Unified HVAC and Refrigeration Control Systems for Small Footprint Supermarkets

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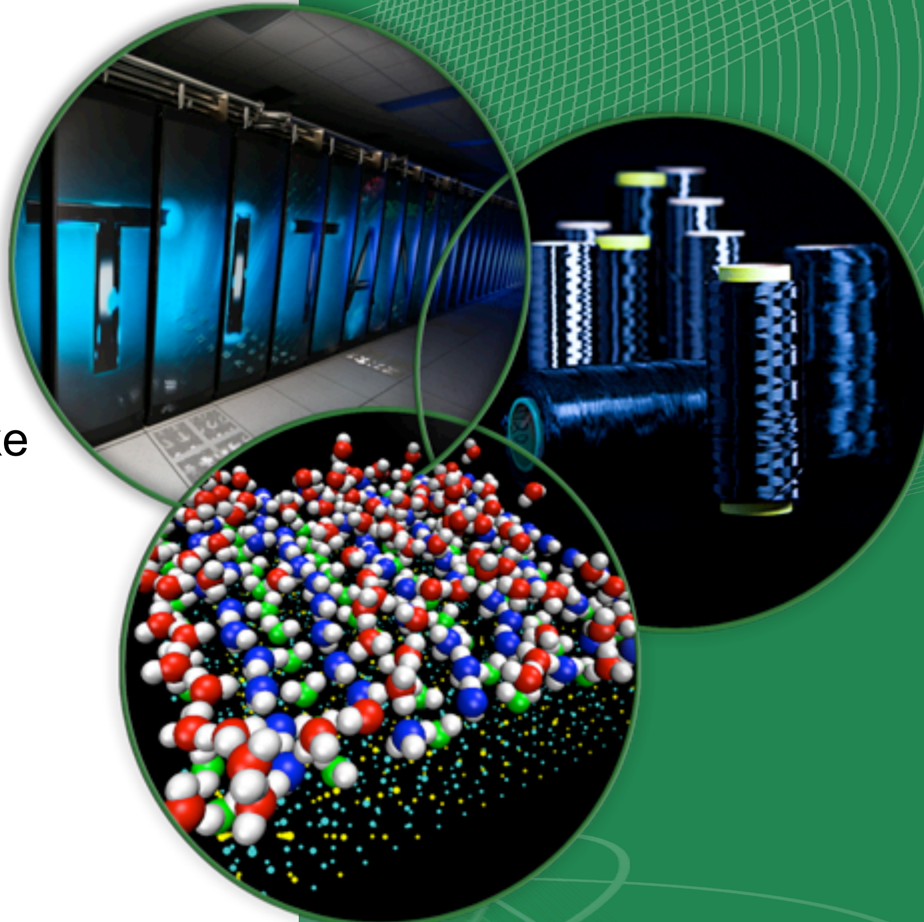

Presented at:

Technical Meeting on Software Framework for Transactive Energy: VOLTTRON

23rd – 24th July, 2015

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Motivation and Objective

- Supermarket Energy Consumption
  - 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 & grocery Stores
  - Convenience stores
  - Restaurants & food services

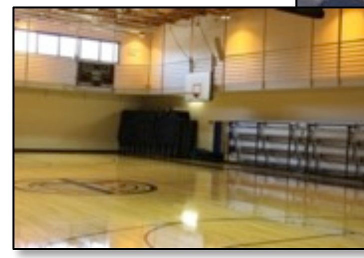
- Develop a retrofit system for coordinating the operation of multiple RTUs and refrigeration systems for the purposes of
  - reducing peak demand
  - reducing energy consumption, and
  - providing transactive energy services to the electric grid

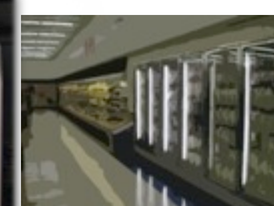
Approach

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

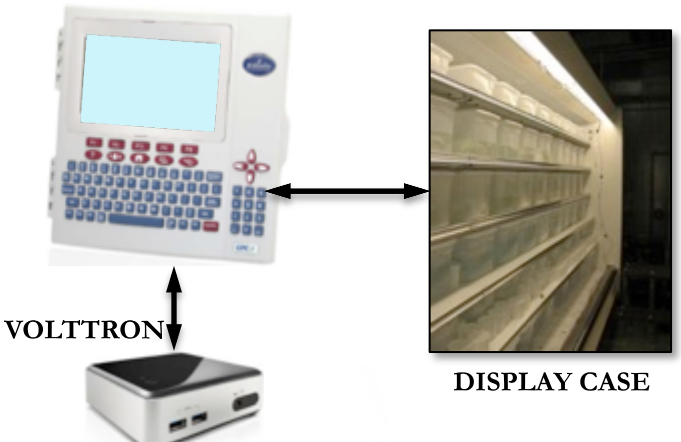


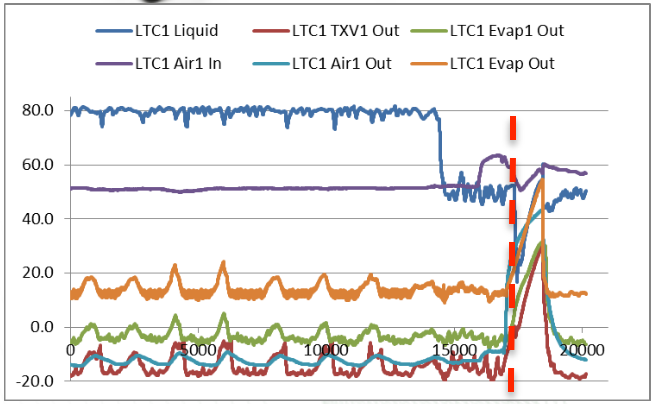


On-demand Defrost Application

EMERSON
Climate Technologies

- Problem:
  - Frost formation decreases operational efficiency
  - Typically defrost cycles are timed and based on 75°F dry bulb temperature and 55% relative humidity
  - Low temp cases: ~720kWh/month/case
- Solution:
  - Utilize existing measurements (discharge air temp) and develop algorithms to perform defrost on-demand
  - Retrofit VOLTTRON platform and control app to Emerson controller to perform on-demand defrosting
- Results
  - Testing data collected at ORNL demonstrated savings potential
  - Application developed and field tested at Emerson Labs, Sydney, OH





