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Innovative Low Cost Building Automation Sensors and Controls

July 12, 2018

SERDP DOD • EPA • DOE | ESTCP

Welcome and Introductions

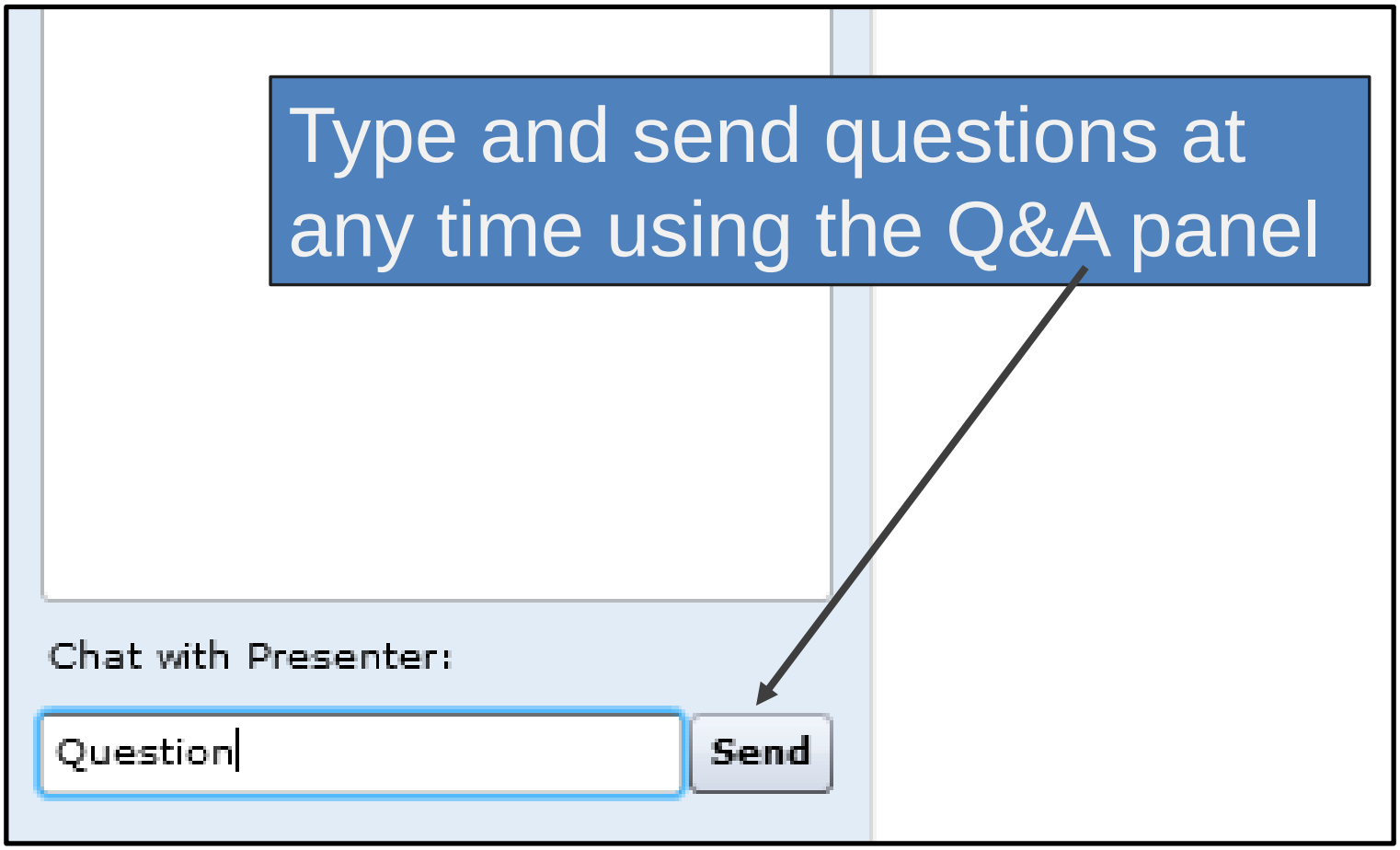
Jennifer Nyman, Ph.D., P.E.
Webinar Facilitator

SERDP DOD • EPA • DOE | ESTCP

Webinar Agenda

- **Webinar Logistics** (5 minutes)
  Dr. Jennifer Nyman, Geosyntec Consultants
- **Overview of SERDP and ESTCP** (5 minutes)
  Mr. Timothy Tetreault, SERDP and ESTCP
- **Wireless Decentralized Energy Management and Control**
  Mr. Julian Lamb, Paragon Robotics (25 minutes + Q&A)
- **Improving Building Performance Using Virtual Water/Air Flow Meters** (25 minutes + Q&A)
  Dr. Michael Brambley, Pacific Northwest National Laboratory
- **Final Q&A session**

How to Ask Questions



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SERDP and ESTCP Overview

Timothy Tetreault
Installation Energy and Water
Program Manager

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SERDP

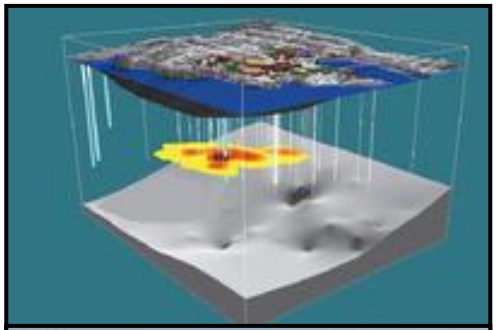
- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced technology development to address near term needs
  - Fundamental research to impact real world environmental management

