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Clean Energy and Transactive Campus (CETC)

A PIONEERING REGIONAL PARTNERSHIP FOR GRID MODERNIZATION

Department of Commerce

U.S. DEPARTMENT OF ENERGY

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Pacific Northwest National Laboratory

VOLTTRON™ 2017

Overview

- Clean Energy and Transactive Campus Project – First GMLC Pioneering Regional Pilot
- Overview
- Phase I Research, Development and Deployment Effort
- Phase II Research, Development and Deployment Effort

U.S. Building Energy Use in Context and Opportunities to Reduce it Through Transactive Controls

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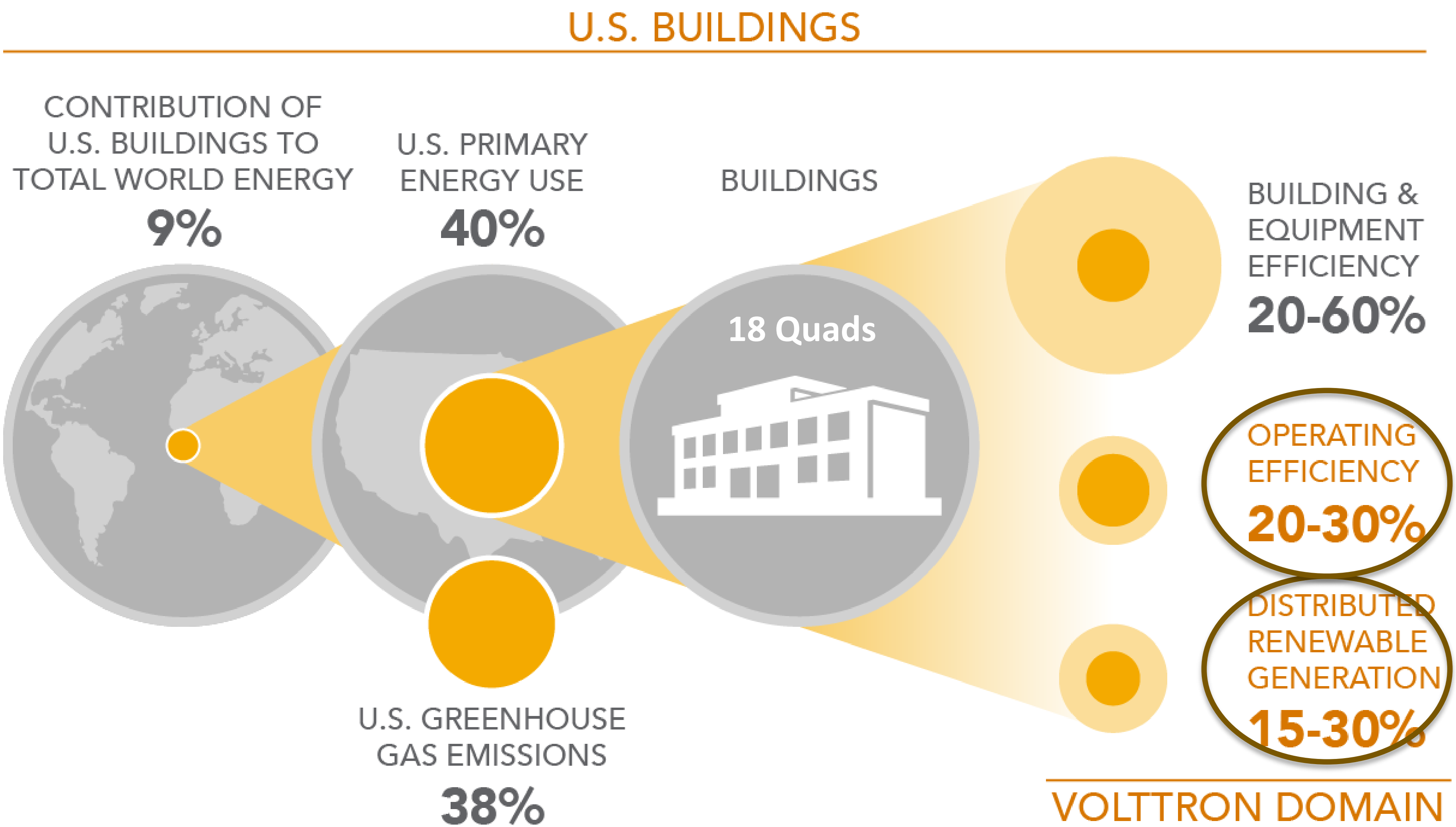
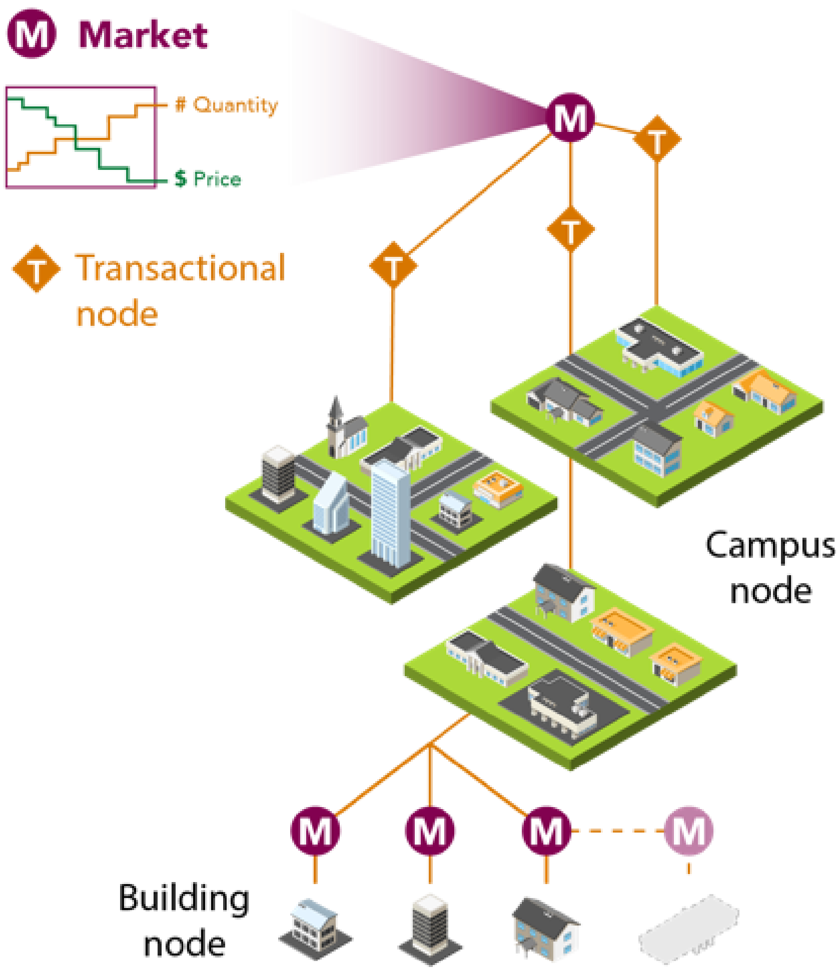


Purpose and Objectives of CETC Project

Problem Statement: Transactive control (TC) technologies provide a viable solution for coordinating responsive building loads and distributed energy resources, benefiting energy efficiency and power grid reliability objectives

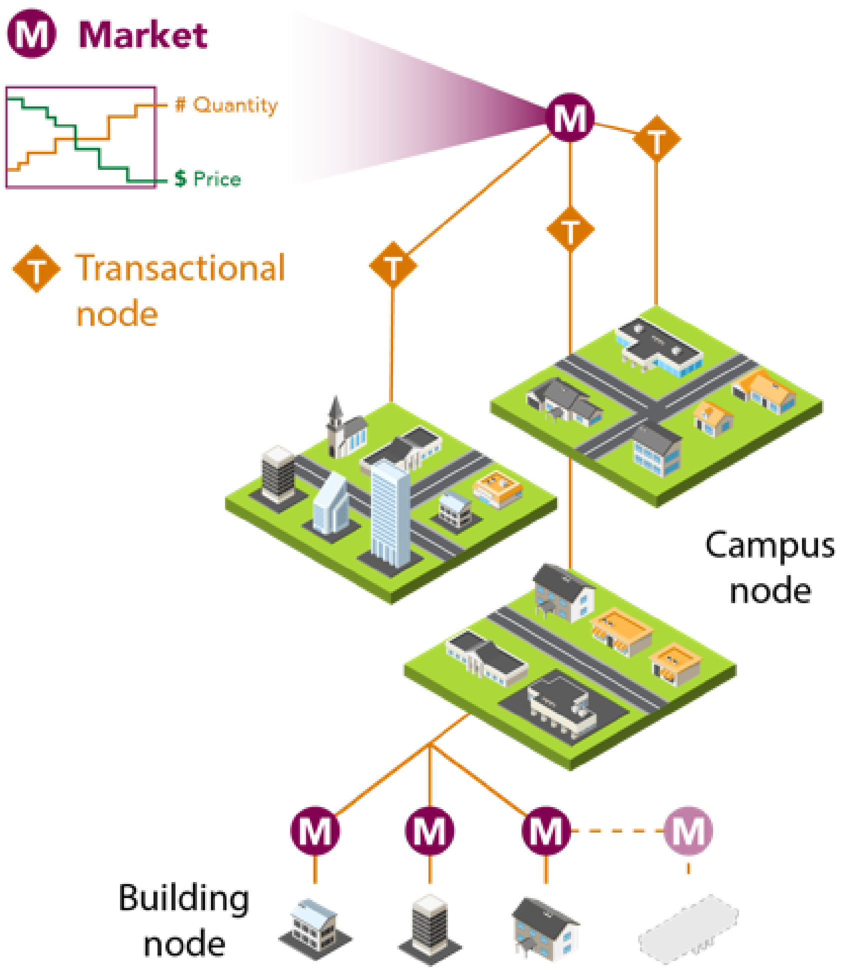
- Transactive controls can reduce cost and potential improve efficiency; however, they have not be tested at scale
- Must be tested in realistic situations
- Must develop approach that enables a single building, sets of buildings, or entire communities to readily adopt them

Target Audience: Utilities considering deploying transactive energy concepts, energy service providers deploying TCs in buildings, any campus that wants to deploy TCs



Project Overview

- The CETC project connects the PNNL, UW, and WSU campuses to form a multi-campus testbed for transactive energy management solutions to demonstrate:
  - A regional flexibility resource and a research and development platform for buildings/grid integration solutions
  - A testbed that will support the integration of renewables and other regional needs, using the flexibility provided by loads, energy storage, and smart inverters for batteries and photovoltaic (PV) solar systems, at four physical scales: multi-campus, campus, microgrid, and building



Partner Projects at a Glance: Phase I

PNNL

- Overall project management
- Develop/implement transactive technologies in PNNL buildings, create network to connect 3 campuses
- Measure/report on project performance

University of Washington

- Install battery energy storage system
- Add inverters to existing/new solar panels
- Translate project data into actionable info

Washington State University

- Establish solar energy modules and integrate in Smart City testbed and WSU microgrid
- Develop strategies for sharing energy between WSU's smart buildings and the solar modules

First implementation of transactive energy at this scale, involving multiple buildings and devices
Key technology: PNNL's open source VOLTTRON™ distributed control and sensing software platform

Partner Projects at a Glance: Phase II

PNNL

- Overall project management
- In addition to WSU and UW, adding two more partners

Case Western Reserve University

- Install battery energy storage system and use that to provide transactive energy services
- Deploy intelligent load controls, transactive controls, and energy efficiency services on campus buildings

University of Toledo

- Install battery storage system and use that to provide transactive energy services
- Deploy intelligent load controls, transactive controls, and energy efficiency services on campus buildings
- Mitigate short-term generation imbalance from existing solar panels

Project Objective: Goals and Solution

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- **The goals of the CETC span EERE programs, yet the common dominator is the buildings' role as outlined in the Transaction Based Controls Reference Guide (Volume 1 and 2)**

  A. **BEYOND DEMAND RESPONSE** – enable buildings, fleets of equipment, and other building assets to deliver services to the grid while maximizing energy efficiency (EE)

  "How can we control equipment within a distribution feeder to deliver valuable services to the owners and operators of buildings and the grid simultaneously?"