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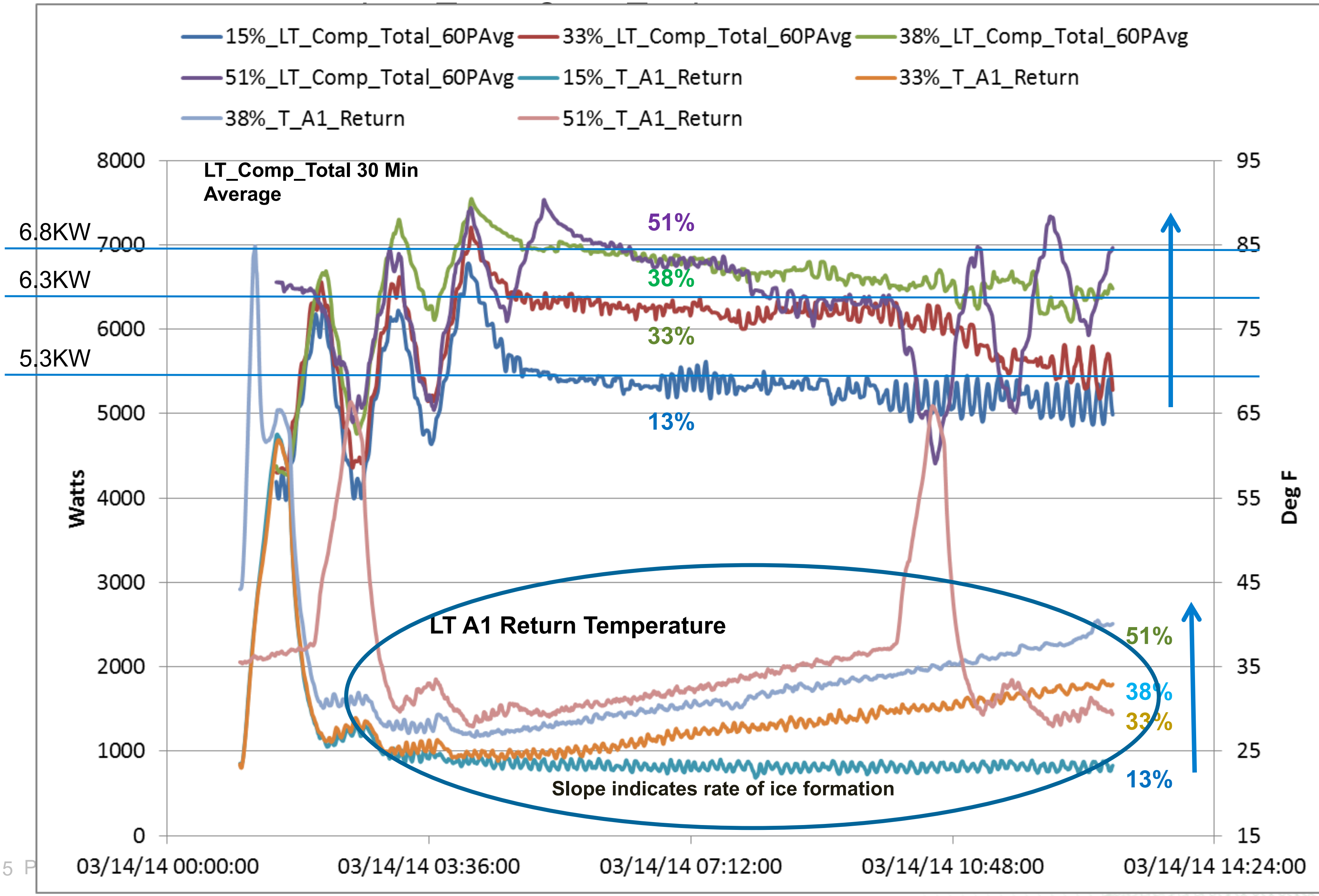
ORNL Refrigeration System – Defrost Study Testing

Compressor Power Metering: LT_Comp_Total = LT Compressor #1 power + LT Compressor #2 power

Power levels increase with humidity

30 min running average



Testing – Emerson Labs, Sydney, OH

The testing was performed on LT Case 1 - evap 1 - TXV with CS100.

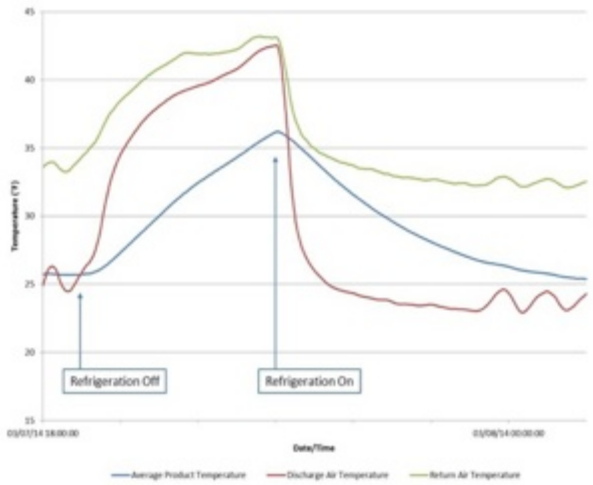
Snapshot of Results

- Visually inspected the evaporator coils
- At ~12:20 pm a defrost event occurred ~ 24 hours since the last defrost event.
- The baseline defrost frequency was every 9 hours.
- The period from 12:20pm 11/14 to 9:15am 11/17 was ~69 hours and would normally incur ~ 7 typical defrost cycles
- Potential exists through monitoring techniques to reduce the number of defrosts
  - The humidity in the room varied from upper 20's to upper teens over the period from 11/14 – 11/17

Unified Control - Small Footprint Supermarkets

- Integration of VOLTTRON with Emerson Controller to enable whole store control
  - Special Version of controller In Controlled Environment
  - Access endpoints in VOLTTRON app
  - Ability to get data and set control
- Control application under development
  - Operate building equipment, such as HVAC and refrigeration systems, as installed
  - Supervisory management layer over existing control systems to enable optimal scheduling