ESTCP

- Environmental Security Technology Certification Program
- Demonstrate innovative cost-effective environmental and energy technologies
  - Capitalize on past investments
  - Transition technology out of the lab
- Promote implementation
  - Facilitate regulatory acceptance

Program Areas

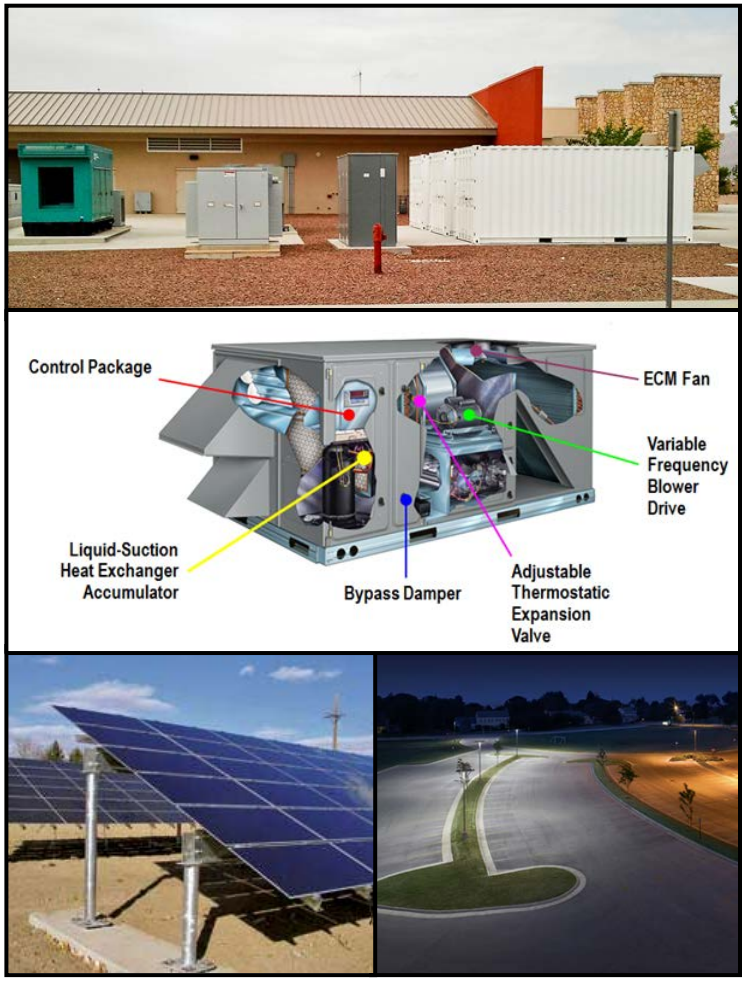
1. Environmental Restoration
2. Installation Energy and Water
3. Munitions Response
4. Resource Conservation and Resiliency
5. Weapons Systems and Platforms





Installation Energy and Water

- Smart and secure installation energy management
  - Microgrids
  - Energy storage
  - Ancillary service markets
- Efficient integrated buildings and components
  - Design, retrofit, operate
  - Enterprise optimized investment
  - Advanced components
  - Intelligent building management
  - Non-invasive energy audits
- Distributed generation
  - Cost effective
  - On-site
  - Emphasis on renewables



SERDP and ESTCP Webinar Series

Date	Topic
August 9, 2018	Energy Sustainable Wastewater Treatment Systems for Forward Operating DoD Installations
August 23, 2018	Sediment Volume Search Sonar Development
September 6, 2018	Informing Restoration Programs for Threatened and Endangered Plant Species
September 20, 2018	Plant Diversity and Biological Nitrogen Fixation in Longleaf Pine Ecosystems at Military Installations
October 4, 2018	Chlorinated Solvents Workshop Overview and Feature Projects

For upcoming webinars, please visit

http://serdp-estcp.org/Tools-and-Training/Webinar-Series

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Save the Date!

A three-day symposium showcasing the latest technologies that enhance DoD's mission through improved environmental and energy performance

November 27 - 29, 2018

Washington Hilton Hotel

Registration is coming soon

Wireless Decentralized Energy Management and Control

Julian Lamb
Paragon Robotics

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Agenda

- Problem statement
- Current DoD practice for energy savings
- Paragon platform
- ESTCP project results
  - Installation stages
  - Energy savings
  - Costs
  - Return on investment
- Next steps

DoD – Department of Defense; ESTCP – Environmental Security Technology Certification Program

Problem Statement

- Smaller DoD buildings (< 50k sq. ft) often do not have advanced HVAC controls to save energy, due to the poor return on investment

1. Retrofit wiring costs are expensive
2. DoD security requirements prevent many off-the-shelf control systems
3. Additional auditing and monitoring hardware is typically required for performance contracts, increasing costs