  B. **GRID SCALE, RIGHT SIZED STORAGE** – enable buildings to function as "virtual" storage devices to reduce the total capacity of grid storage needed to meet the needs of a utility

  "How can we utilize building loads and control of equipment to lessen the physical storage we need to maintain grid reliability?"

  C. **BEHIND THE METER RESPONSE TO PV** – lessen, dampen, and otherwise minimize the effects of building and distributed PV as seen by the utility

  "How can we utilize groups of loads and buildings to make site installed PV appear as a non-variable generation source to the utility?"

- **First campus-scale demonstration in the nation in which ideas to address these goals are being deployed, measured, and tested, as well as exposing them to researchers, faculty, staff, and students**
  - *The project's outcome is to create a recipe for replication of transactive equipment, buildings, campuses, districts, and fleets in real-life as utilities, municipals, and building owners are facing larger deployments of clean energy technologies, aging infrastructure, and new regulations*

Phase I: PNNL Work Summary

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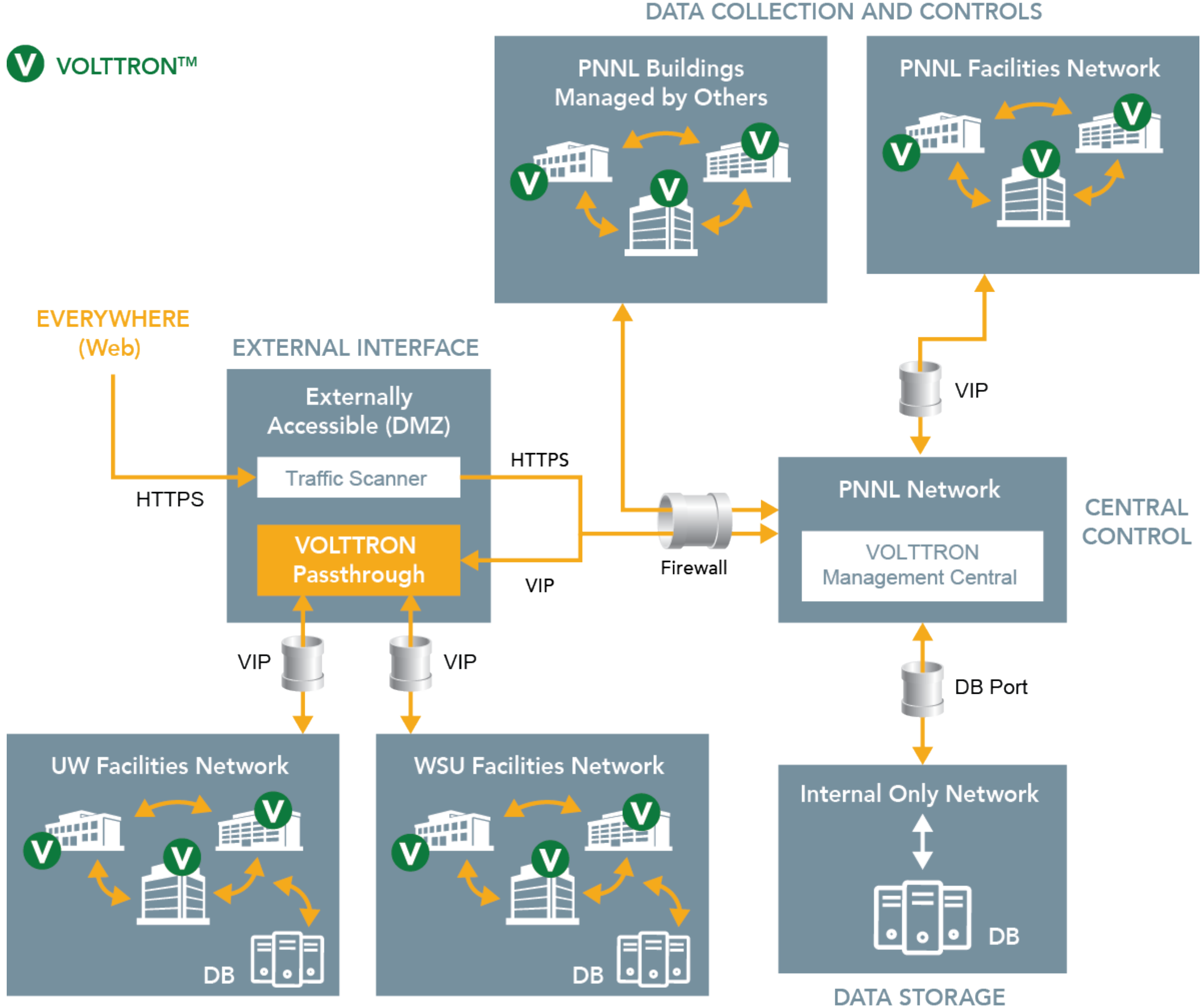
- Coordination of the work done by the three organizations
- Making Electricity Infrastructure Operations Center (EIOC) operational in the new Systems Engineering Building
- Designing and deploying VOLTTRON™ network infrastructure on PNNL campus, including the ability to integrate with UW and WSU in the future
- Design, develop, implement and validate energy efficiency and grid service experiments on PNNL campus buildings
  - Automated fault detection and diagnostics and automated identification of Re-tuning™ (AIRx) opportunities
  - Intelligent load controls (ILC) to manage building peak demand or consumption (or budget)
  - Transactive controls and coordination (TCC) to deliver various grid services
  - Increasing the hosting capacity of renewable energy generation

Network Infrastructure



VOLTTRON™ Deployment on PNNL Campus

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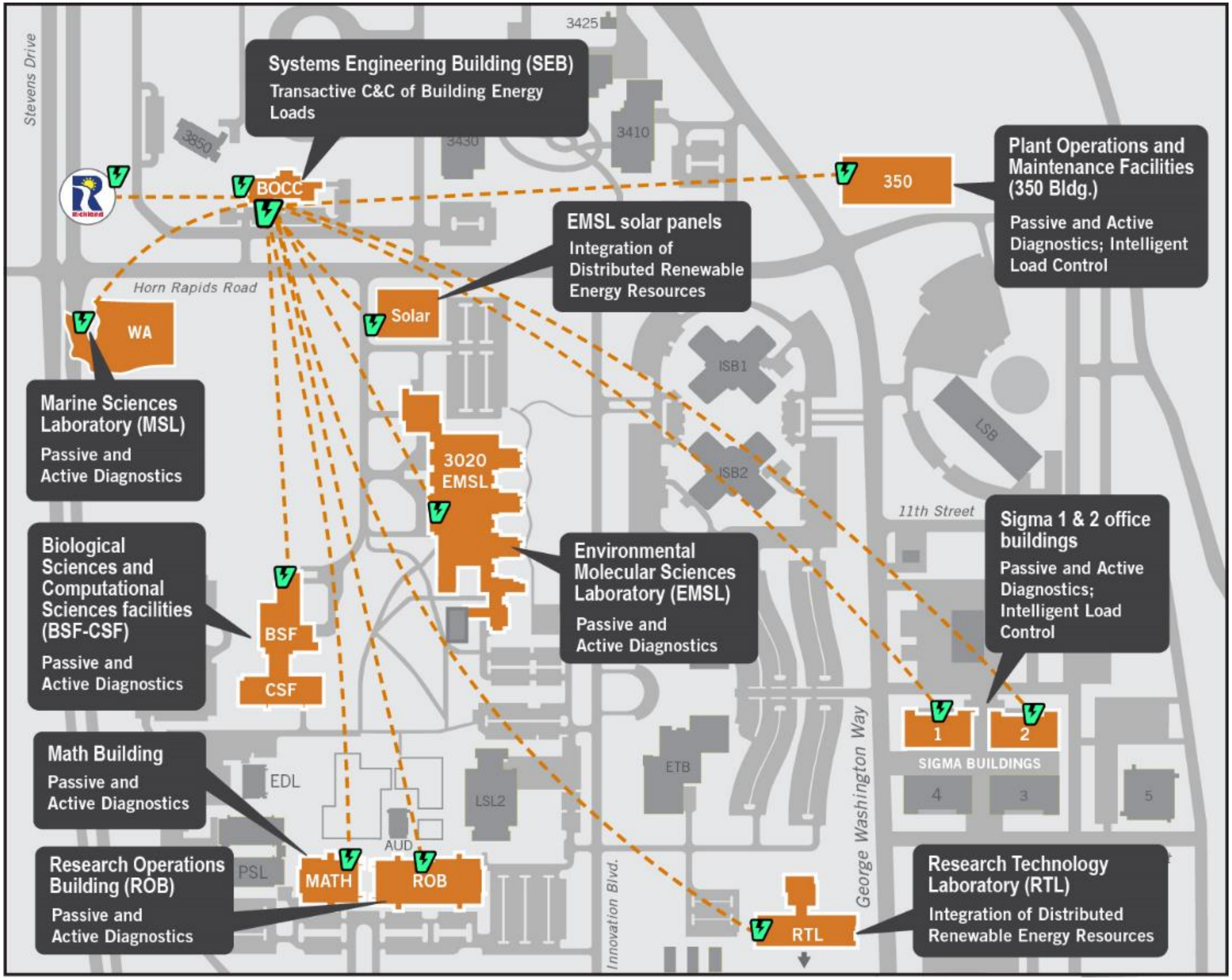

Experiment #1 Grid Service Intelligent Load Control (ILC) Status

- **Experiment Status**: Designed, scripted in Python, validated through simulation and deployed on three buildings on the PNNL campus:
  - Phase I: Managing buildings to a static target demand/cost
  - **Phase II: Managing buildings to support dynamic load shaping: a) capacity or demand bidding and 2) responding to transactive signals**
- **Documentation**: Completed a technical report a journal paper and an user guide
- **Code**: Number of Python scripts required to run ILC:
  - Target v-agent that estimates the dynamic target
  - Peak electricity long-term hourly forecasting v-agent (wbe.py)
  - Capacity bidding program baseline v-agent
  - Price/Capacity bidding v-agent
  - The main ILC v-agent (agent.py) for prioritizing and controlling the loads to the desired dynamic target
- Example configuration files are also included in the repository