EMERSON. Climate Technologies



HVAC Control Strategy

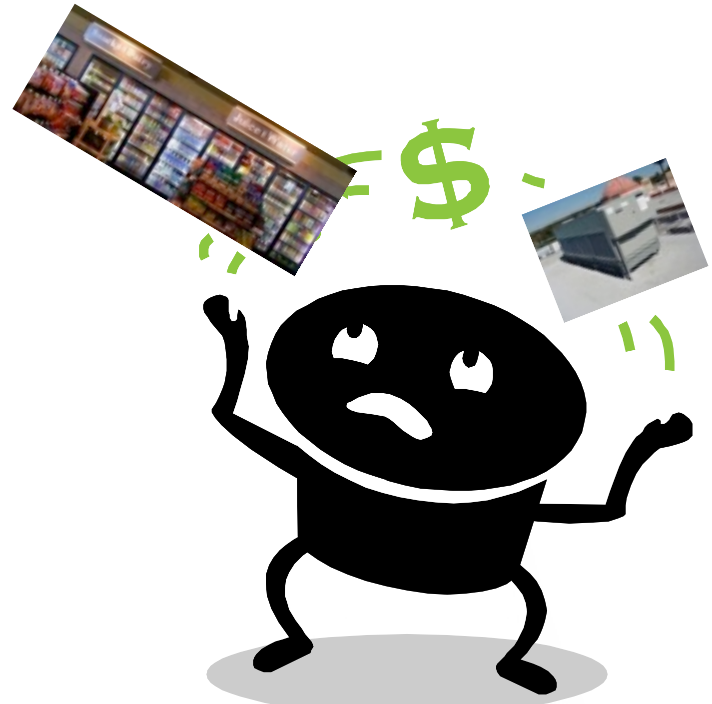
- Control strategy builds on prior work to limit number of simultaneously operating units to reduce peak power
- Extensions to include
  - Vary number of units to improve comfort
  - Account for humidity levels
  - Reduce energy consumption

Control	Tracking error	Monthly peak power & $ savings
Legacy	1.8 ± 0.1 deg. F	60 kW, $0 savings
MPC	2.2 ± 0.1 deg. F	30 kW, $360 savings

Maintain energy savings while reducing the tracking error

Coordinate HVAC and Refrigeration

- Extend control to account for power used by refrigeration equipment
  - When cooling
  - During a defrost event
- Use thermal storage to shift cooling and avoid coinciding with HVAC operation
- Using on demand defrost to reduce and stagger energy use for case defrosting



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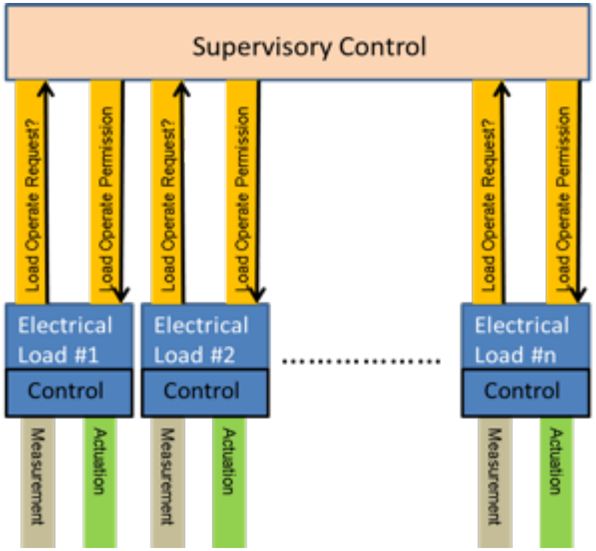
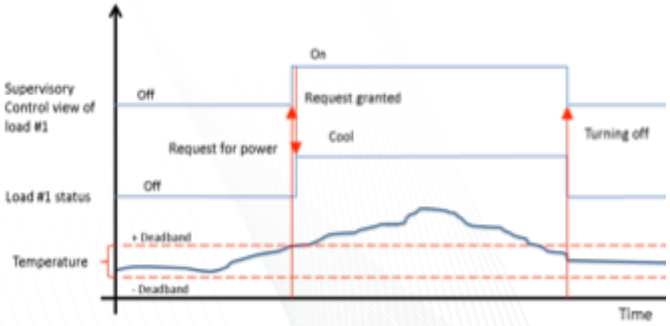
Auto-Discovery of EndPoints

- VOLTTRON
  - Many endpoints abstracted into application interfaces
  - Needs an auto-discovery framework
- Created Python based software
  - Automatically generates relevant modules and classes
  - Generates get and set wrappers
  - Set wrapper generated only if endpoint is writable