- 45% of all DoD floorspace are small buildings (highest of all Federal agencies)
- < 40% of DoD small sector floorspace is estimated to currently have BMS control

HVAC – Heating Ventilation and Cooling; BMS – Building Management System

Energy Savings: Current DoD Practice

Performance contracts are one of the most common contracting vehicles for improving DoD installation energy efficiency

Loggers

Controllers

Meters

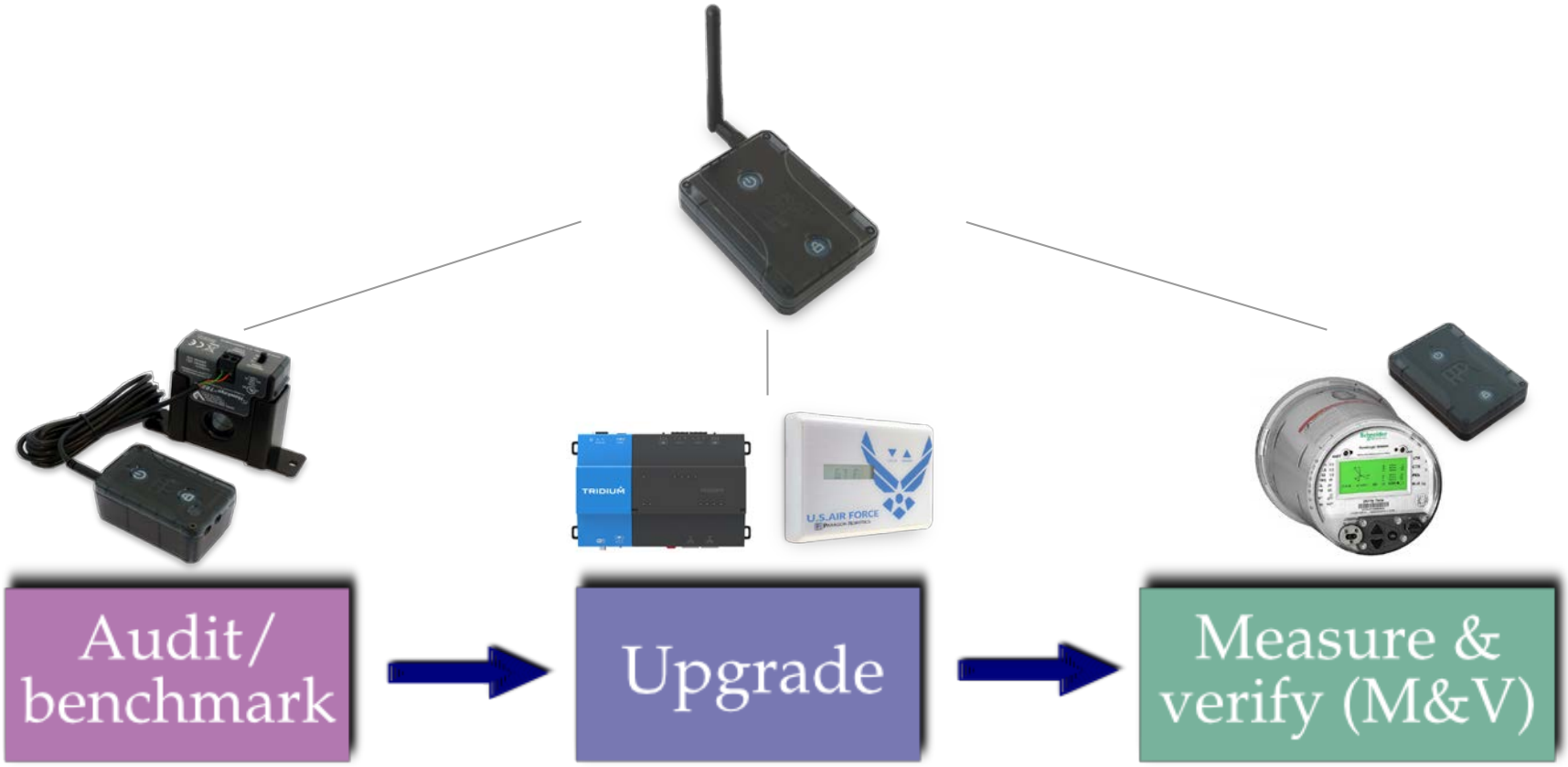
Audit/ benchmark → Upgrade → Measure & verify (M&V)