ILC: Capacity/Demand Bidding Program

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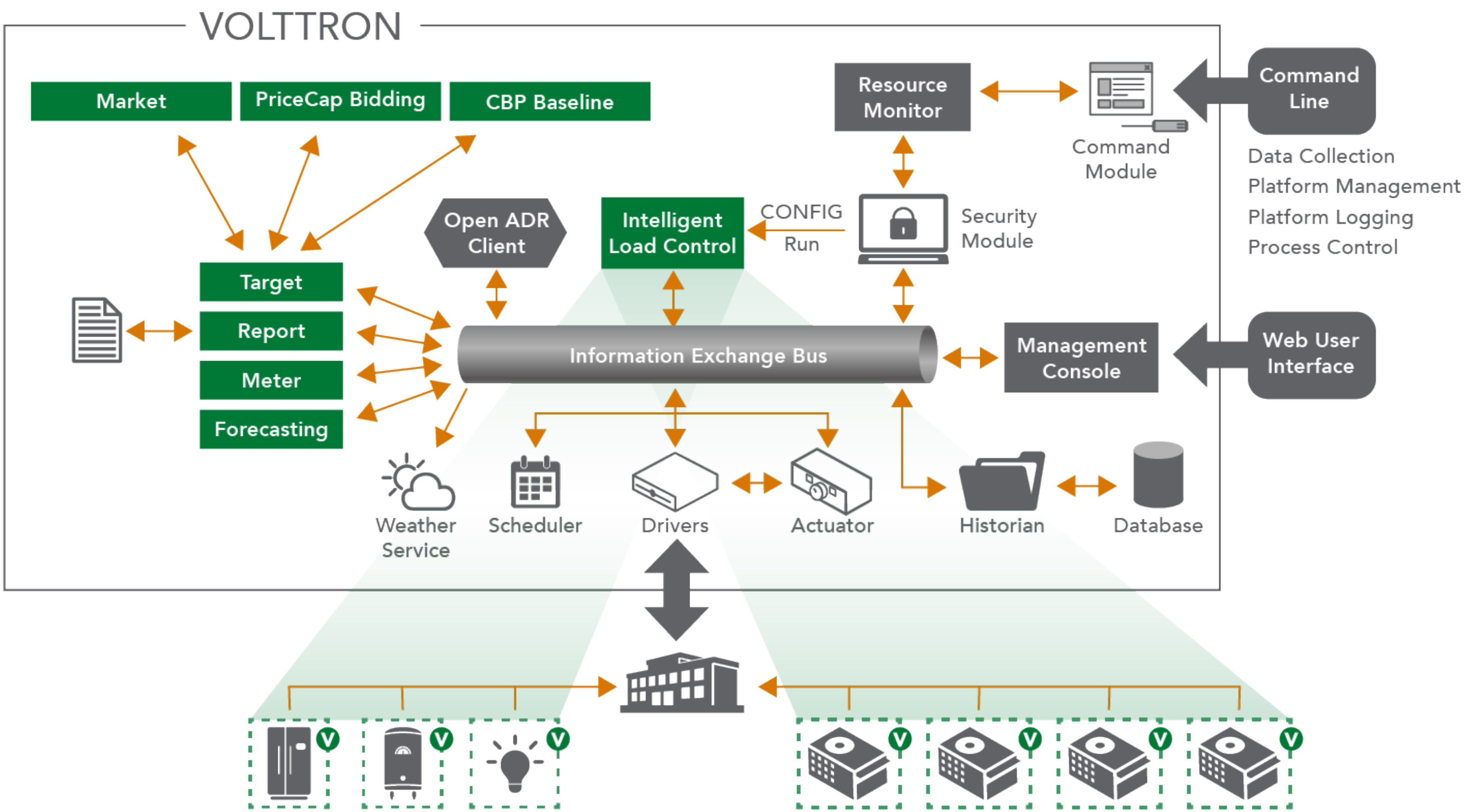
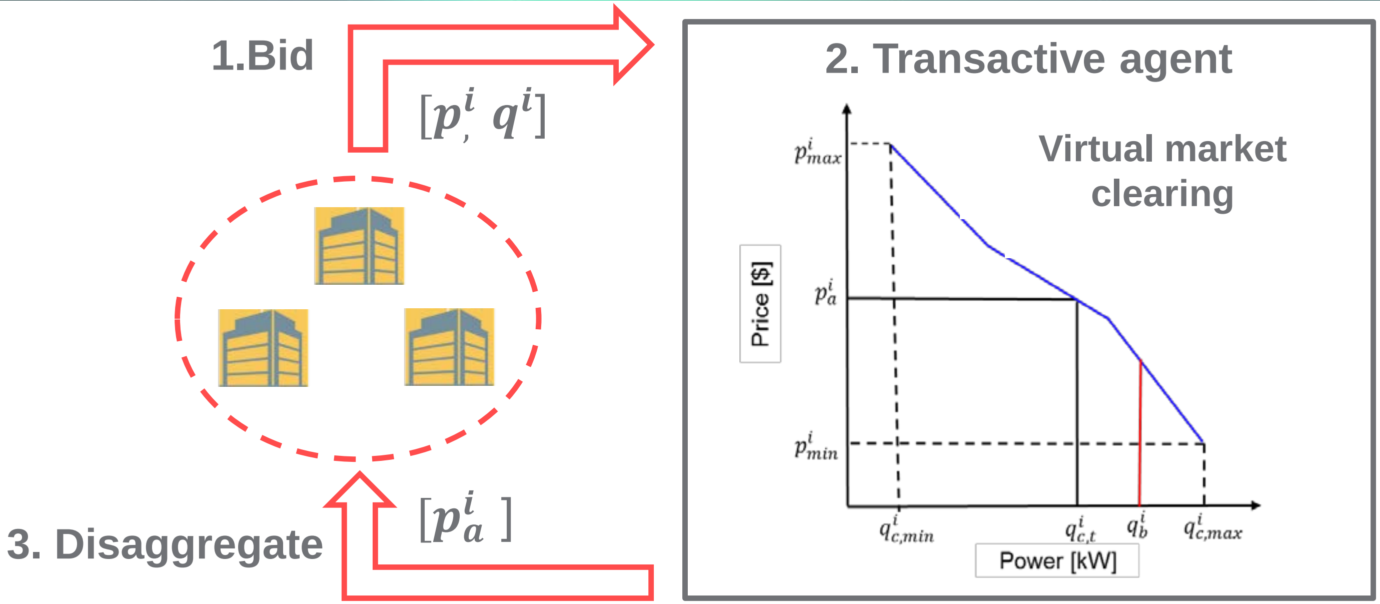


ILC: Transactive Energy Service



1. Bid — Each building creates and submits bid information to the transactive agent before the next market cycle

2. Transactive Agent — Virtual market collects and aggregates bids from buildings, forming the combined price-capacity curve

Transactive agent clears virtual market based on the transactive signal (e.g. dynamic price)

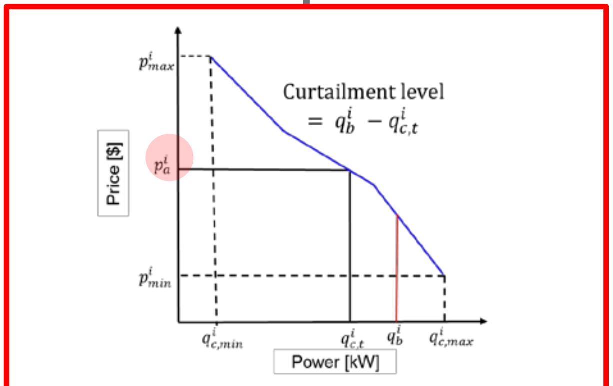
3. Disaggregate — Virtual market broadcasts the clearing price and provides allocation of target power to each building

Generating Price-Capacity Curves

Electricity

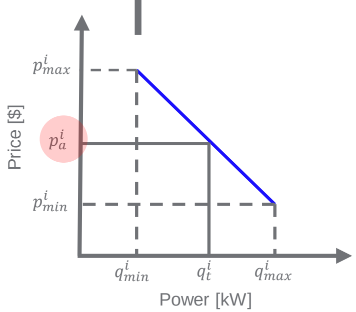
Aggregated demand curve

Select target price (p_a^i) based on curtailment level (= $q_b^i - q_{c,t}^i$)

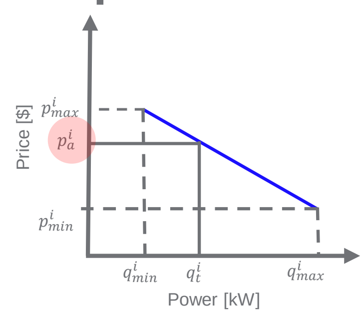


q_b^i	Baseline power
$q_{c,t}^i$	Campus target power
p_{max}^i	Maximum electricity price
p_{min}^i	Minimum electricity price
q_{max}^i	Maximum building power
q_{min}^i	Minimum building power

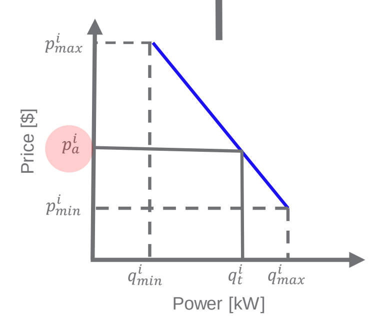
Select each building ILC target(q_t^i) based on target price (p_a^i)



Building A demand curve



Building B demand curve



Building C demand curve

Experiment #3 Grid Service Transactive Coordination & Control Status

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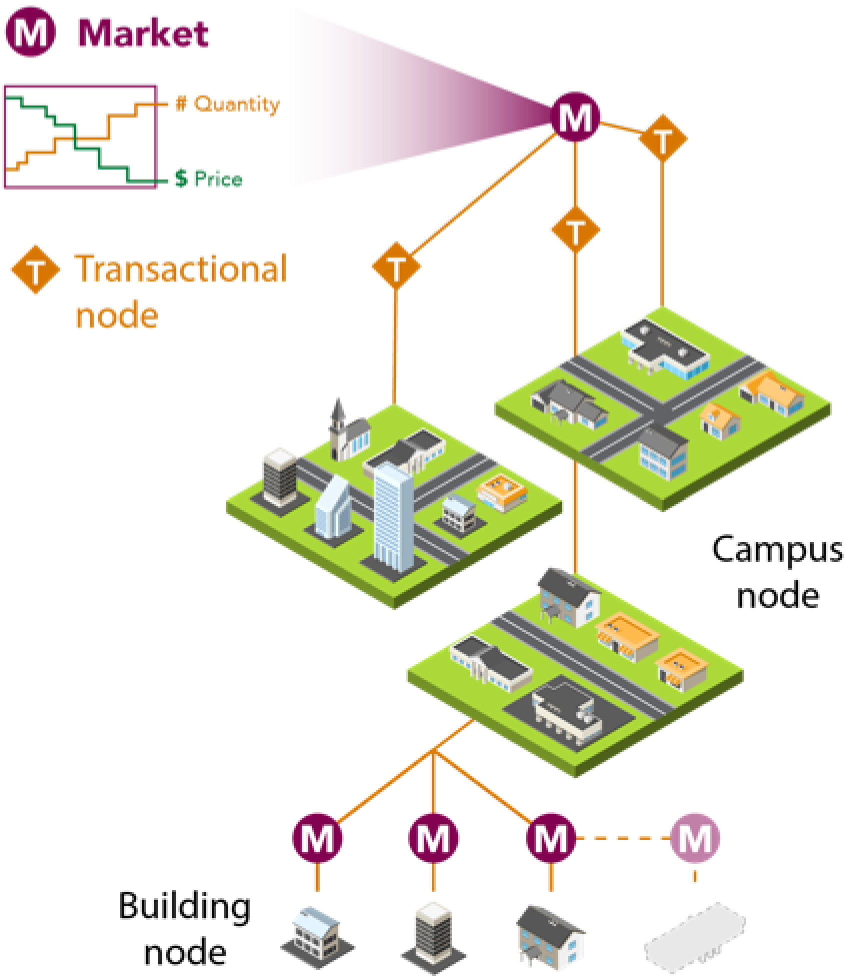
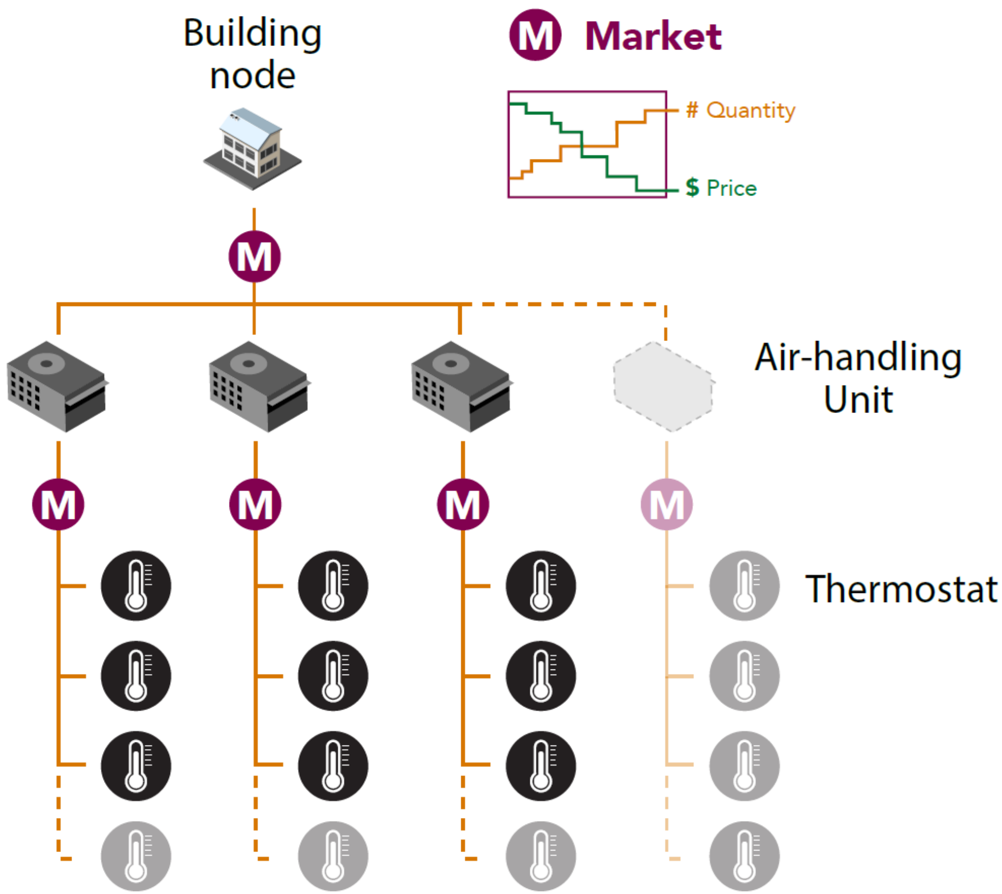
- **Experiment Status**: Designed, scripted in Python, tested using simulation and deployed in one building on PNNL campus
- **Documentation**: Technical report is complete, while the user guide is pending
- **Code**: The code developed for the TCC experiment is significantly more complex than existing VOLTTRON™ v-agents:
  - **vpubsub** package: a package containing base classes common to other packages. These base classes provide useful functions for defining topic subscriptions and message handlers through a configuration file
  - **venergyplus** package: a package containing the classes used for connecting VOLTTRON™ to an EnergyPlus model for co-simulation. This package enables control algorithms to be tested in simulation prior to deployment
  - **vmarket** package: a package containing the classes for creating transactive agents and markets. These classes are very generic in nature and can be used to create multi-layer markets of arbitrary complexity
  - **vmodels** package: a package containing physical models of zones and equipment. These include: simple combined fan and chiller model; first-order thermal zone model; simple RTU model; regression-based RTU model
  - **vtrxhvac** package: a package containing the transactive market agents used in the physical experiments on the PNNL building with built-up air-handling units, and those created for two other buildings on PNNL campus with RTUs
- Additionally, an agent that automates parameter identification for the fan and first-order thermal zone models has also been created

