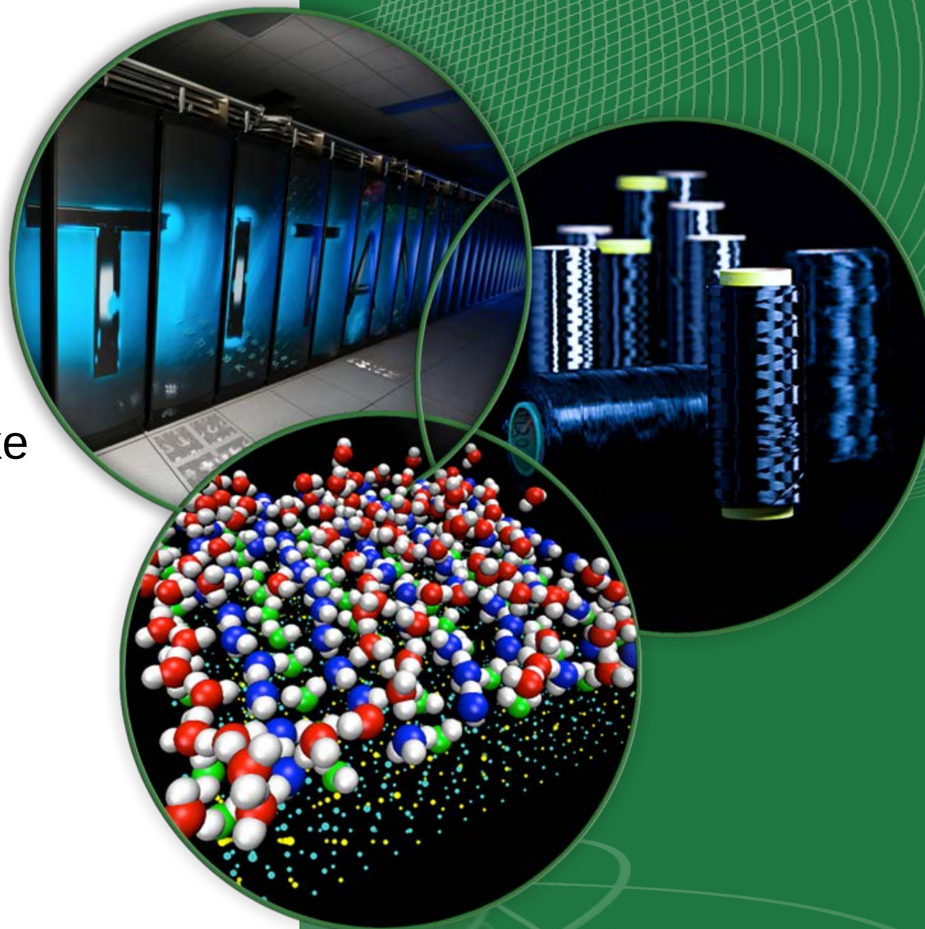
Utilizing VOLTTRON™ Platform for Enabling Energy Efficiency and Grid-Responsiveness of Building Loads



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Oak Ridge National Laboratory

John Wallace

Emerson Climate Technologies

Presented at:

Technical Meeting on Software Framework for Transactive Energy: VOLTTRON

4th – 5th August, 2016

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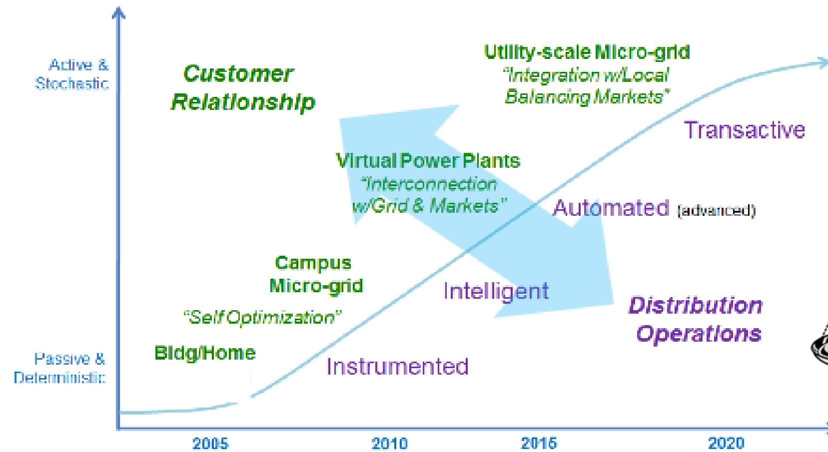
Goals - The Transactive Letter

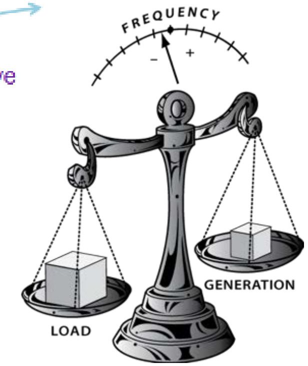
- From the Grid Perspective
  - Increase and enhance the hosting capacity of EE and RE technologies at scale - *"thinking beyond DR"*
    - (Fast) Demand Response
    - Ancillary Services
    - Load Shifting
- From the Building Perspective
  - encourage transactive markets, both regulated and non-regulated, behind the meter to **drive EE** deeper or through new means - *"thinking beyond EE"*
    - Fully automated, self learning, dynamic and responsive
    - Create a market for EE solutions to DRIVE
    - Seamless deployment