3 stages, each typically requiring separate equipment and software

How Paragon Products Fit In

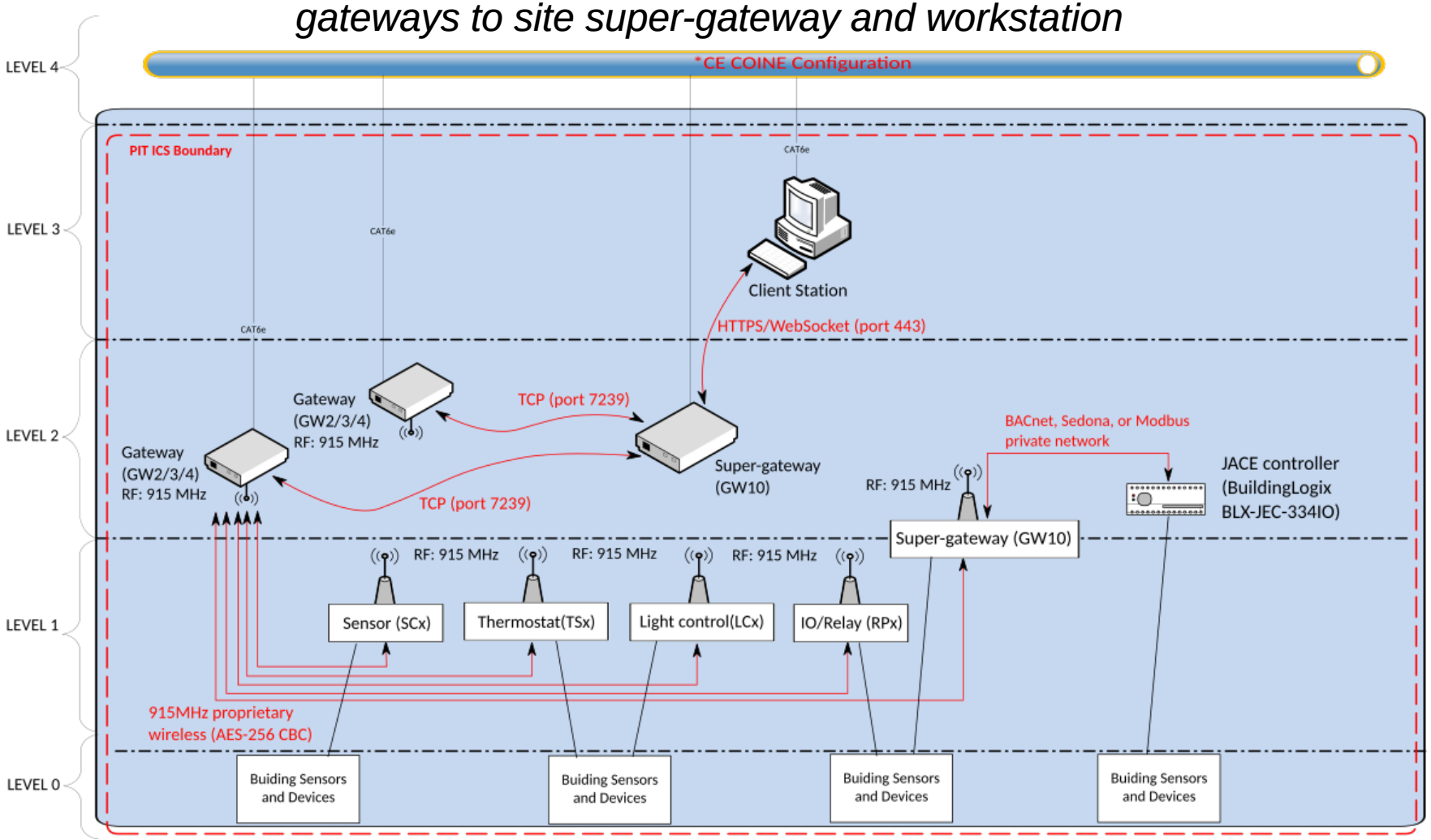
One hardware/software platform from start to finish

- Single platform integrates Paragon hardware with third party equipment, reducing costs and security approvals



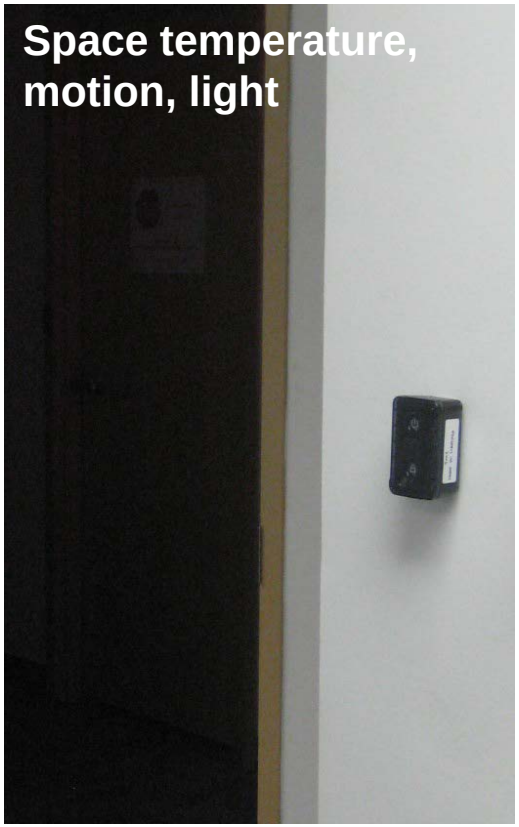
Network Topology

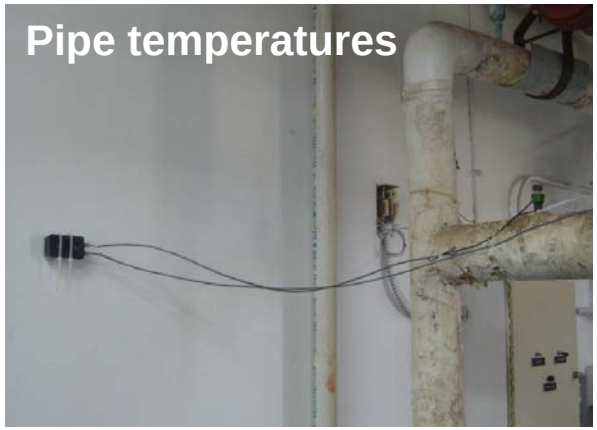
Wireless communication from building devices to building gateway, wired network from gateways to site super-gateway and workstation



