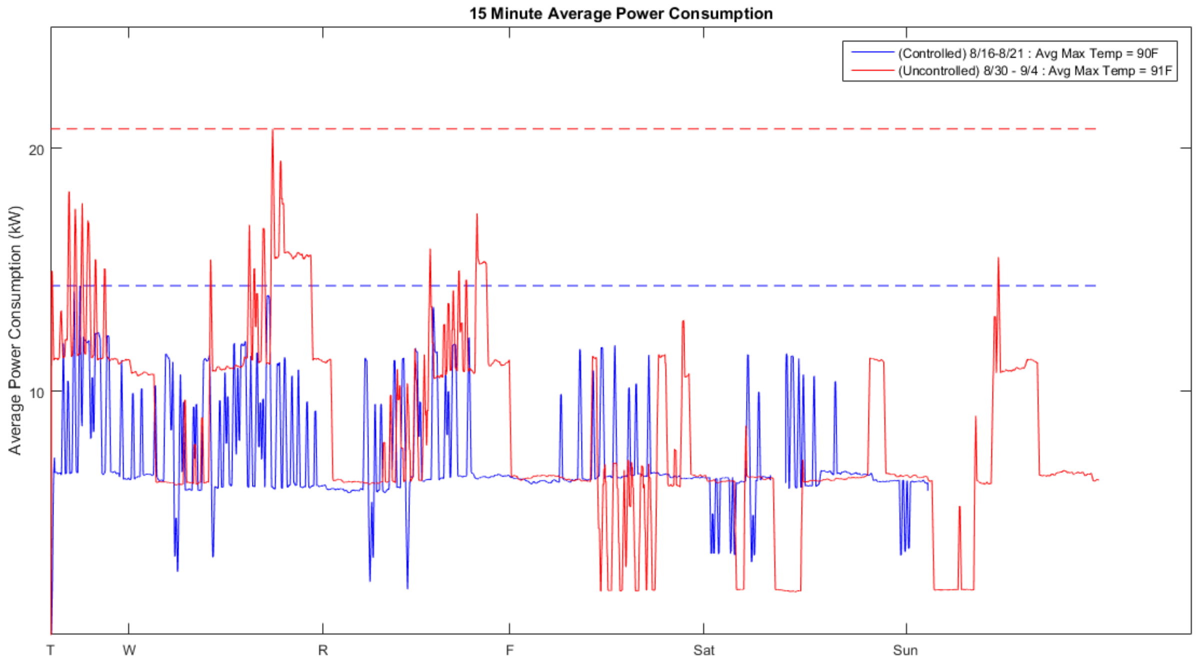
VOLTTRON™ – Security

- VIP holds several authentication steps to allow external platform communication
- Authentication is confirmed by public and private security keys generated by the platforms
- **Authentication Steps**
    - Platforms only accept connection requests from “known hosts” (IP + security key)
    - Incoming published messages must present themselves with security keys generated by the agent and known to the subscriber
    - Security permissions can be made more sensitive by allowing only specific agents access to different platforms

Deployment Plan

- Demonstration of retrofit supervisory controls for buildings/stores
- Deployment in Dollar General Stores
- Open-source solution expandable to other small foot-print supermarkets

EMERSON
Climate Technologies



Progress and Accomplishments

Accomplishments:

- Supervisory control framework developed to interact with building/store loads
- Peak demand reduction developed and tested at real building
- Algorithm for using refrigerated display cases for demand response developed
- Preliminary control formulation for grid-responsive load shape generation
- Thermostat formulation of control with VOLTTRON™
- Integration with OEM equipment controls and utility through partnerships

Market Impact:

- Reduce the cost barrier to deploying advanced sensors and controls to optimize energy usage (improve by 20-30%) with in buildings.
- Control algorithm transitioned to Emerson for field deployment and Dollar General, FL
- Demonstrations to potential industrial partners and engaging in discussions tailored for building monitoring applications.

Awards/Recognition: None

Lessons Learned: Understanding of equipment operational performance is required for seamless deployment; Address interoperability and automated discovery tools for seamless deployment.

Project Integration and Collaboration and Next Steps

Project Integration: The project is led by ORNL and the team includes experts from control systems, building technologies, and HVAC equipment. ORNL team is collaborating with Emerson Technologies – building equipment manufacturer. Bi-weekly phone calls are used for project progress discussion.

Partners, Subcontractors, and Collaborators: The project team is working with Emerson to enable deployment and understand requirements for the small footprint supermarket. Team is working with Southern Company to understand utility signals

Communications:

- Brian Fricke, Teja Kuruganti, James Nutaro, David Fugate, Jibonananda Sanyal, "Utilizing Thermal Mass in Refrigerated Display Cases to Reduce Peak Demand", 2016 Purdue Conference on Refrigeration and Air Conditioning, July 11-14, 2016, West Lafayette, IN
- James Nutaro, Ozgur Ozmen, Jibonananda Sanyal, David Fugate, Teja Kuruganti, "Simulation Based Design and Testing of a Supervisory Controller for Reducing Peak Demand in Buildings", 2016 Purdue Conference on High Performance Buildings, July 11-14, 2016, West Lafayette, IN
- Jibonananda Sanyal, James J Nutaro, David Fugate, Teja Kuruganti, and Mohammed Olama, "Supervisory Control for Peak Reduction in Commercial Buildings While Maintaining Comfort," ASHRAE and IBPSA-USA SimBuild 2016 Building Performance Modeling Conference, Salt Lake City, UT, August 8-12, 2016
- M. M. Olama, T. Kuruganti, J. J. Nutaro, J. Dong, and J. Sanyal "Coordination and Control of Building HVAC Units to Provide Ancillary Services to the Smart Grid," IEEE Transactions on Smart Grid, October 2016 (*Submitted, In Review)*

Next Steps and Future Plans:

- Deploy peak demand reduction controls at Dollar General in Florida
- Develop control application to demonstrate grid-responsive load shape
- Deploy fault detection and diagnosis technologies for improving energy efficiency
- Deliver open-source platform for achieving utility-scale grid responsive controls

REFERENCE SLIDES

Project Budget

Project Budget: $450K (FY16), $300K (FY17)
Variances: None
Cost to Date: $200K
Additional Funding: None

Budget History					
FY 2016 (past)		FY 2017 (current)		FY 2018 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$450K	$100K	$700K	$100k	$850	$100K

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Project Plan and Schedule

Project Schedule												
Project Start: 3/31/2016	Completed Work											
Projected End: 9/30/2018	Active Task (in progress work)											
	Milestone/Deliverable (Originally Planned) use for missed milestones											
	Milestone/Deliverable (Actual) use when met on time											
	FY2016				FY2017				FY2018			
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												
Q4 Milestone: Develop draft reference guide for retrofit whole-building control platform using VOLTTRON incoportating peak demand management control, and grid-responsive												
Q4 Milestone: Deployment site selection in collaboration with Emerson and Southern and document field deployment site selection												
Q1 Milestone: Document detailed economic benefit analysis opportunity for small- and medium-sized buildings												
Current/Future Work												
Q2 Milestone: Extend control to enable dynamic load shaping and document testing of control with dynamic load shaping on a suitable commercial building test site using												
Q3 Milestone: Develop draft reference guide for retrofit whole-building control platform using VOLTTRON incoportating peak demand management control, and grid-responsive												
Q4 Milestone: Deploy in collaboration with Emerson and Southern and document field deployment site selection												

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