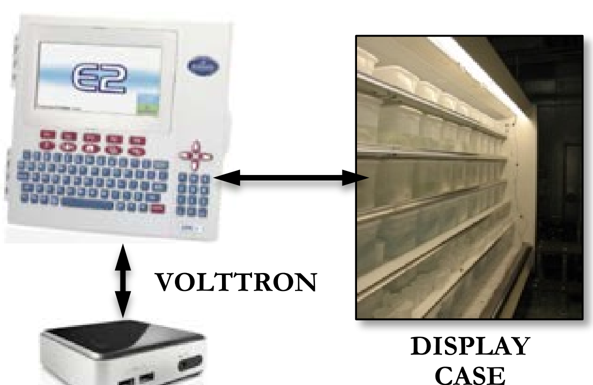
Transactive Energy – Energy Efficiency & Grid-responsive

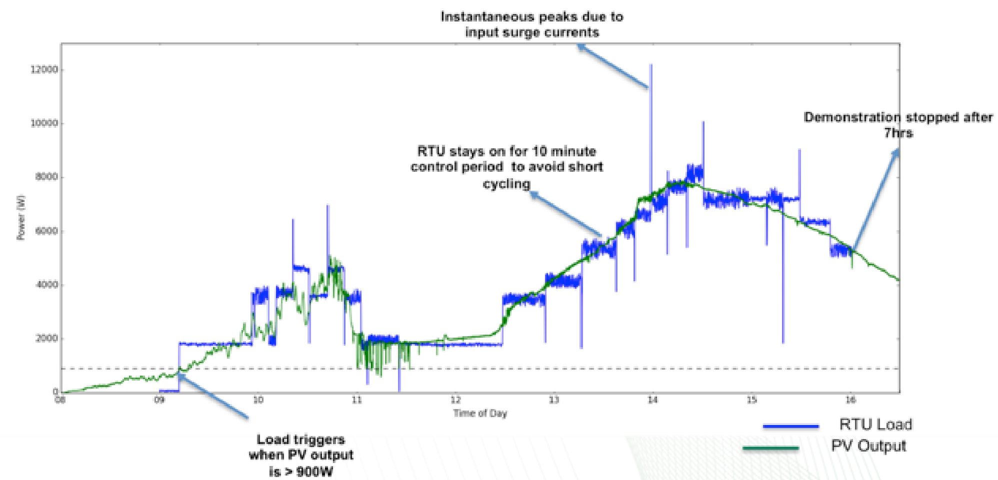
- High-speed wide area control loosely coupled loads
- Control response
  - Centralized or distributed
  - Utility level information
  - Building-level loads
- VOLTTRON Platform
  - Unlocking Load Potential



Stages of adoption of transactive operations for industry
Source: Paul De Martini, 1st International Conference and Workshop on Transactive Energy[9]







EMERSON. Climate Technologies

5.5 million commercial, 117 million residential,
projected to be 80% of load growth through 2040

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Key Applications

Connected Loads

Supervisory Control of Various Building Loads

Modulate Load Shape – Renewables, EE, Grid Response

DER Integration

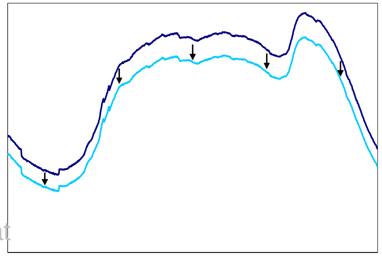
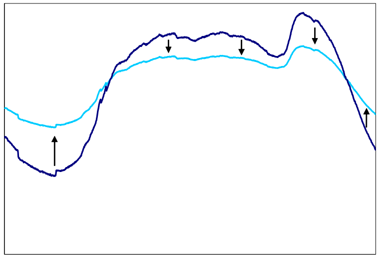
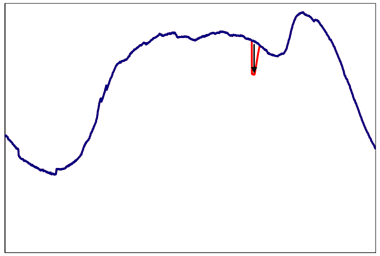
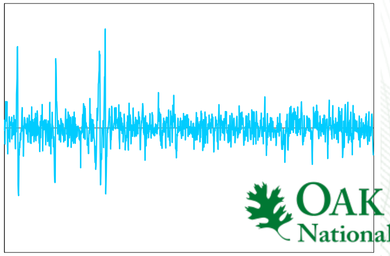
Open-source Interfaces to Inverters and Appliances