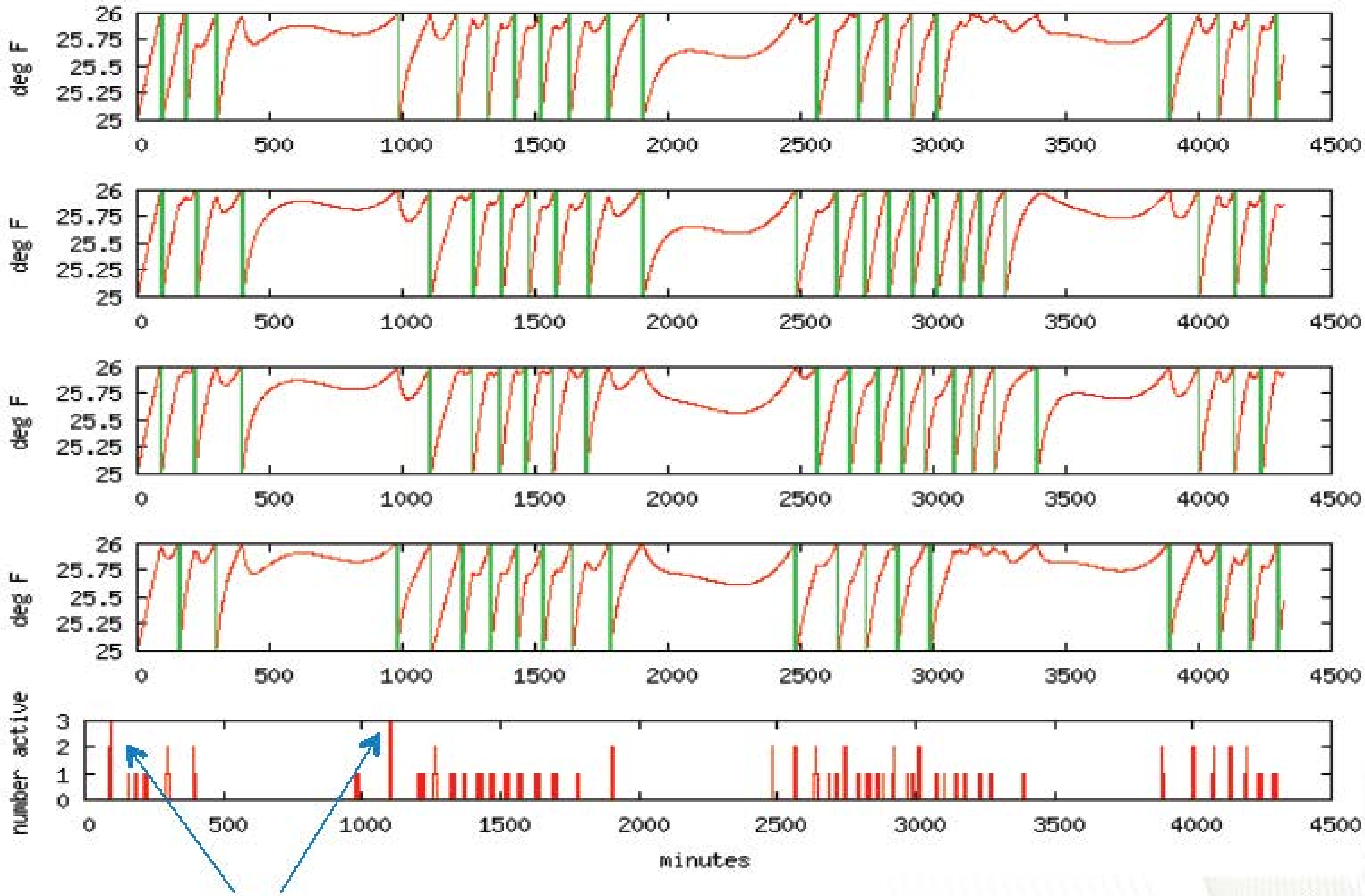
Supervisory Load Management

- Control Strategy:
  - Each electrical load has its own control strategy
  - No a priori information. Permission to run is controlled by the supervisory layer
  - The electrical load supplies two items of information
    - The minimum length of time that the load must be active before it can be turned off
    - The maximum length of time for which the load can wait before its request is served.
  - There is some number *N* of electrical loads that can operate simultaneously without incurring peak demand charges.