Auditing Equipment

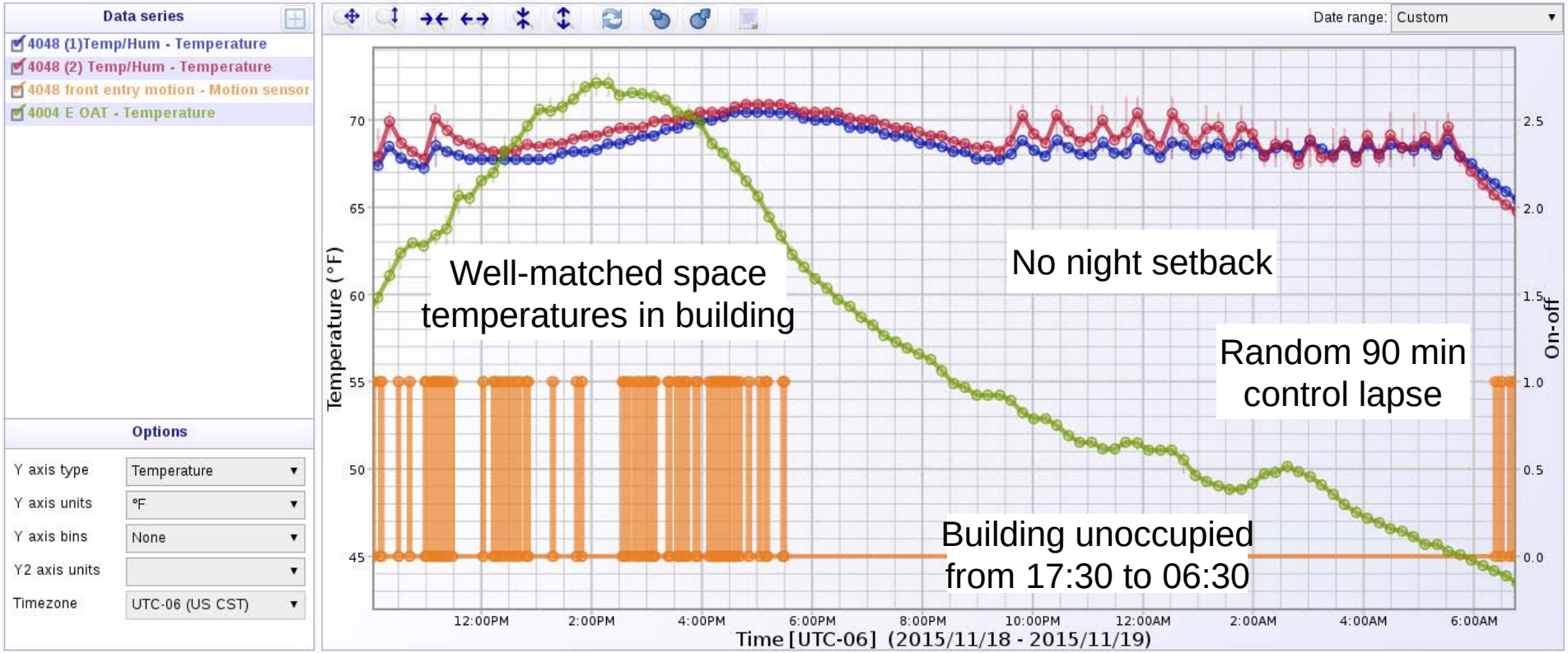
Measurements of power, temperatures of HVAC equipment and occupied spaces, and many other parameters





Auditing: What to Look For

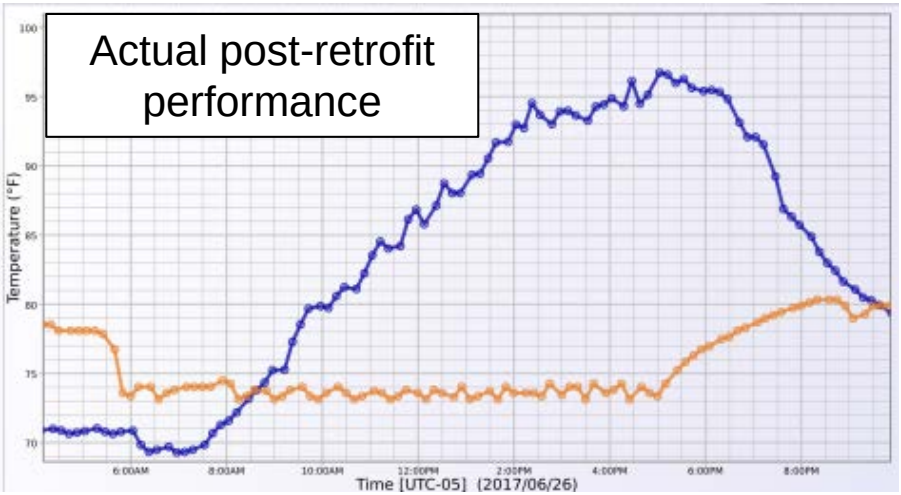
Deficiencies in HVAC control, equipment performance