RE-responsive load control

Demonstrations

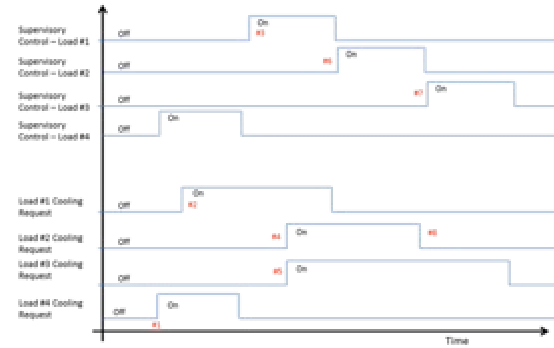
Connected Homes

Connected Neighborhood

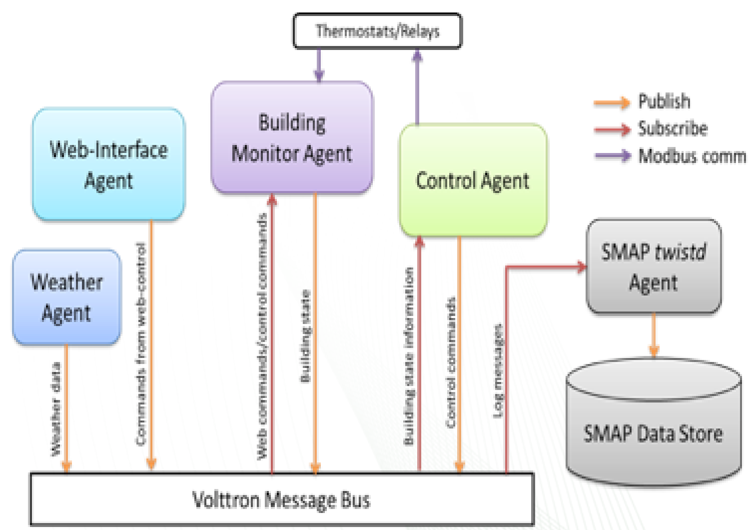





Connected Loads

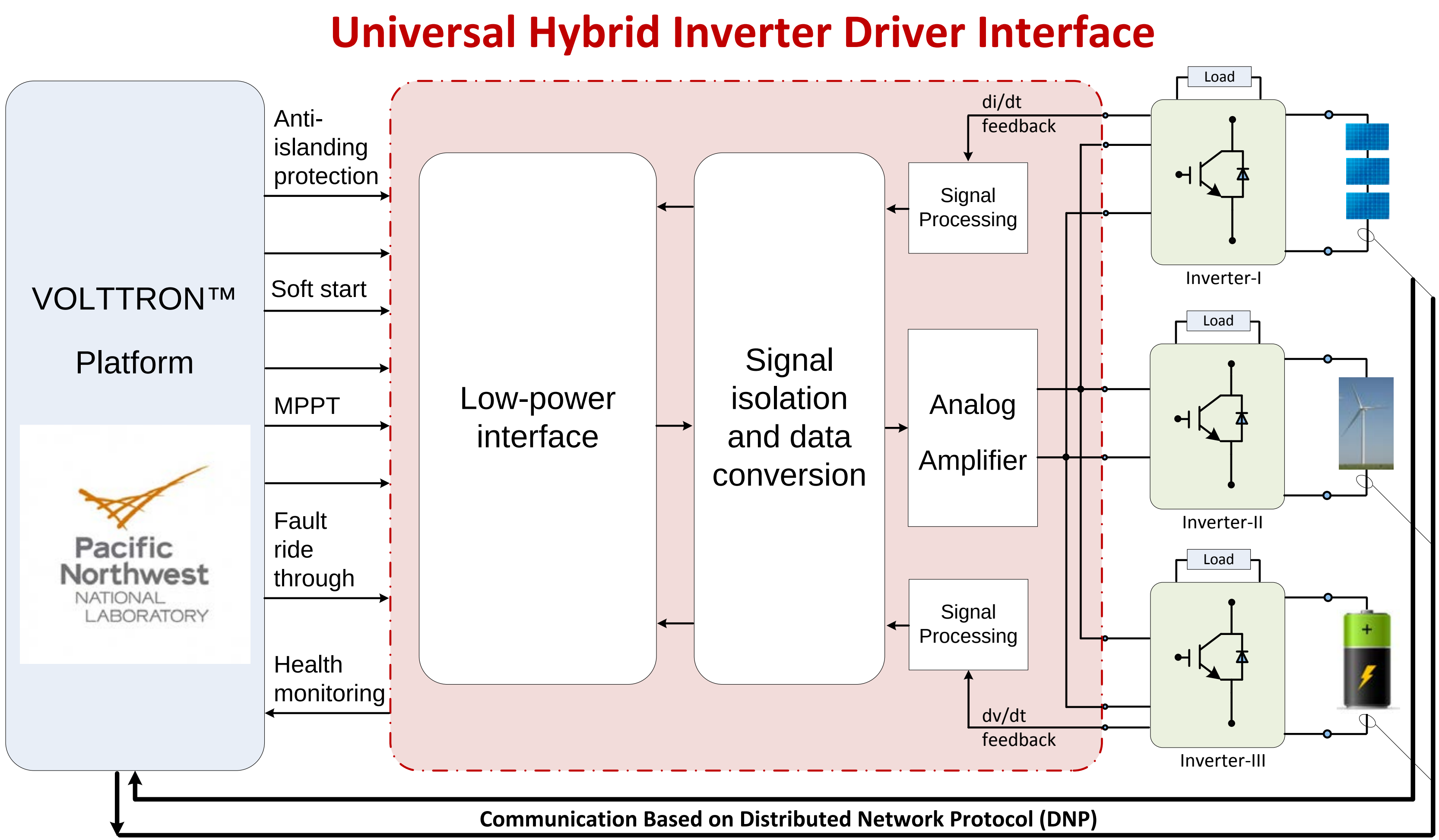
- Supervisory load control for flattening or otherwise shaping the load profile
  - Flat load profile to reduce peak demand charges
  - Intelligent load shed prioritization
  - Enable transactive applications such as demand response, support for renewables, etc. that generate revenue generating for the building owner
  - Generate desired load shape
- 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
- Data-driven analytics for fault-detection
  - Reduce operational inefficiencies of refrigeration and HVAC systems