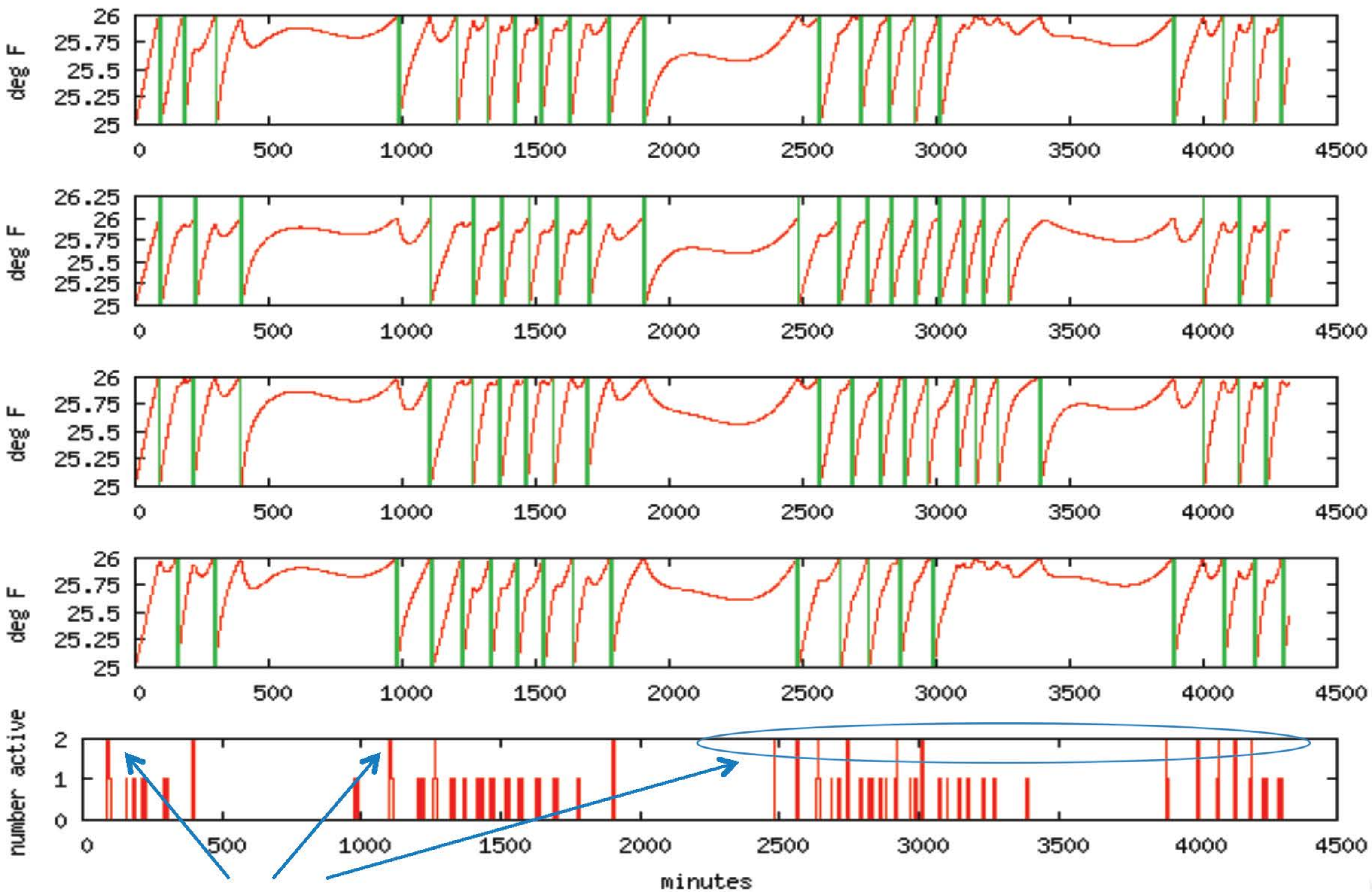


Simulation Results - Baseline



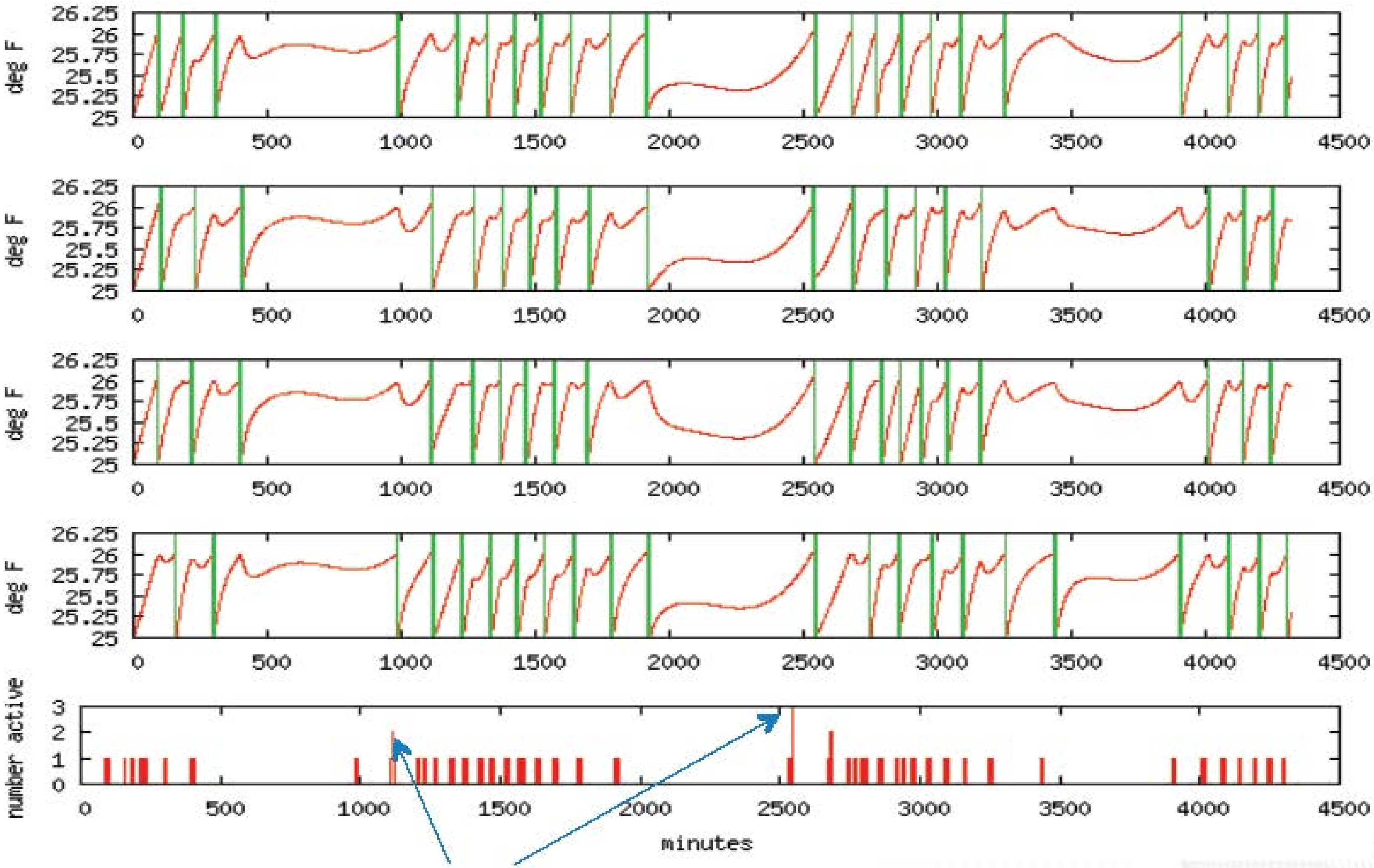
Peak load is 3 HVAC units without the proposed control

Simulation Results – Limit 2 units



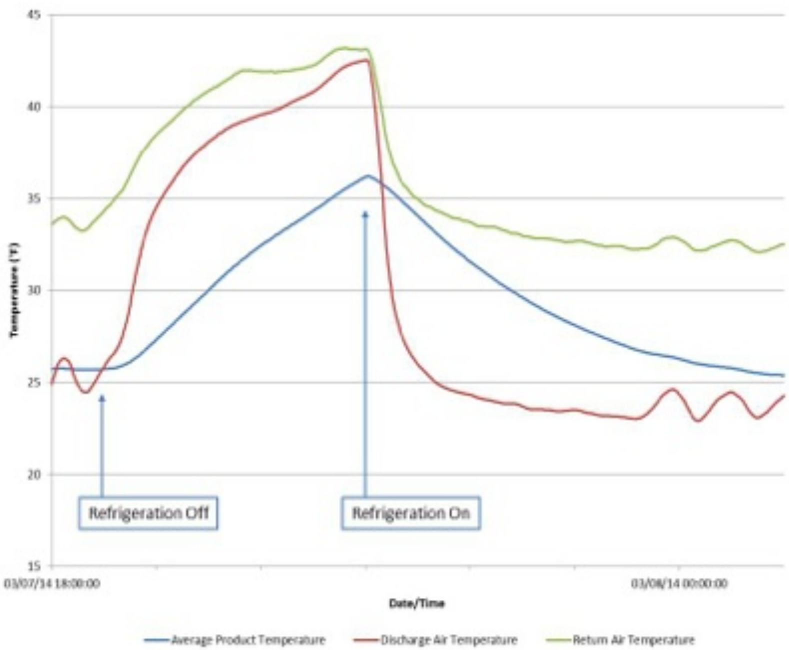
Peak load is 2 HVAC units with the proposed control

Simulation Results – Limit 1 unit



Performance of the control degrades gracefully when its objective cannot be met

Measuring Thermal Storage in a Display Case



- Simulated product
  - One-pint containers
  - 50% ethylene glycol & 50% water mixture
- Stored in medium-temperature open refrigerated display case