Transactive Control and Coordination (TCC): Overview



Use of signals from external markets to create markets at campus and individual building levels, result in better management of energy consumption, lower energy cost, potentially improve comfort and result in a reliable electric grid

TCC: Use Case

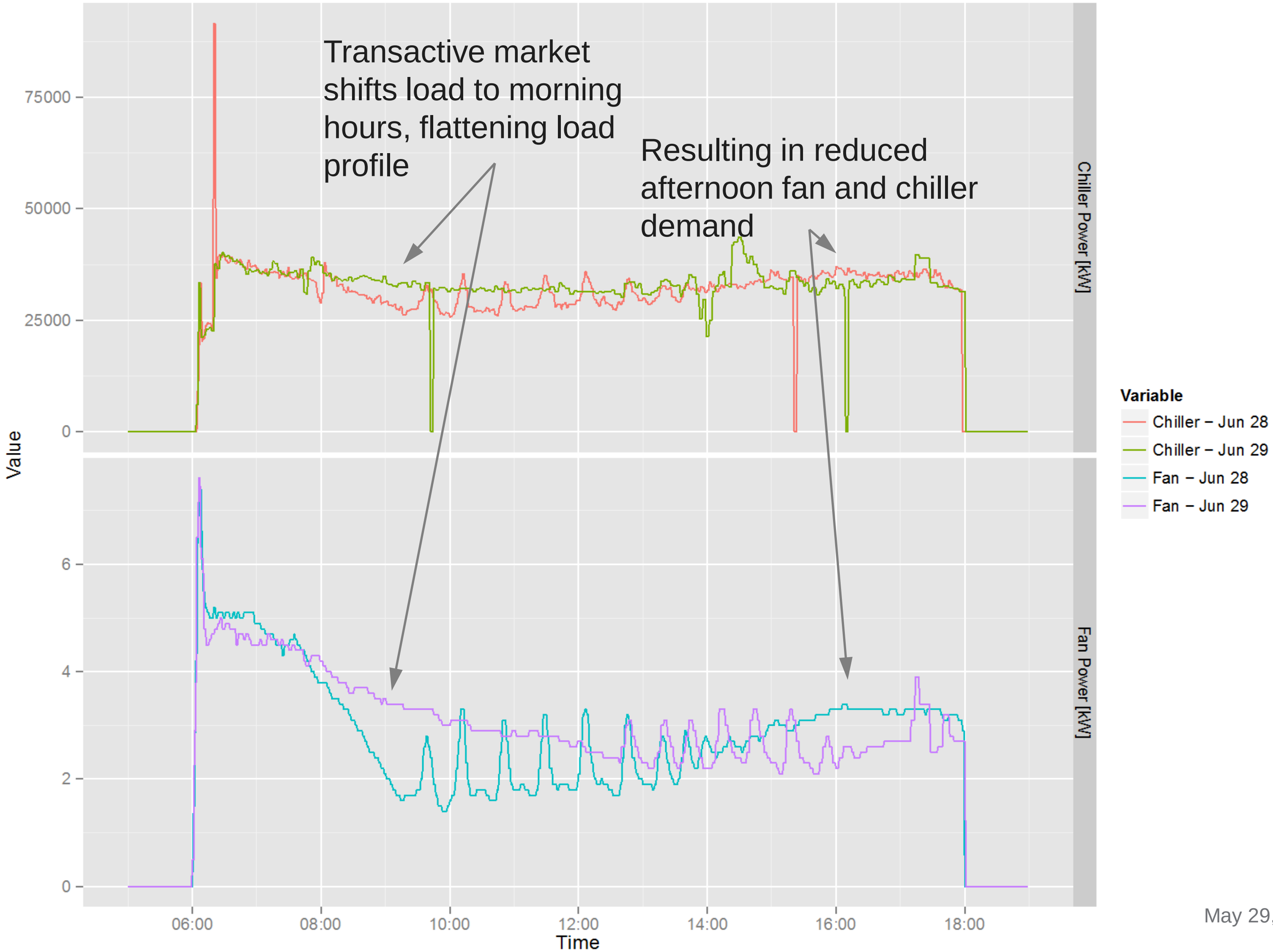


Under the TCC approach, controllable devices, such as, rooftop units, hot water heaters, variable-air-volume boxes serving building zones and devices become markets that “negotiate” prices and service levels

TCC: Phase II

- Multiple buildings with a market at a campus level
- Multiple campus with a market at the distribution level
- Develop a generalized approach to create empirical models dynamically and make changes to them adaptively
- Develop a library of price-capacity bid curves for end use loads
  - Hot water heaters, pumps, variable-frequency drives, appliances, miscellaneous plug loads, etc.
- Develop synthetic transactive signal that are reflective of current utility rate structures

Transactive Coordination and Control: Example Test Results



Experiment #2 Building Efficiency Automated Diagnostics and Automated Re-tuning Status

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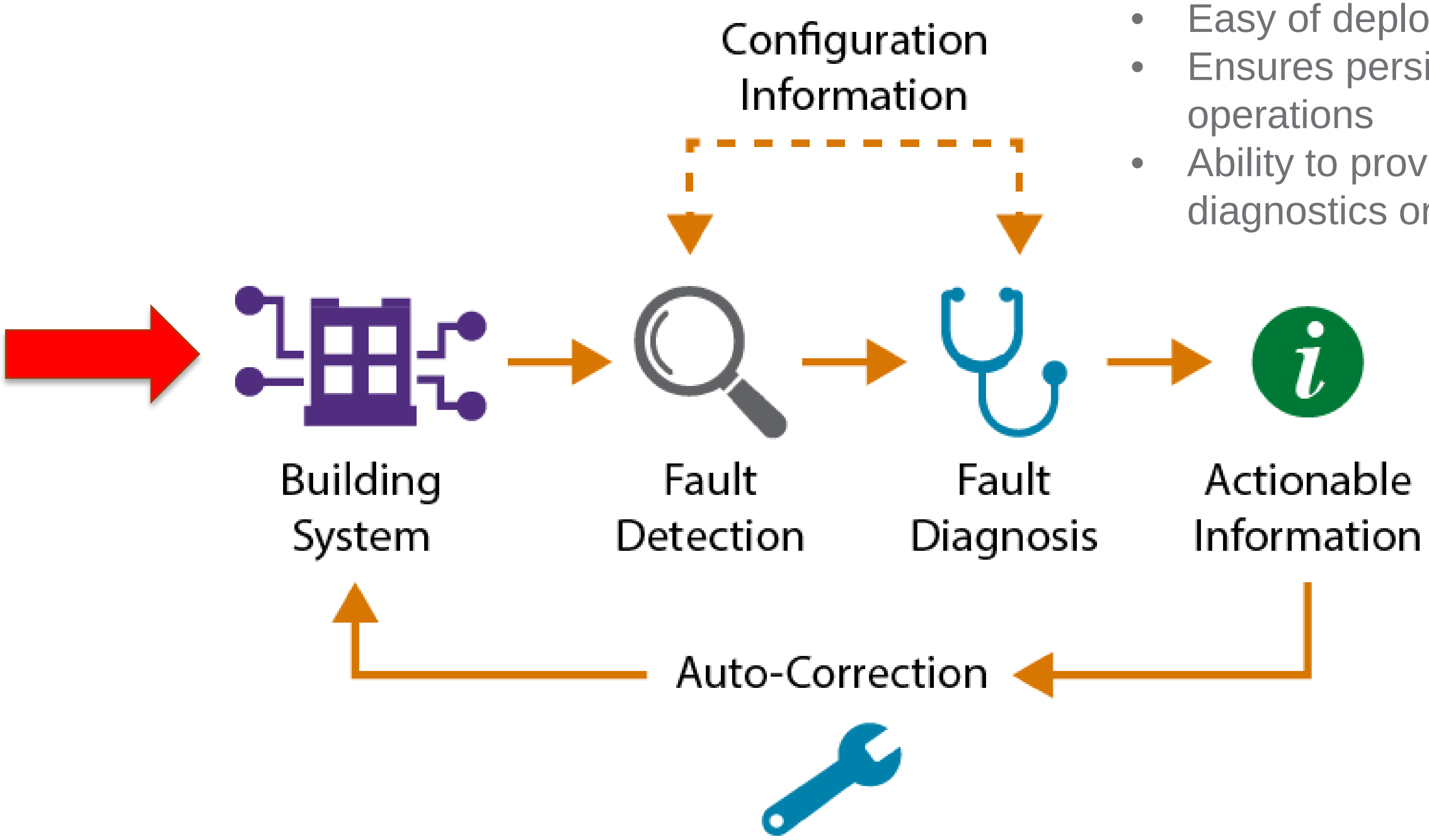
- **Experiment Status**: Designed, scripted in Python, validated through simulation and deployed on 10 buildings on the PNNL campus
- **Documentation**: Technical report completed and a draft of the user guide is pending
- **Code**: Two main Python scripts represent this experiment:
  - a set of proactive diagnostics to detect economizer controls can be found in economizer_RCxAgent.py and
  - a set of proactive automated Re-tuning opportunities can be found in airside_retuning_rcx.py
- Example configuration files, required for both scripts, are also included in the repository. The v-agents also use a number of platform services, including *driver, scheduler, actuator, weather, etc*