Supervisory Control Example for Multiple Load Case



VOLTTRON™ Enabled DER Power Electronics Applications



Connected Homes & Neighborhood

- Open-source VOLTTRON platform enabling the full potential of connected equipment in residential buildings
- Demonstrate technologies in partnership with Southern Company in their “**Neighborhood of the Future**”
- Quantify impacts of transactive controls, energy efficient construction, and building-level renewable generation and storage.

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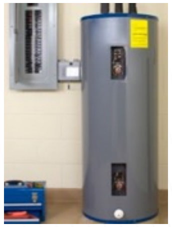
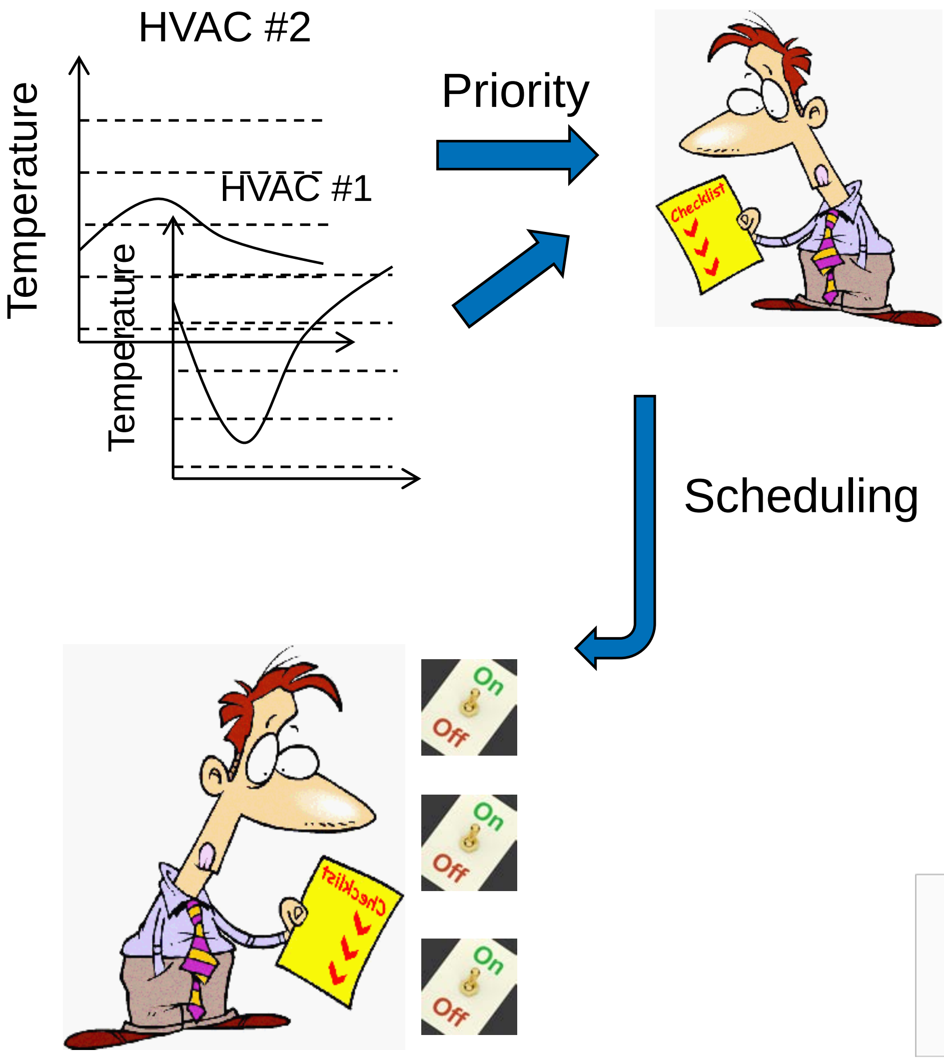
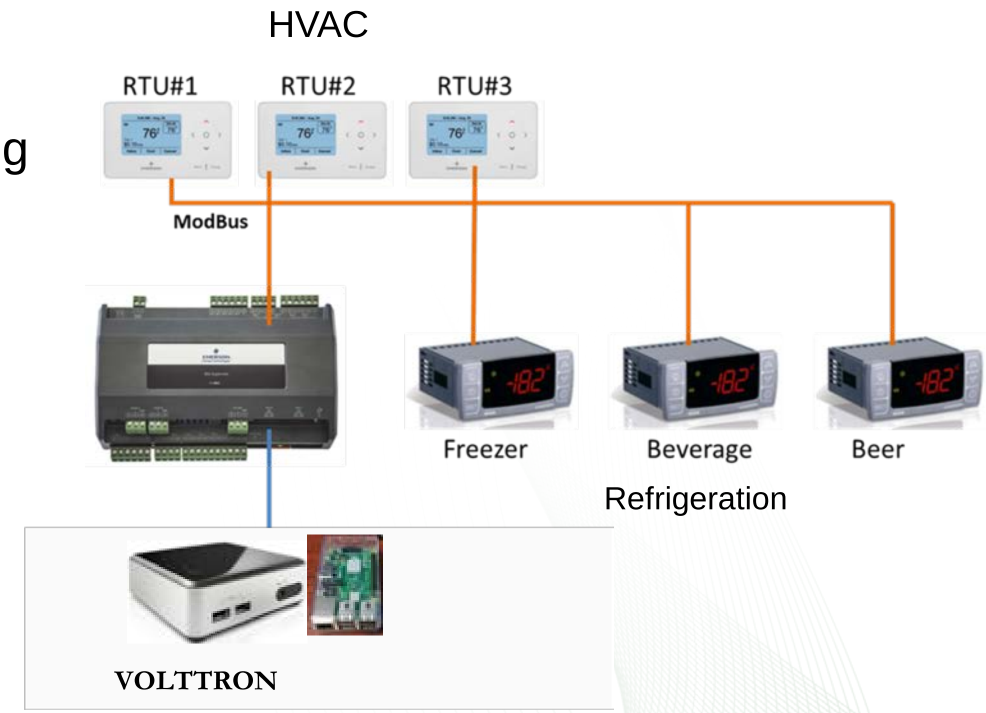
Emerson
Southern Company
GE
UTSA
AO Smith
Johnson Controls
EPRI
Rheem
Pacific Northwest National Laboratory
ecobee
REALTOR
NREL National Renewable Energy Laboratory