At 18:30, 3/7

- T_{air} = 25°F
- $T_{product}$ = 25.6°F
- Refrigeration turned off

At 21:00, 3/7/2014

- T_{air} = 43°F
- $T_{product}$ = 36.2°F
- Refrigeration turned on

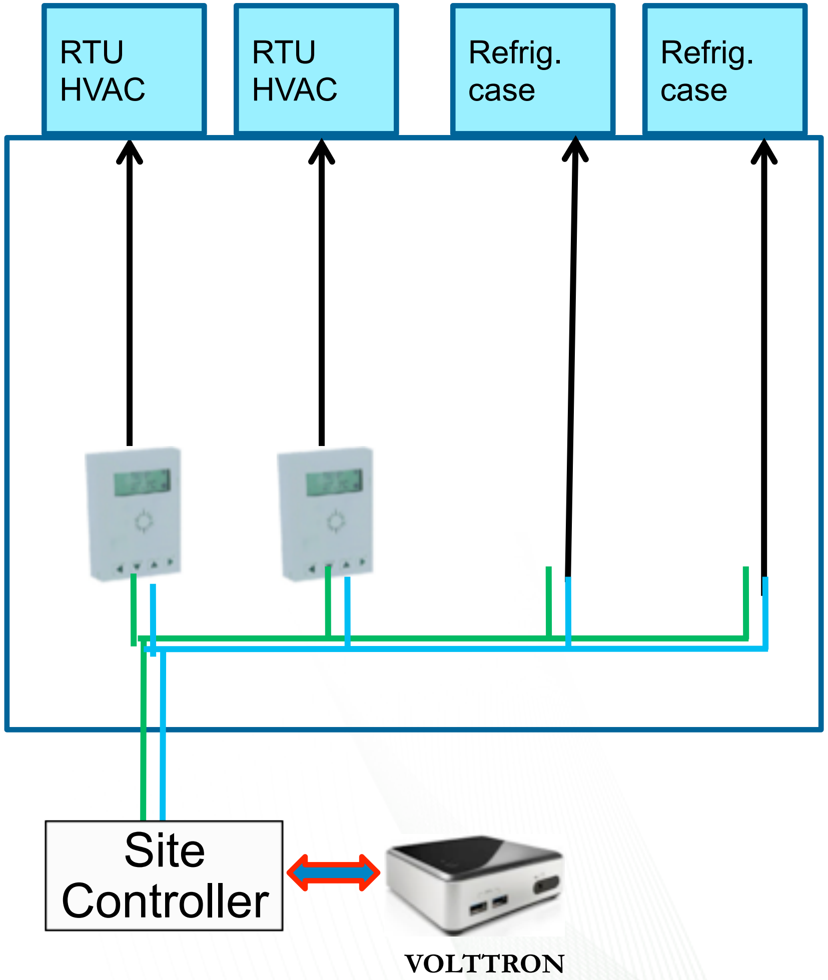
At 0:40, 3/8/2014

- T_{air} = 23.8°F
- $T_{product}$ = 25.6°F

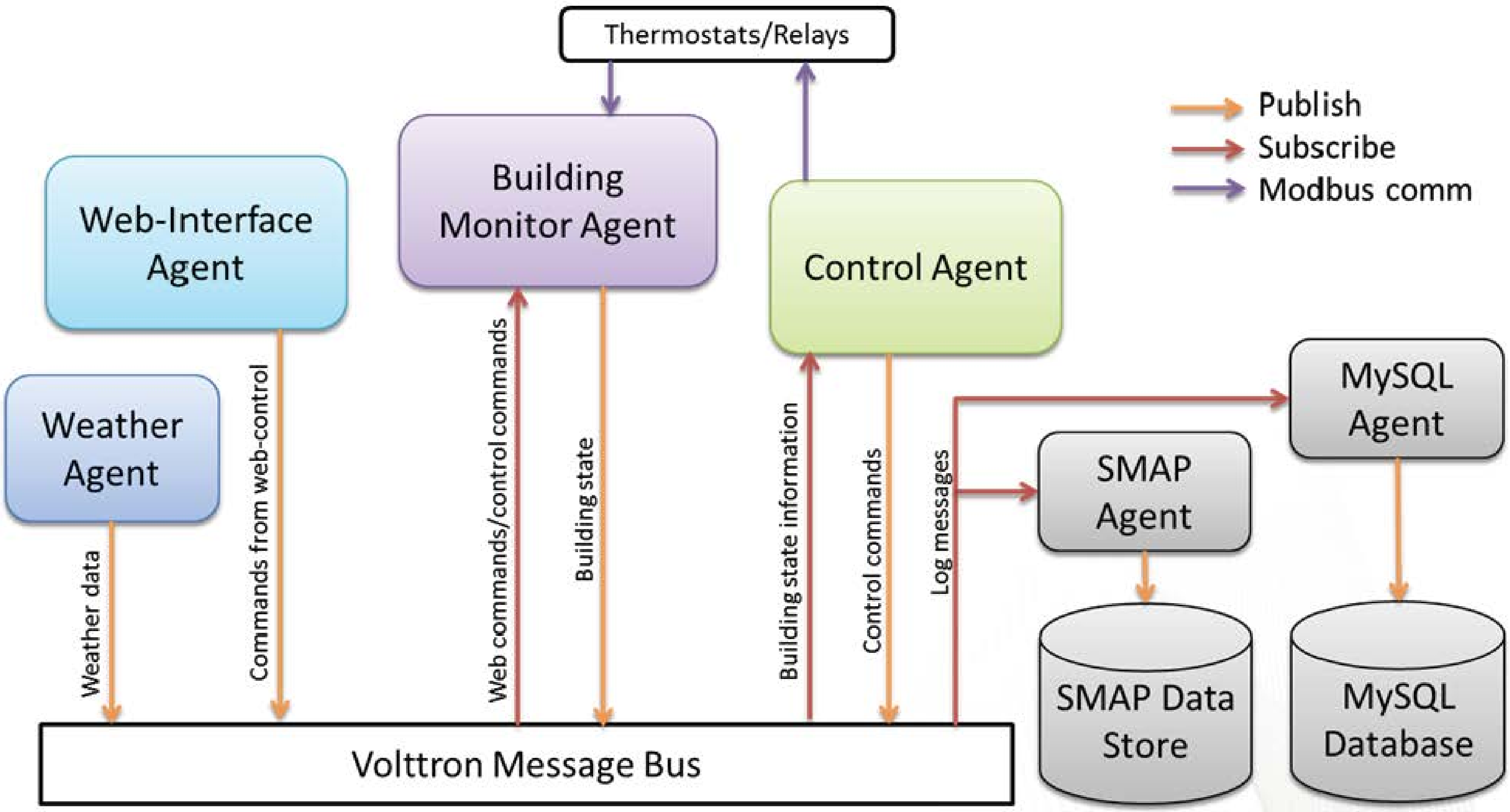
- Thermal Storage
  - 2.5 hours for product to increase by 10°F
  - 3.5 hours for product to recover