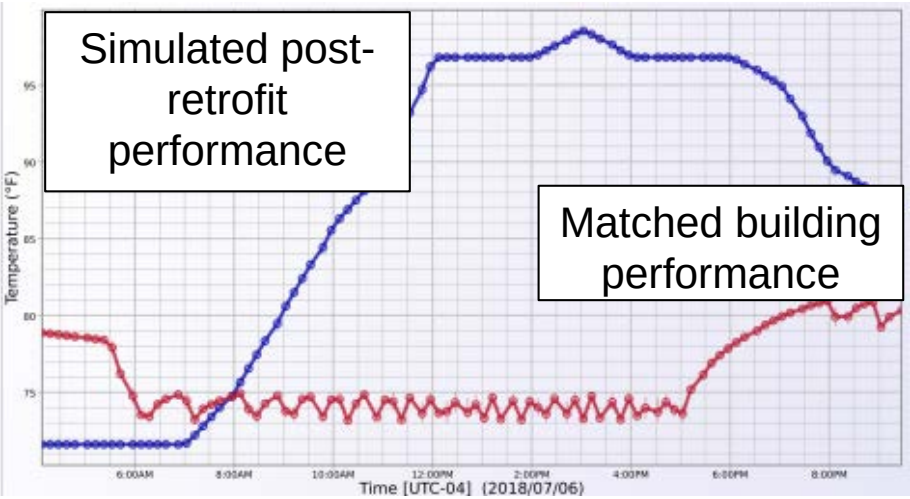


Thermodynamic Simulation

Calculates energy savings from conservation

- 1-minute sample data from actual buildings gave us high-resolution view
- Used our internal SystemSimulator software to build models which match actual performance
- Run simulator for a typical climate year to determine potential utility savings





Installation Focus

Reduce costs while meeting performance

- Gateway installation required the most engineering to minimize real-world costs
- Thermostats, AHU, boiler, and chiller controller installation processes were also streamlined