Supervisory Control – Peak Demand Reduction

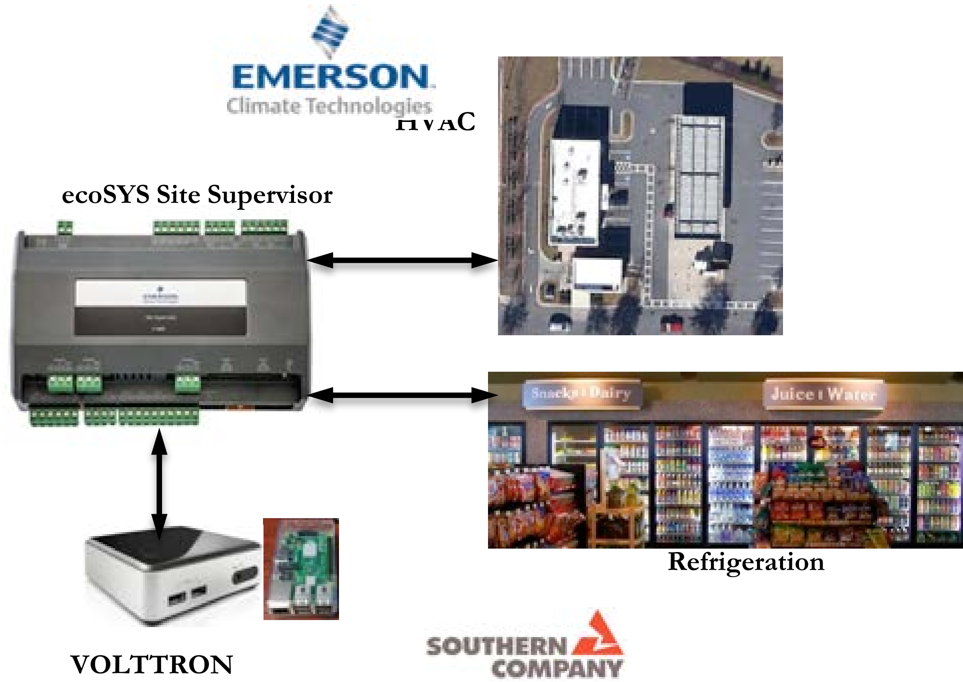


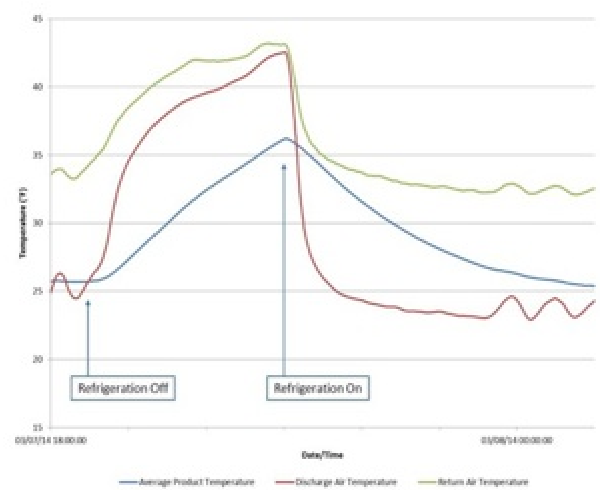
$$p = \begin{cases} \text{ceil}\left(\frac{T-S}{0.1}\right) & \text{if } 0 < T - S < 1 \\ 0 & T \leq S \\ 10 & T - S \geq 1 \end{cases}$$



Deployment Strategy

- Retrofit deployment to existing buildings/stores
- Emerson has significant market
  - Supermarkets – 22,641
  - Small Format – 19,600
  - C Store – 5800