Experiment #2 Building Efficiency Automated Diagnostics and Re-tuning

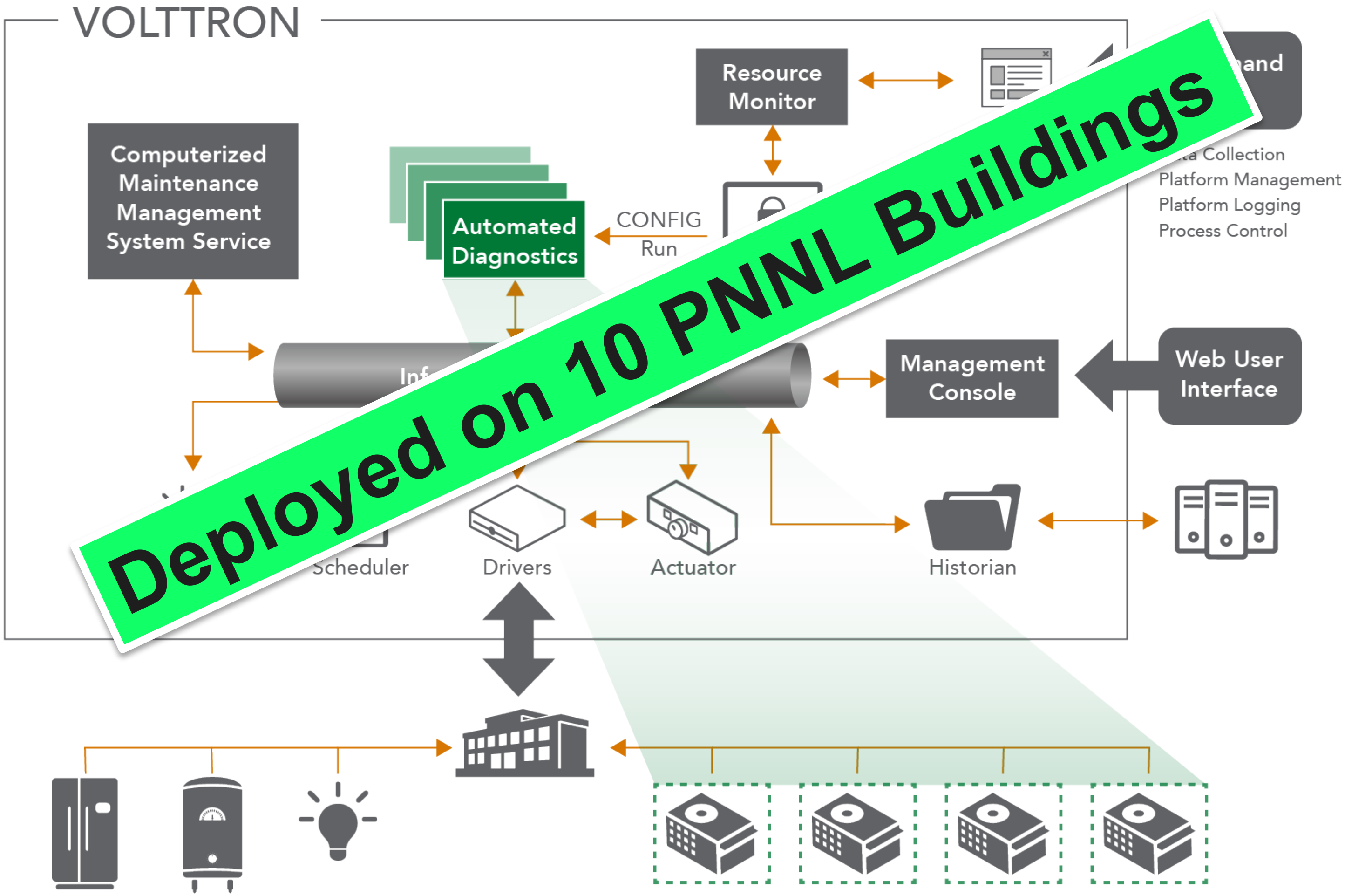
Automated Retro-Commissioning and Self-Correcting Controls identify and correct building problems that impact operations and efficiency

- Easy of deployment
- Ensures persistence of operations
- Ability to provide passive diagnostics or self-correction



Automated Diagnostics and Re-tuning: Deployment

PNNL's VOLTTRON™ platform enables deployment of automated diagnostics and self-correcting controls in building devices



Automated Diagnostics and Re-tuning: Results

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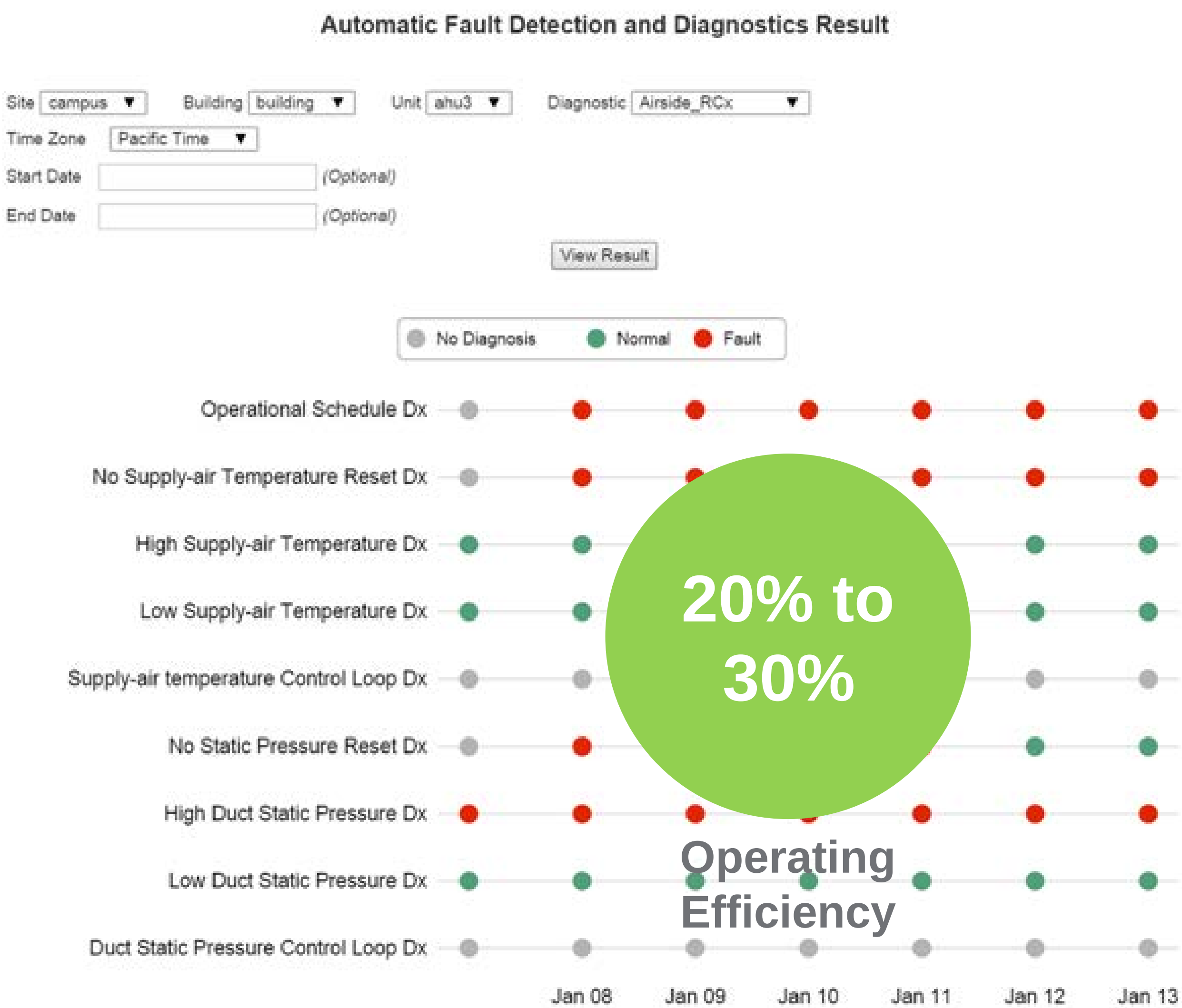

20% to 30%

Operating Efficiency

Katipamula S, RG Lutes, G Hernandez, JN Haack, and BA Akyol. 2016. "**Transactional Network: Improving Efficiency and Enabling Grid Services for Building**." Science and Technology for the Built Environment (2016), 22(6), pp 643-654 doi:10.1080/23744731.2016.1171628

Katipamula S, K Gowri, and G Hernandez. 2016. "**An Open-source automated continuous condition-based maintenance platform for commercial buildings**. Science and Technology for the Built Environment (2016) 00, 1–11 doi: 10.1080/23744731.2016.1218236

Phase II CEF and DOE work

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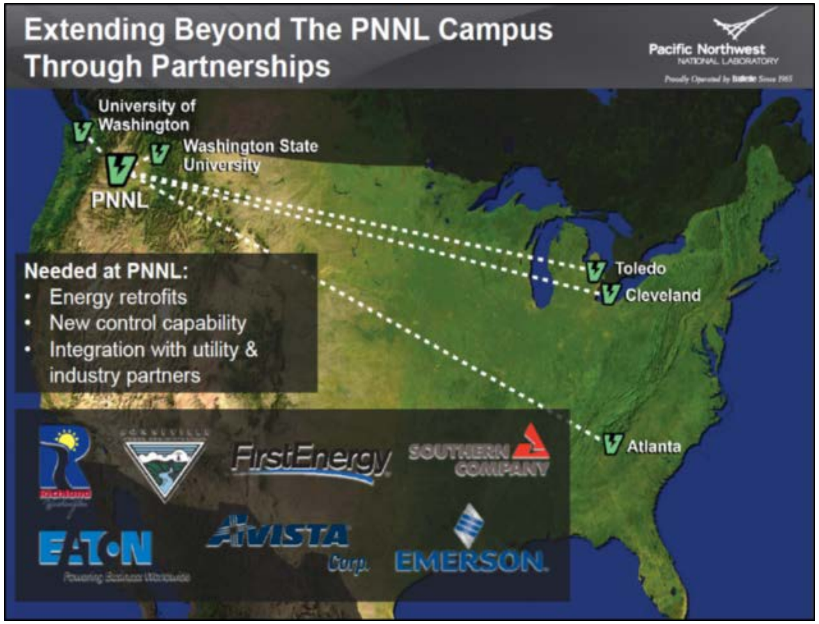
- Focus for Phase II will be:
  - Coordination of experiments across multiple buildings on a campus
  - Coordination of experiments across multiple campuses using transactive signal
- Design and deploy advanced “grid friendly” controls
- Deploy energy efficiency and grid services on the University of Washington campus
- Deploy transactive microgrid with distributed generation, distributed storage and demand response on WSU campus
- Environment test chambers – to ascertain the extent to which providing grid services affects equipment performance and equipment life
- Thermal energy storage system – test the ability to extend grid services without impacting occupant comfort and also extend hosting capacity of renewables on buildings

Extension to Ohio

- **Further refine transactive controls developed in Pacific Northwest**
- **Seamless coordination** from transmission to the "last mile" with responsive customer assets to provide grid stability and system efficiency
- **Ensure that building-recruited flexibility can be matched** with a broad array of local, distribution and transmission grid services needs
- **Utilize simulation, modeling and advanced valuation methodologies** to evaluate different load topologies against grid specific constraints and requirements



Backup Slides

Transactive Concepts Definitions (1)

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These terms have been established in Building Technologies Office's (BTO's) public meetings and reference documents (through review and comment):

- **Transaction** – an exchange or interaction between entities, it can be:
  - Physical (in our case, Energy + Information)
  - Logical (in our case, controls or control systems that act on information)
  - Financial (in our case, a price to determine value to users)

- **Transactive Energy** – Gridwise Architecture Council definition - "techniques for managing the generation, consumption or flow of electric power within an electric power system through the use of economic or market-based constructs while considering grid reliability constraints"
  - The term "transactive" comes from considering that decisions are made based on a value to the parties involved. The decisions may be analogous to (or literally) economic transactions

Transactive Concepts Definitions (2)

- **Transactive Devices** or **Connected Equipment** – consumer products with information and communication technologies (ICT) that enable them to be exercised through transactions – without boundaries
  - Many available technologies are typically proprietary (e.g. vendor specific ICT)

- **Transaction-Based Controls** – controls that exchange, negotiate, and respond to information through ICT
  - Most common signal is economics based: “price” (others include, renewable imbalance, frequency, voltage, etc.)
  - Needs advancements in fundamental sensors and controls – like plug-n-play, auto-mapping, etc.

- **Transactional Platform** – a software platform (e.g. ICT and related physical hardware) that allow applications to be programmed and negotiate/act on the exchange of information
  - An example platform, VOLTTRON™ is fully supported throughout DOE (OE, EERE, others) and is open source

Transactive Concepts Definitions (3)

- **Transactive Buildings** – buildings that can dynamically respond to signals or messages from entities outside the building
  - Can provide a measurable response to entities outside the building by "flexing" loads inside the building
  - Self-aware (continuously aware of building state such that availability can be quantified) and continuously interacting with the larger systems they are a part of (e.g. campuses, neighborhood, grid, etc.)