AHU – Air Handler Unit

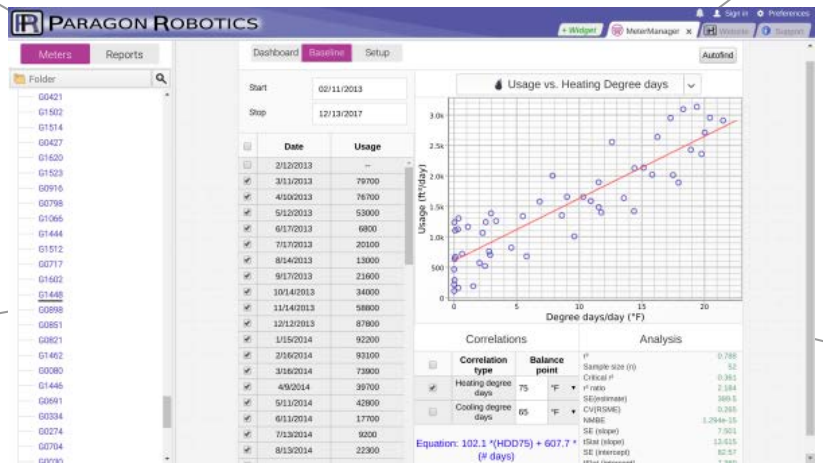
Monitoring and Verification

Data are combined into MeterManager software

Paragon equipment

Electricity/gas meters

BMS data

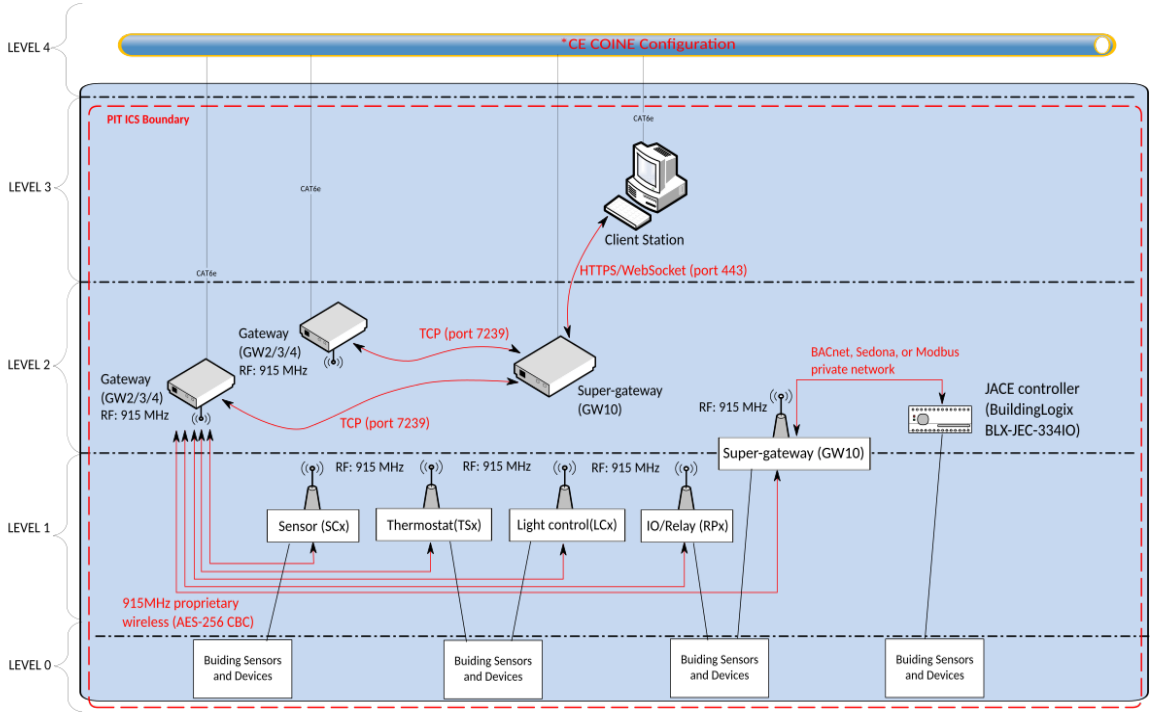


MeterManager software

Manual spot check readings

Cybersecurity

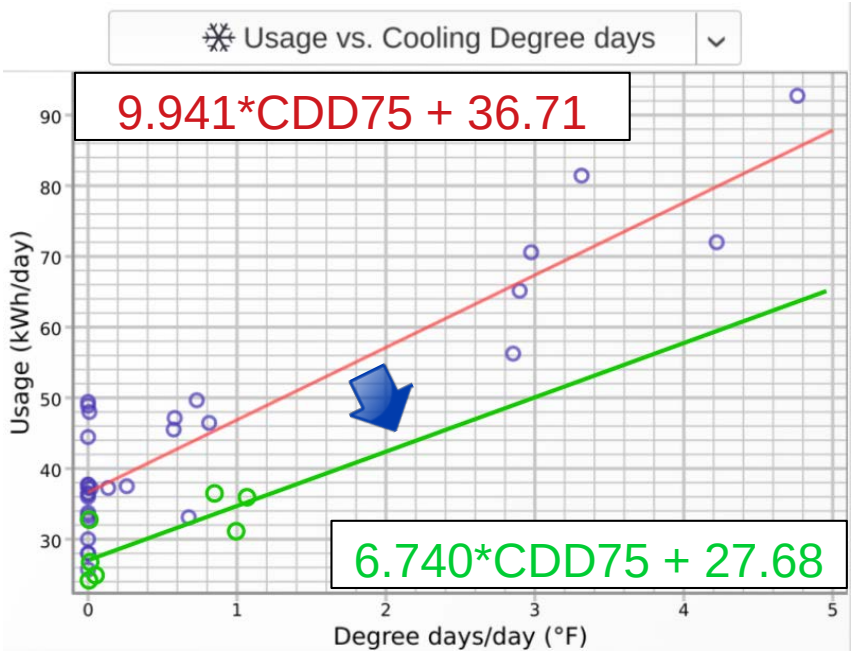
- DoD requires Authority to Operate (ATO) for all ICS systems
- Many improvements were made to BMS to meet ATO requirements during demonstration
- Air Force Civil Engineering Command (AFCEC) approved ATO in May 2017



Results: Energy Savings

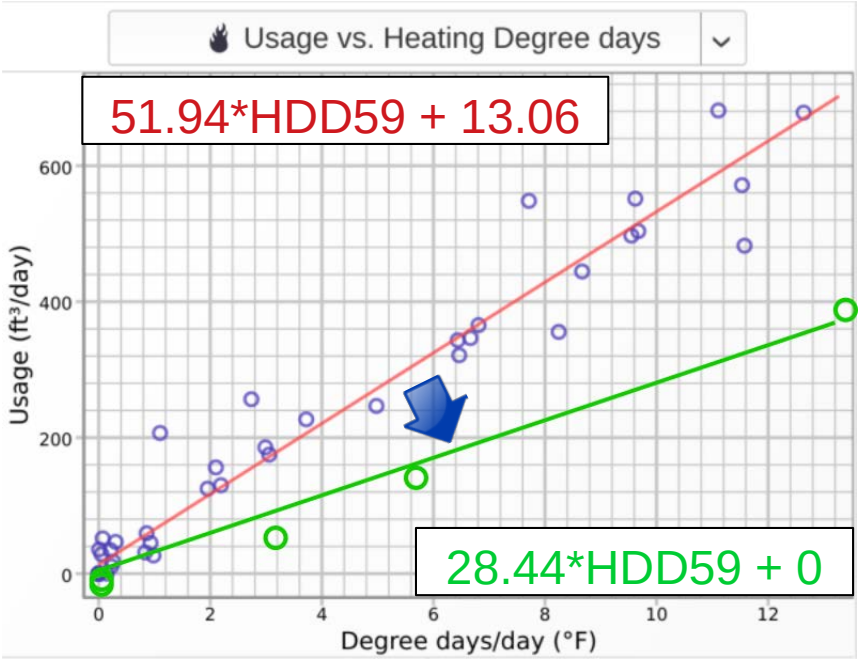
*Retrofit buildings showed >30% building savings**