- Southern Company
  - Demand side research
  - Neighborhood of future
  - Utility rate structure
  - Commercial buildings
- VOLTTRON device – retrofit integration with site supervisor/E2 for control demonstration and validation
- Embedded computing devices that interact with loads to improve controllability





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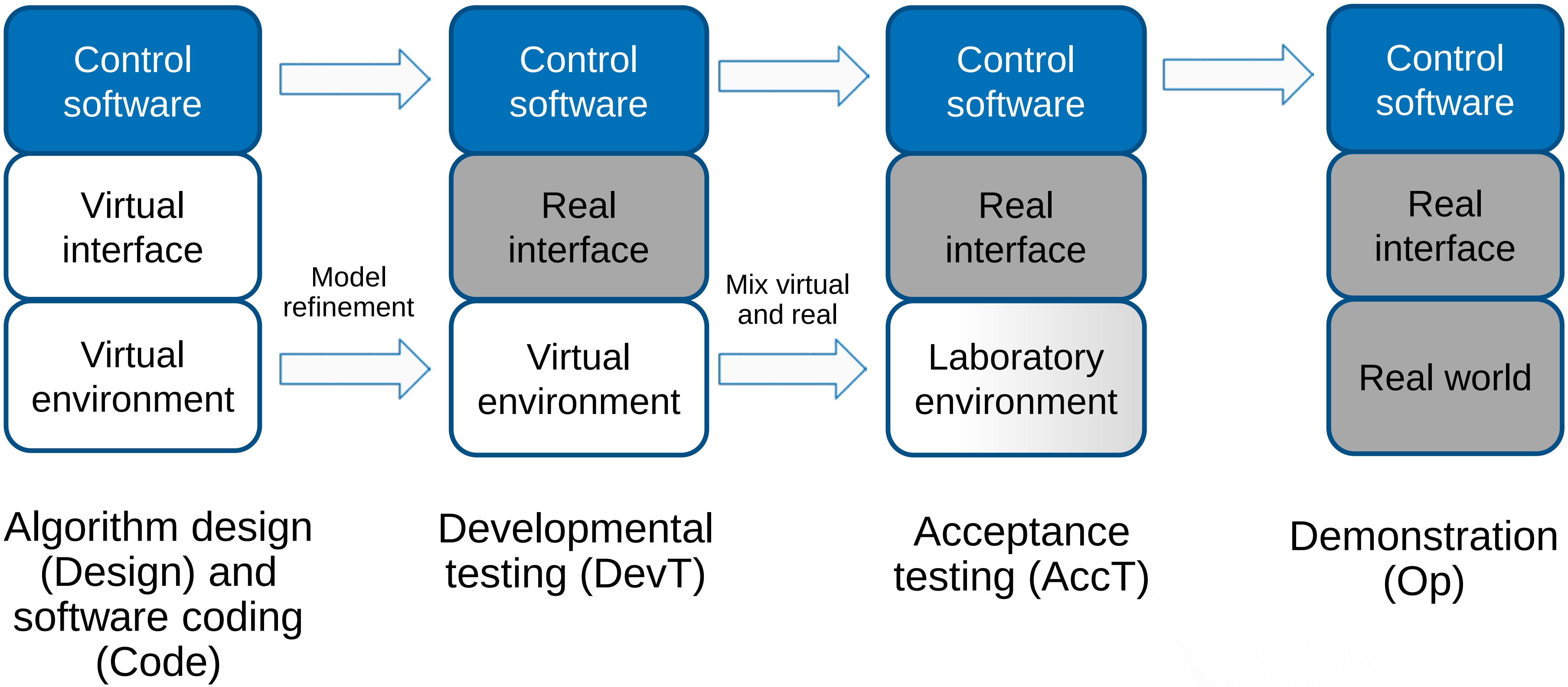
Incremental approach to Scalable Applications