- **Transactive Campuses** are the physical locations of fully integrated collections of "transactive" equipment, buildings, and other energy efficiency and renewable energy assets
  - Transactive locations can deliver energy market and grid services through the management/interactions of installed assets, devices, and loads

ILC: Traditional Utility Rate Structure

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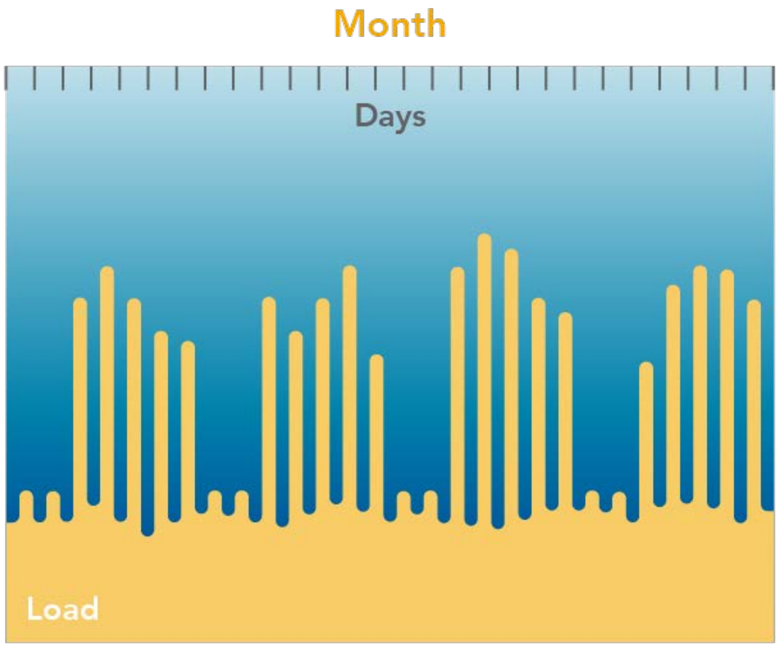
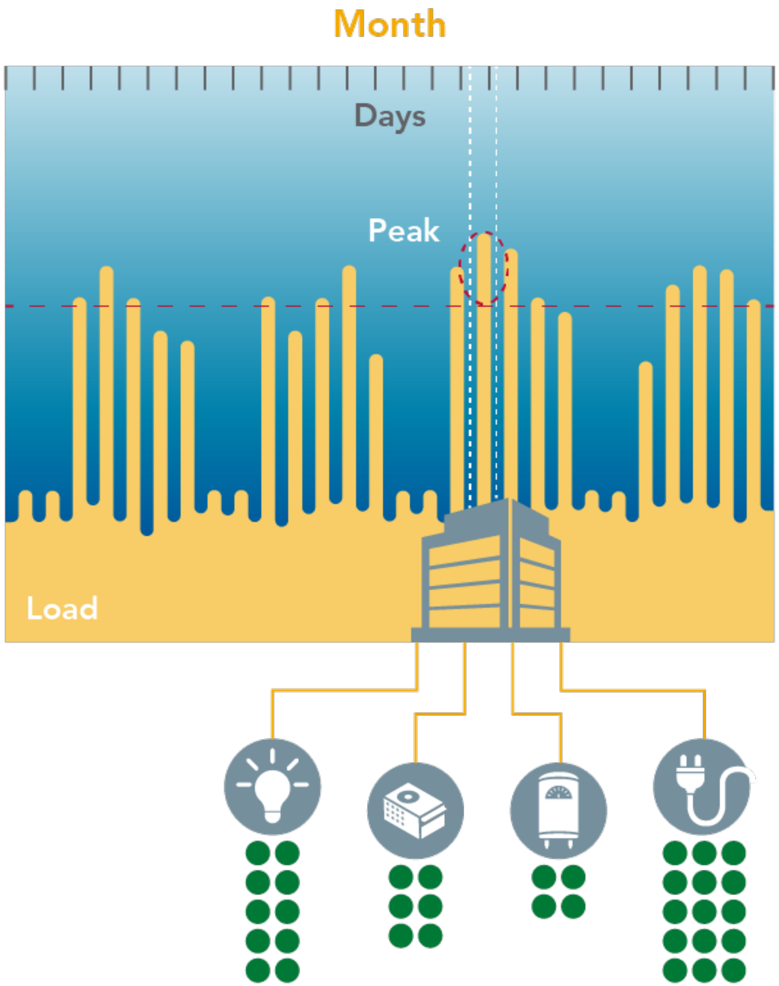
Forecast the Load for the Next Billing Cycle



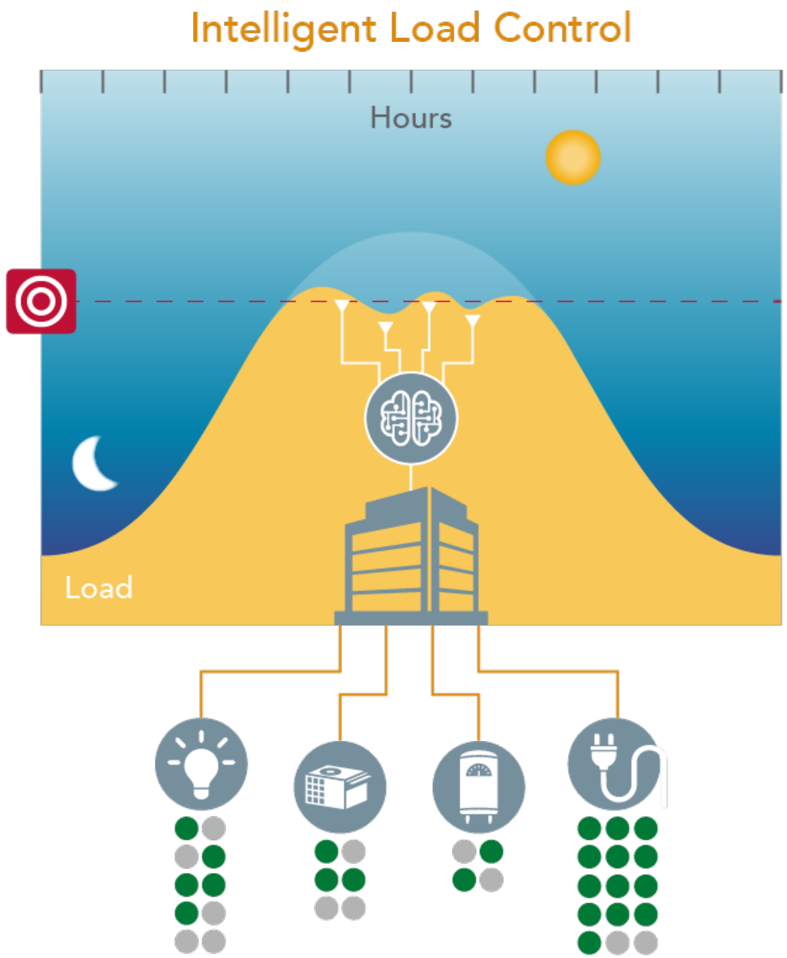
Establish the Target Peak



ILC: Results

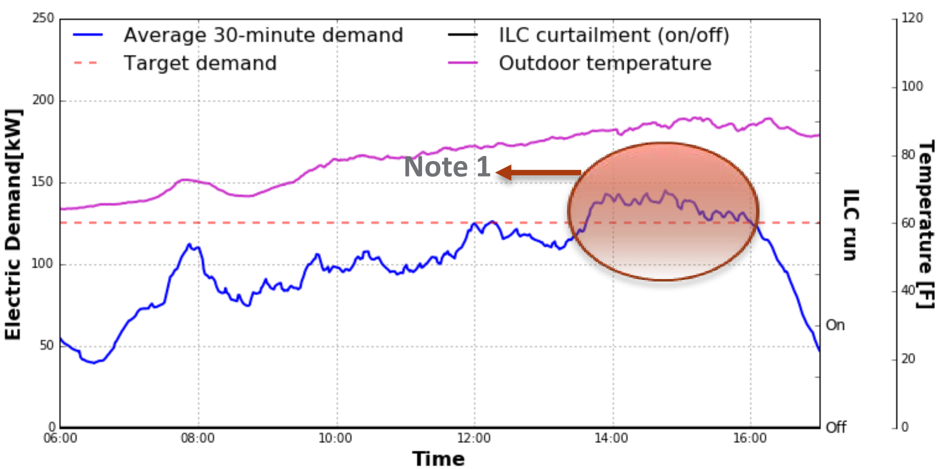
- Tested and deployed on three PNNL buildings to date
  - *Does* manage or reduce peak electricity demand
  - *Doesn't* impact occupant comfort

Kim W, and S Katipamula. 2017. "**Development and Validation of an Intelligent Load Control Algorithm**." Energy and Buildings, 135 (2016), pp 62-73. http://dx.doi.org/10.1016/j.enbuild.2016.11.040



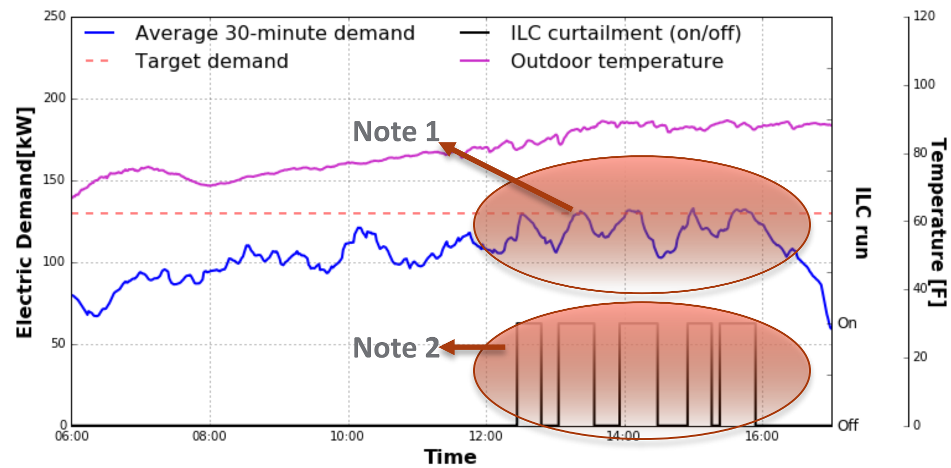
ILC Test During Cooling Season

Business-As-Usual, No ILC: July 12



- **Note 1**: Peak demand for this day is 145 kW, which occurred between 2 p.m. and 4 p.m.
- Also, note that the duration of the peak demand was significant in this case

Dynamic Load Shaping with ILC: July 11



- **Note 1:** Peak demand for this day **never exceeds** the target of 135 kW, which was set several times between 12:30 p.m. and 4 p.m.
- **Note 2**: Some end use loads were turned off to manage the load shape
- If ILC were operational the previous day, the building could have avoided approximately $50 in Pacific Northwest or $200 in CA or NY

Temperature Profile and Heat Pump Status: Cooling Season

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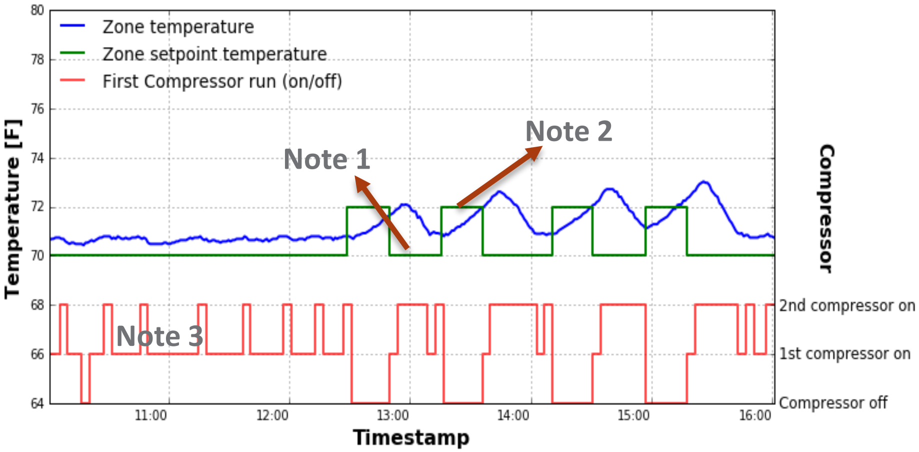
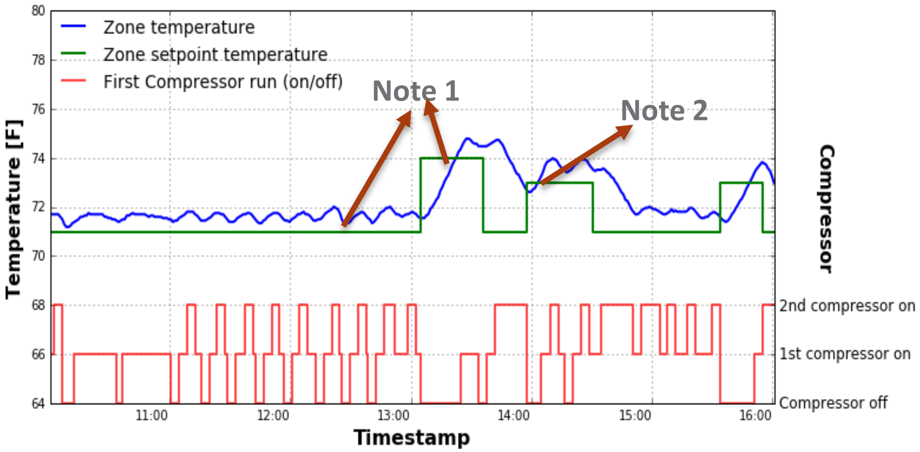
Heat Pump 4