Build, deploy, and operate prototype

- Derive system requirements from control strategy and data gathered from the deployment site
- Build and test control system to be used in deployment
- Monitor operation of new system to
  - Confirm energy savings
  - Identify and resolve latent problems in software, hardware, and control strategy



Software Agent Architecture



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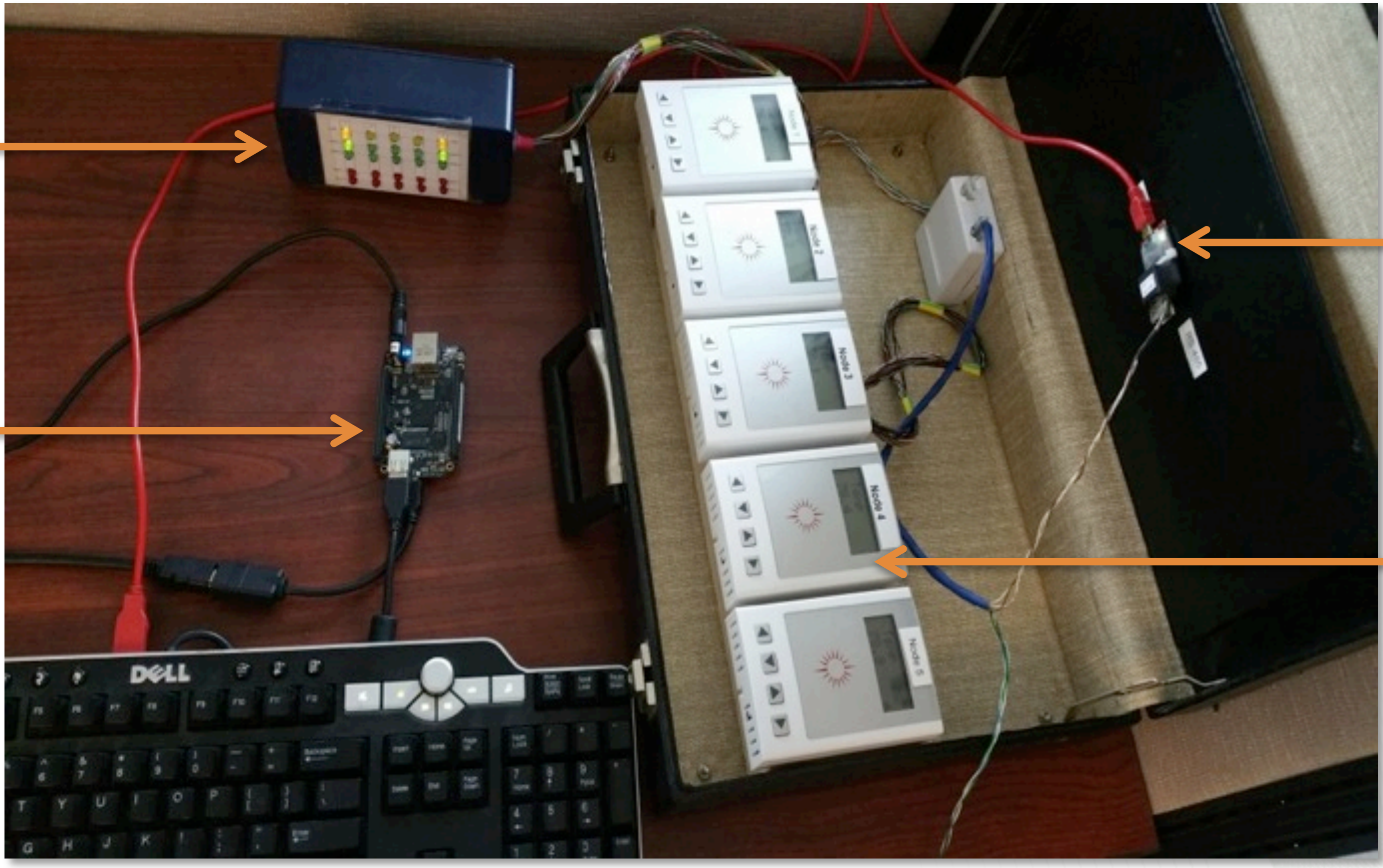
Building Control Hardware Emulation

HVAC states display

RS 485 to USB

BeagleBone Black

TEMCO thermostats



"Building in a box"

Benchmark Volttron on small devices

Intel Next Unit of Computing (NUC)

~ $350 - $400

Raspberry Pi 2

~ $35
($85 fully loaded)