- VOLTTRON on TinyCore
  - ~200 MB footprint – took some orchestrating
  - Connects over simulated serial to virtualized devices
  - Connects over simulated network to other V nodes
- Write & Test code as they are to be deployed and used

Developmental Testing

- A simulated building is accessed by the new control software via simulated Modbus library calls and operating systems calls.
  - The simulated Modbus library and system calls are implemented in a software library that is linked with the control software for testing
  - For deployment, the control software is linked with the actual Modbus library and operating system functions
- This approach allows much of the software *as it will be deployed* to be tested in *faster than real time*
  - More comprehensive testing that is possible in a hardware testbed
  - Enables model continuity – can avoid error prone transition from modeled control algorithm to deployable software

Building model

$$T_1 = \frac{1}{C_1}\left(\frac{T_2 - T_1}{R_{12}} + \frac{T_4 - T_1}{R_{14}} + \frac{T_a - T_1}{R_{a1}} + Q_{s1} + u_1 h_1\right)$$

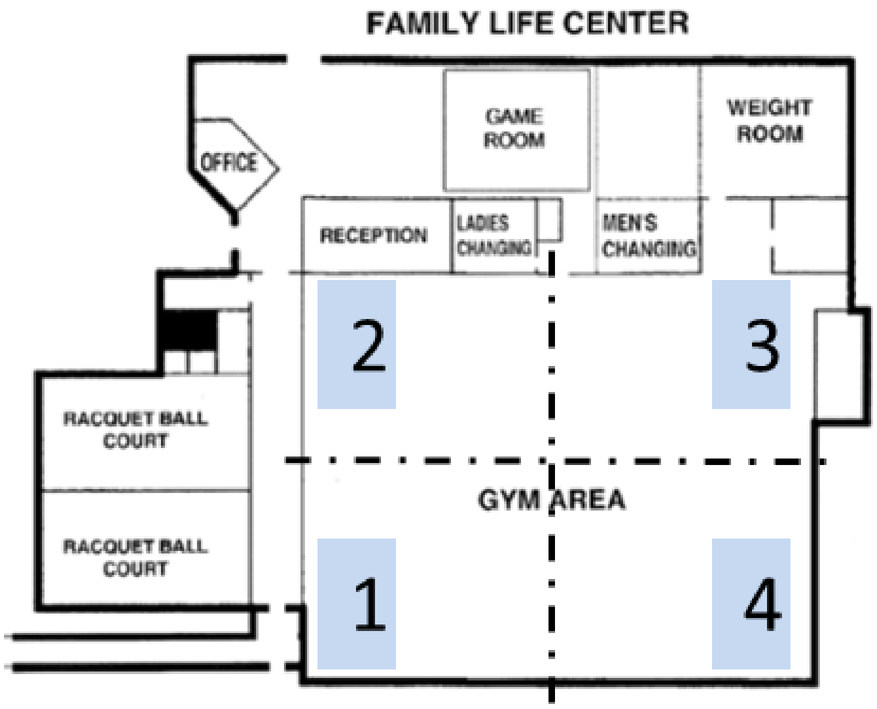
$$T_2 = \frac{1}{C_2}\left(\frac{T_1 - T_2}{R_{12}} + \frac{T_2 - T_3}{R_{23}} + \frac{T_a - T_2}{R_{a2}} + Q_{s2} + u_2 h_2\right)$$

$$T_3 = \frac{1}{C_3}\left(\frac{T_2 - T_3}{R_{23}} + \frac{T_4 - T_3}{R_{34}} + \frac{T_a - T_3}{R_{a3}} + Q_{s3} + u_3 h_3\right)$$

$$T_4 = \frac{1}{C_4}\left(\frac{T_1 - T_4}{R_{14}} + \frac{T_3 - T_4}{R_{34}} + \frac{T_a - T_4}{R_{a4}} + Q_{s4} + u_4 h_4\right)$$

Table 1: Ranges for parameter values

Parameter	Value range	Units
C_k	252,628.5 ± 10%	Joules / Degrees Centigrade
R_{ik}	1000 ± 10%	Watts / Degrees Centigrade
R_{ai}	10 ± 10%	Watts / Degrees Centigrade
Q_k	1,710 ± 10%	Watts
h_k	17,500 ± 10%	Watts
S	21.111 (70)	C (F)