- **Note 1**: Normal cooling set point is 70ºF for this heat pump
- **Note 2**: When ILC wants to control the unit, it increases the set point to 72ºF
- **Note 3**: Heat pump status
- Note the set point excursions are modest, to get the desired result; extending set point excursions to 2ºF or 3ºF will result in more deeper load management

Heat Pump 8



- **Note 1**: Normal cooling set point 71ºF and the set point was increased to 73/74ºF (stage 1/2) for load management
- **Note 2**: Although the unit was supposed to be OFF, it is released as soon the zone temperature exceeds the set point

ILC: One Day's Result (July 11, 2016)

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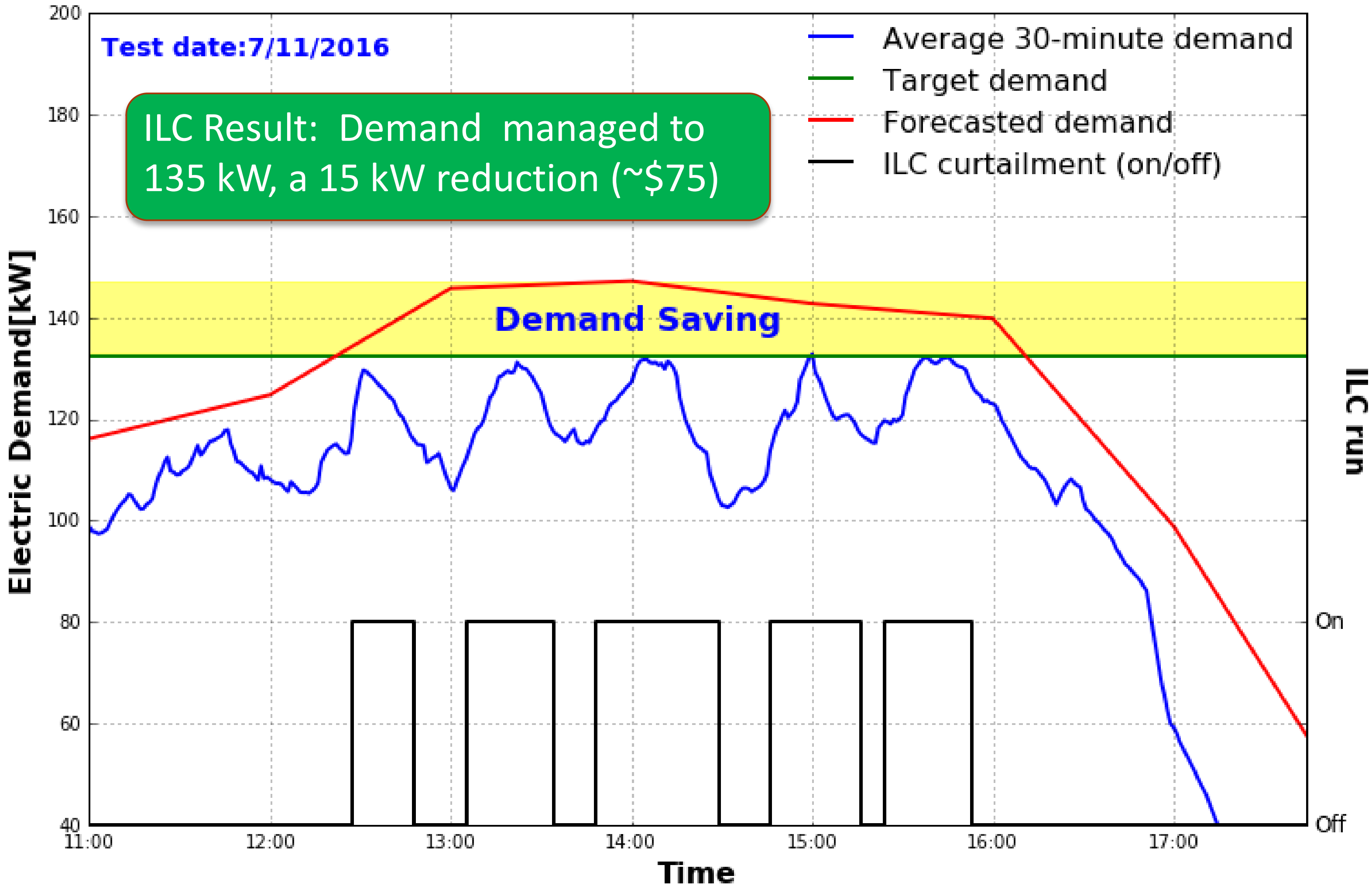

ILC: One Day's Result (April 13, 2017)

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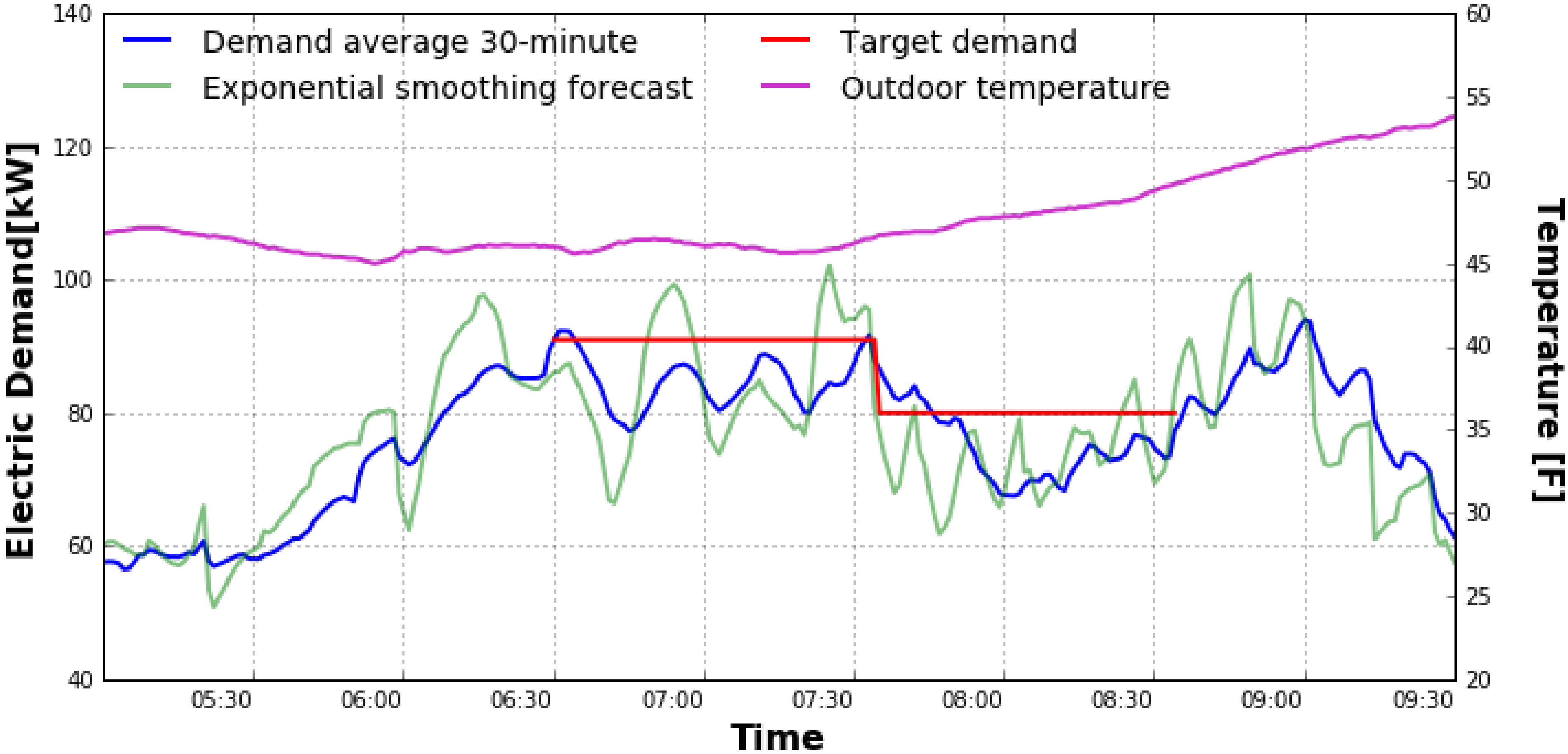

Experiment #4 Grid Service Renewables Integration Support Status

- **Experiment Status**: Designed, scripted in Python, tested using simulation and in the laboratory and ready for testing on PNNL campus buildings
- **Documentation**: Technical report completed and a draft of the user guide is pending
- **Code**: Four main Python and/or MATLAB scripts were developed:
  - Fan system identification agent (IDAgent.py) identifies relationship among fan power, fan speed, and supply air flow, etc.
  - Indirect fan speed controller (FanICAgent.py) that indirectly controls the fan speed via changing the duct static pressure set point using PID loop. It applies to the supply fan in AHUs
  - Direct fan speed controller (FanDCAgent.py) that directly controls the fan speed using the identified fan power-fan speed model. It applies to a variable speed fan in a roof top unit
  - A MATLAB script that determines the ON/OFF status of a population of water heaters, and a MATLAB-VOLTTRON interface written in MATLAB and Python to use VOLTTRON to turn ON/OFF of physical water heaters
- These scripts have not yet been posted to the project repository. They are waiting final tests and quality checks before they are posted. All scripts require configuration files and example configuration files will also be posted to the repository when the scripts are posted. Additionally, the agents in (2), (3), and (4) use a number of platform services, including *driver*, *scheduler*, *actuator*, *listener*, and *historian*, etc.

Renewables Integration

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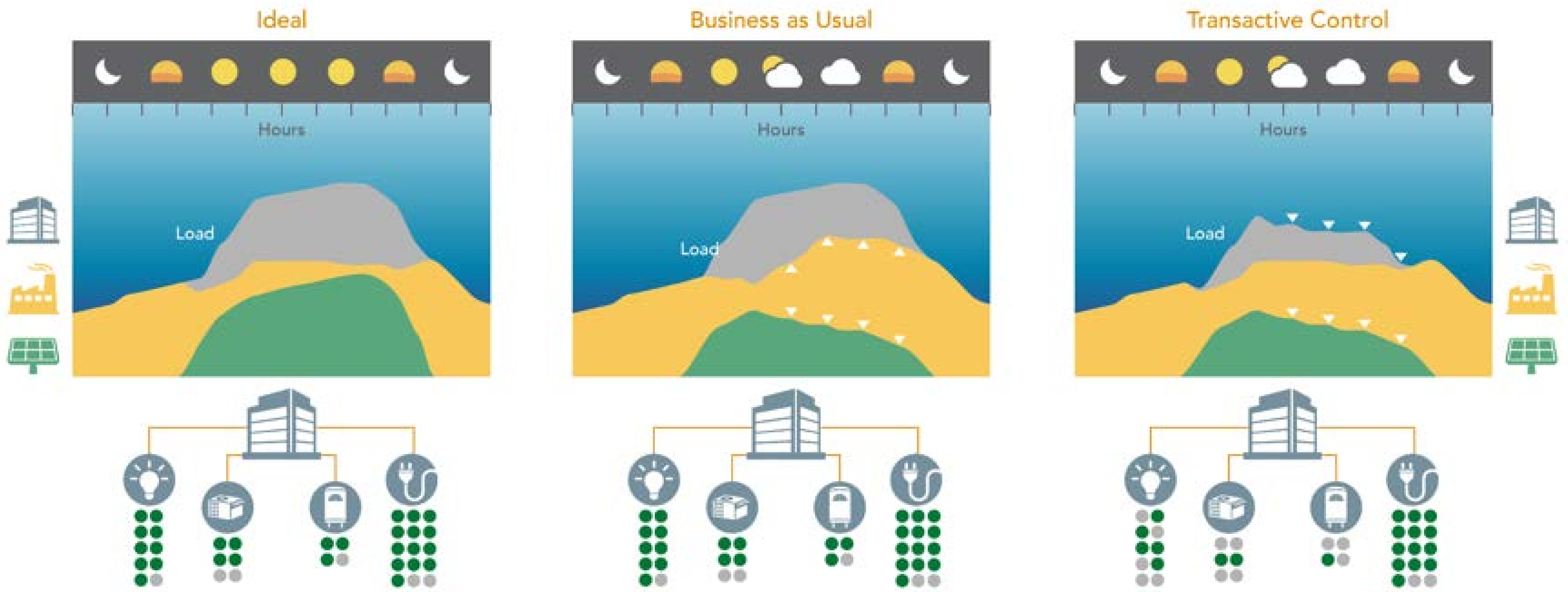