BeagleBone Black

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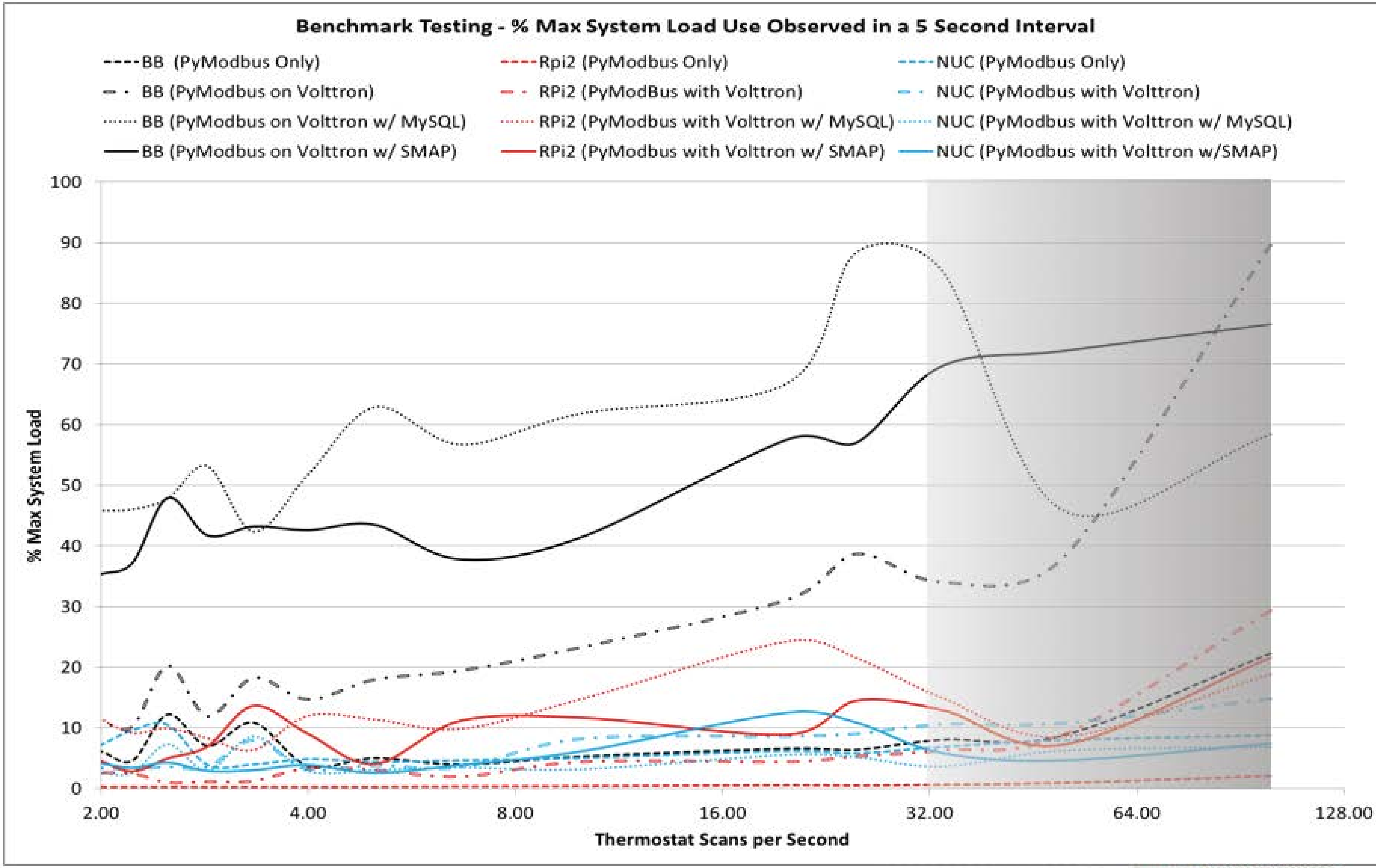
Performance Comparison



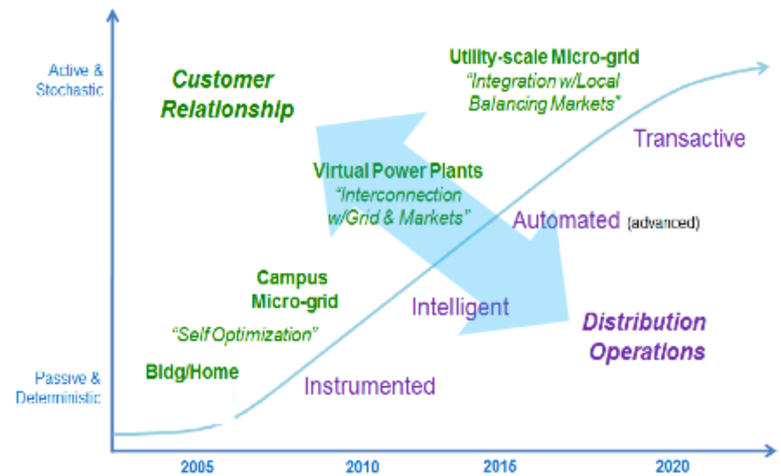
Note: Grey region exhibited communication errors

Lessons Learned

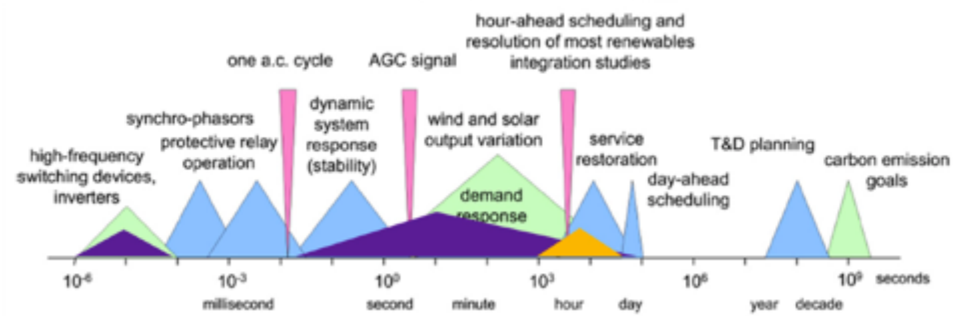
- Debugging in VOLTTRON - Installation structure
  - Apps install to a ~/.volttron directory - All the agent code
  - Debug changes must be made here - App reinstall cycle (package, configure, install, run, debug)
  - Replace installed files and symbolic links - cut down debug time
  - When multiple agents interact
    - Message bus & Inter-app behavior has to be monitored
- Benchmark before deploying on small-footprint devices
- Several advantages as a retrofit deployment platform
  - After development optimize for the application needs
  - Expandability – only compute limitations
  - Distributed application deployment – understand limitations
  - Access to essential data sources/ drivers are readily supported
  - Repeatable installation of software
  - Coordinated pushing of updates

Applications Supporting Transactive Energy

- Transactive energy requires high-speed wide area control of loosely coupled loads
- Control response can be generated in a centralized or decentralized fashion
  - Utility level information
  - Building-level loads
- Embedded transactive devices that can control building systems over wide-area heterogeneous networks
  - How to guarantee quality of service?



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



" To 33% and Beyond: Grid Integration Challenges for Renewable Generation", Alexandra von Meier, CIEE, presented to UCLA Smart Grid Thought Leadership Forum, March 28, 2012

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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
  - e.g., applications consisting of large numbers of loosely coupled sub-systems that can be wrapped in an agent
- Can make good use of functionality that is part of the VOLTTRON system
  - e.g., coordinating access to shared resources
- Are readily conceived as performing tasks that can be accomplished by autonomous, but communicating, agents

Discussion

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