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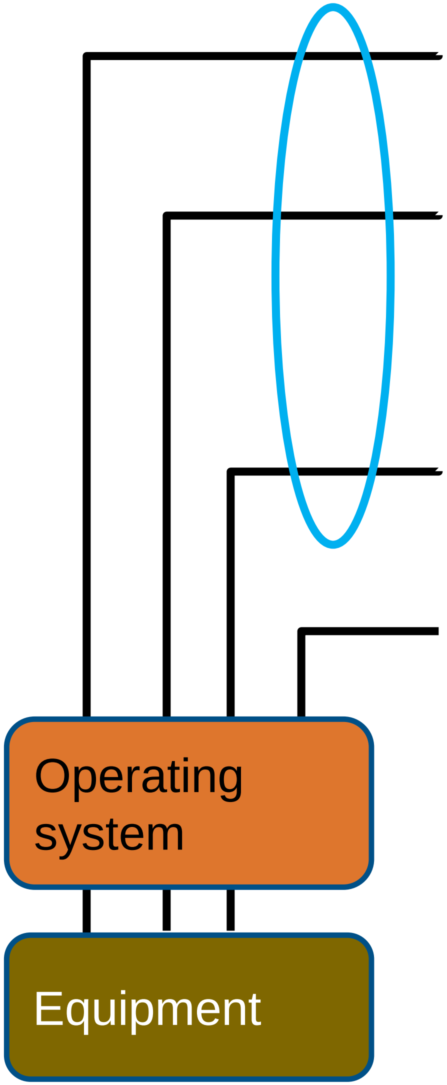
Testing with hardware

```
// Wait 10 minutes
sleep(10*60);
// Fetch temperature measurement
// from serial port
temp = read_temp_from_serial_port();
// Decide on a control action
what_to_do = process_data(temp);
// Send the command out through
// the serial port
write_cmd_to_serial_port(what_to_do);
// Record measurement and action
// to a file on disk
write_to_disk(temp,what_to_do);
```



Calls that **interact with the world outside of the software** are handled by the operating system, which by operates in real time

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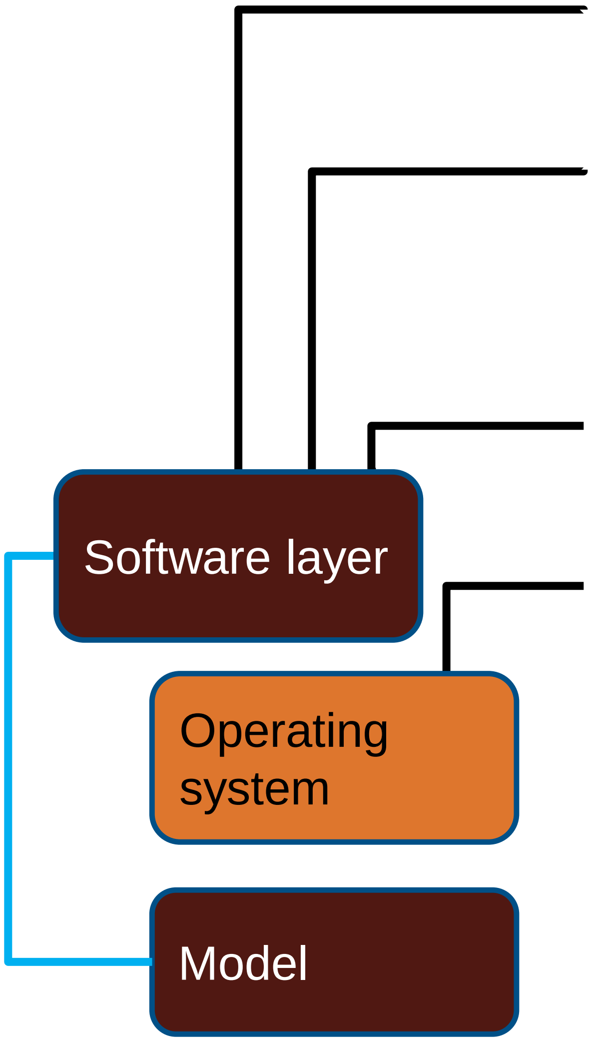
Testing with simulation




```
// Wait 10 minutes
sleep(10*60);
// Fetch temperature measurement
// from serial port
temp = read_temp_from_serial_port();
// Decide on a control action
what_to_do = process_data(temp);
// Send the command out through
// the serial port
write_cmd_to_serial_port(what_to_do);
// Record measurement and action
// to a file on disk
write_to_disk(temp,what_to_do);
```

Redirect interactions with the world outside of the software and redirects those to a model; calls that do not interact with the outside world continue as before

Outcome & Deployment Plan

- Control reduces peak load in the vast majority of cases while satisfying temperature constraints
  - Best results are achieved with N set to half the number of available units
  - Units with maximum priority will always run
    - Algorithm degrades gracefully under pressure
- Main logic of the software *as it will be deployed* was exercised for 40,000 days of simulated operation
  - Much more testing than would be feasible without the simulation
- Deployed at CBC Family Life Center operational for the month of August alternating between baseline and new control
- Testing at Home depot Fuel Store in September

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Moving Forward

Applications that are a good fit for implementing with VOLTTRON will have several distinct features:

- They naturally call for a publish/subscribe type architecture
  - Applications consisting of large numbers of loosely coupled sub-systems that can be wrapped in an agent
  - Access to essential data sources are readily supported
- Can make good use of functionality that is part of the VOLTTRON system
  - coordinating access to shared resources
  - Access to essential data sources are readily supported
  - Repeatable installation of software
- Are readily conceived as performing tasks that can be accomplished by autonomous, but communicating, agents
- Seamless deployment requires:
  - Advanced Monitoring - Innovative "real" and "virtual" sensors
  - Automated Response - Distributed control strategies
  - Scalable Testing Platforms - Large-scale validation

Recent Publications

- 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

Discussion


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