Control building loads such as variable-frequency-drives (VFDs) on fans in AHUs and packaged rooftop units (RTUs) to absorb renewables generation losses and reduce grid fluctuations

Renewables Integration: Deployment

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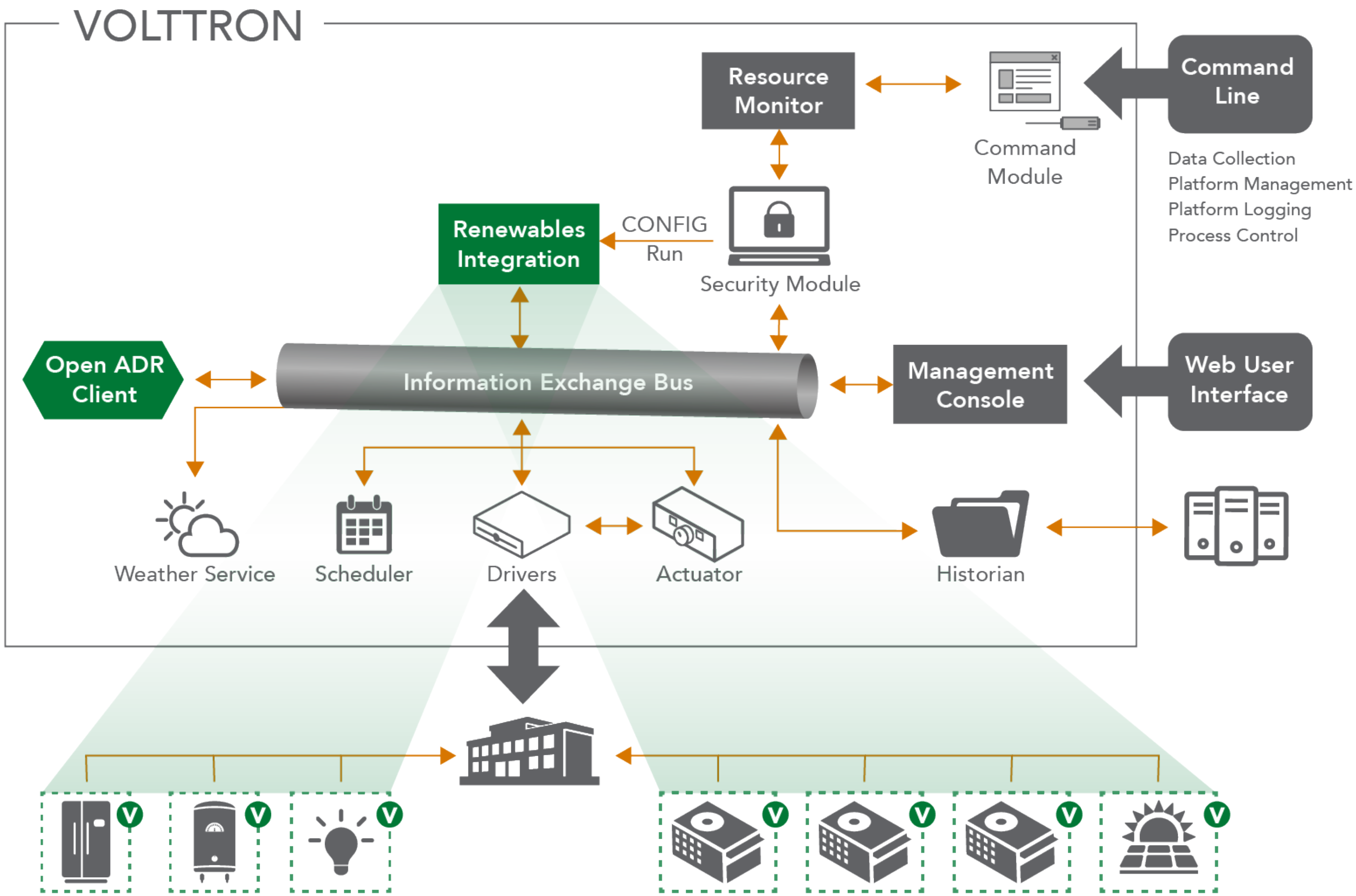
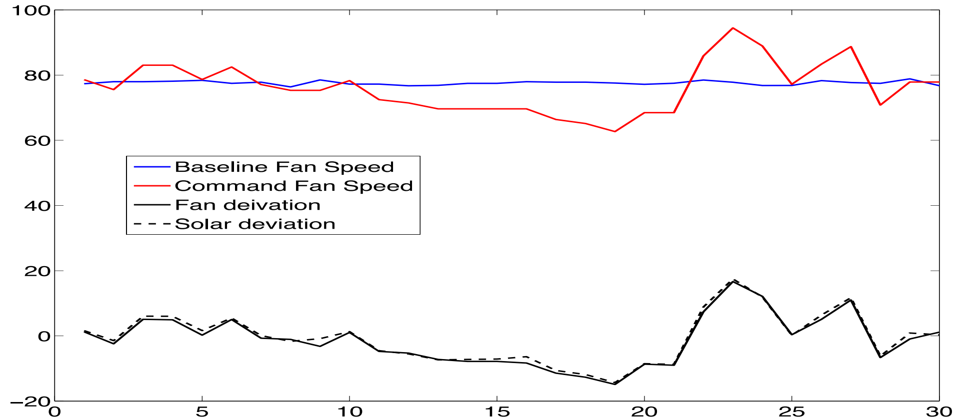
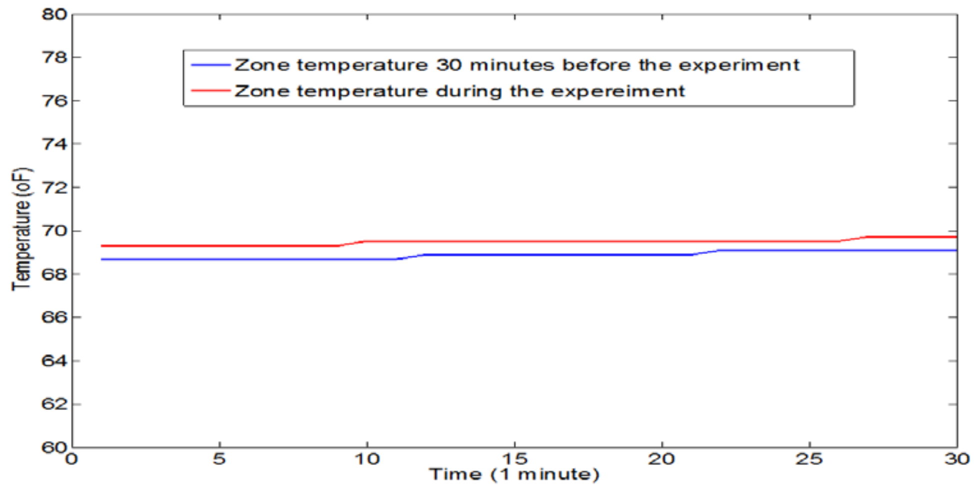
PNNL's VOLTTRON™ platform enables deployment of Renewables Integration approach in building devices



Renewables Integration: Results

- Fan speed controlled to track with a dispatch signal, e.g., renewable generation deviation
- The experiment is to see if a fan speed can follow a "solar" generation (low/high) signal





WSU: Resiliency of Distribution Systems

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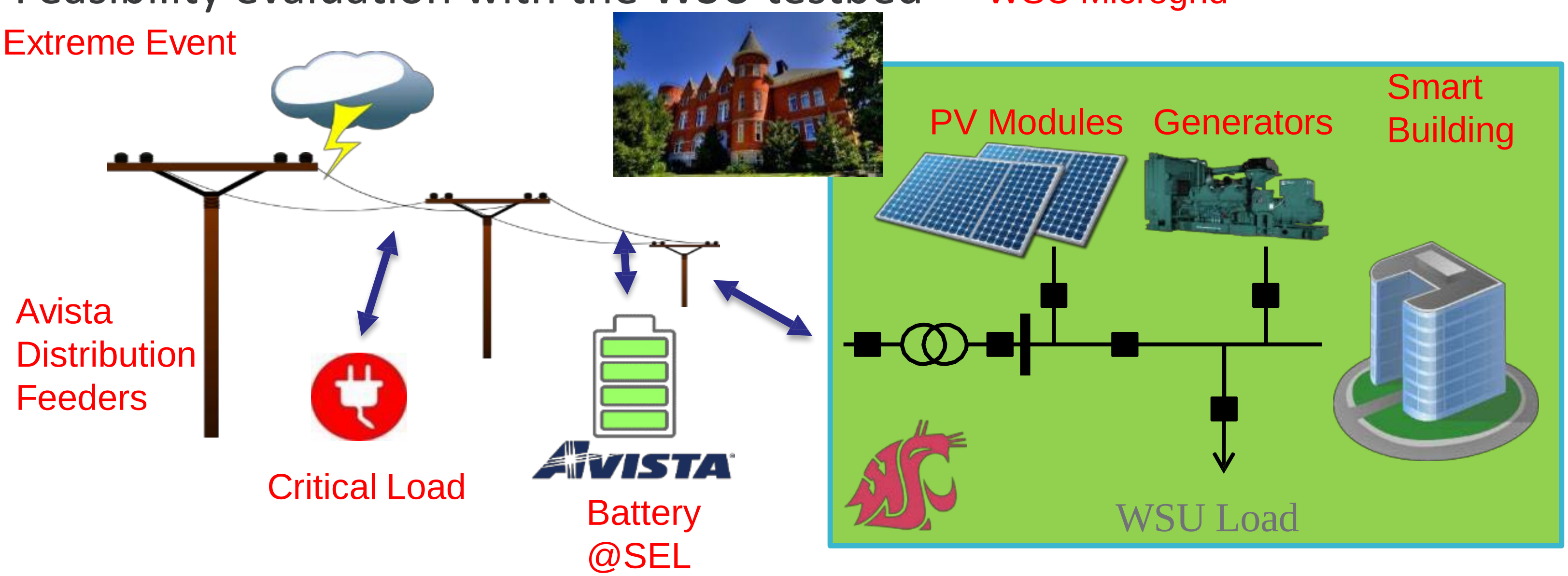
PVs, Batteries, and Smart Buildings

- Define resiliency for an isolated distribution system with PVs, batteries, smart buildings, and WSU microgrid generators
- Optimal utilization of PVs, batteries, and WSU microgrid generators to serve critical load during system restoration
- Explore the role of smart buildings in resiliency enhancement
- Feasibility evaluation with the WSU testbed



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- Kim W, and S Katipamula. 2017. "**Development and Validation of an Intelligent Load Control Algorithm**." Energy and Buildings, 135 (2016), pp 62-73. http://dx.doi.org/10.1016/j.enbuild.2016.11.040
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Publications to Date: Technical Reports and User Guides

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- Kim W, S Katipamula, RG Lutes, RM Underhill. 2016. "Behind the Meter Grid Services: Intelligent Load Control" PNNL-26034, Richland, WA.
- Hao H, G Liu, S Huang, S Katipamula. 2016. "Coordination and Control of Flexible Building Loads for Renewable Integration; Demonstrations using VOLTTRON" PNNL-26082, Richland, WA.
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