B4068 Electricity



26% metered electricity savings for building

B4068 Gas



49% metered gas savings for building

**M&V methodologies were used to calculate true utility savings across demonstration buildings*

Results: Total Installation Costs

Analysis of competitors' costs

- Lowest cost competitors
  - Thermostatic control
    - o BACnet building controller with wireless Zigbee thermostat
  - AHU control
    - o JACE with CAT5 wiring to mechanical room
- Competitor installed cost is higher than Paragon
  - 36-89% higher in all small to medium building situations

B4068	Paragon	Viconics
Hardware	$620	$1756
Software	$150	$150
Labor	$360	$660
Audit/proposal	$200	$200
G&A (15%)	$300	$415
Profit (8%)	$170	$254
Buffer (10%)	$180	$300
Total	$1,980	$3,735 (+89%)

B4029	Paragon	JACE
Hardware	$11,400	$21,210
Software	$2,100	$2,100
Labor	$21,690	$24,890
Audit/proposal	$800	$800
G&A (15%)	$5,400	$7,350
Profit (8%)	$3,311	$4,508
Buffer (10%)	$4,470	$6,086
Total	$49,170	$66,944 (+36%)

Results: Return on Investment

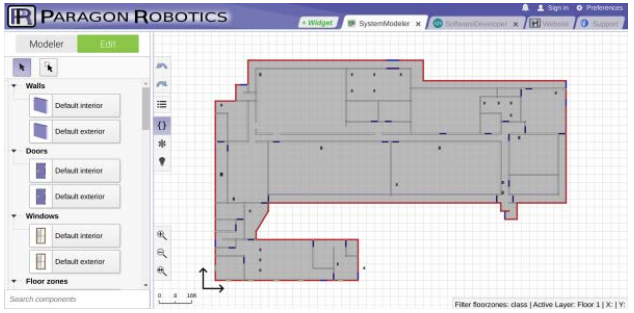
Can achieve ~7 year simple payback

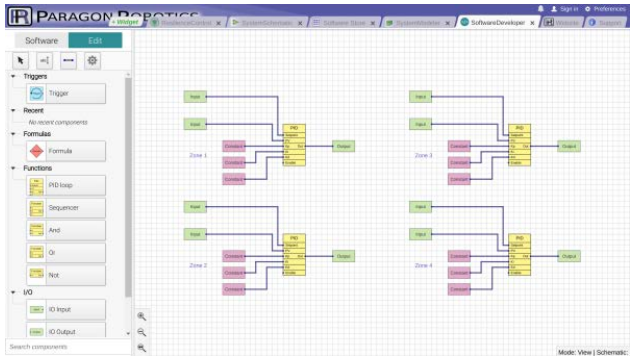
- Only worst-case installations cannot achieve 10 year simple payback even with $0.055/kWh and $0.49/therm
- Paragon has audited >140 further buildings at Tinker with similar results
- Overall savings are sufficient to bundle and retrofit 100% of buildings

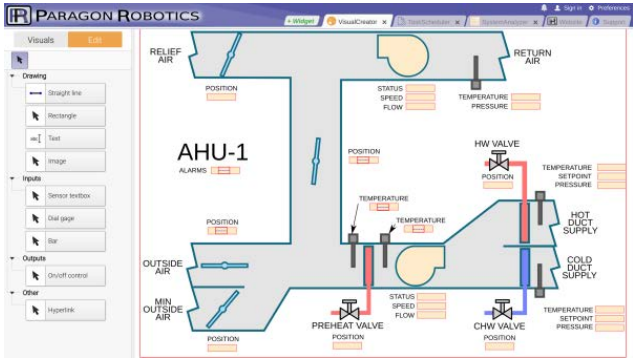
	Square feet	Utility savings	Installed cost	Simple payback
B4001	2195	$842	$4,398	**1.7**
B4004	11798	$2,668	$7,592	**2.8**
B4008	7423	$1,092	$1,877	**1.7**
B4012	14028	$4,228	$47,910	**11.3**
B4023	3687	$362	$3,639	**10.1**
B4028	1870	$446	$3,692	**8.3**
B4029	19220	$12,269	$47,910	**3.9**
B4031	3425	$567	$3,692	**6.5**
B4032	1803	$210	$1,877	**8.9**
B4045	164	$216	$1,877	**8.7**
B4048	2583	$1,137	$4,093	**3.6**
B4049	3731	$416	$3,583	**8.6**
B4057	9898	$1,865	$18,148	**9.7**
B4064	50780	$7,939	$78,036	**9.8**
B4068	1483	$297	$1,877	**6.3**
B4069	4704	$779	$5,584	**7.2**
B4077	2450	$522	$4,522	**8.7**
B4078	2428	$158	$4,522	**28.6**
B4079	3674	$609	$2,927	**4.8**
Total	147,344	$36,622	$247,756	**6.7**

Commercialization

- Control hardware and BMS software are now available off-the-shelf
- Recently added engineering and installation management services to our offerings
- Primary sales channels: ESCOs and utilities for DoD retrofit applications using performance contracts
- Prime contractor to DoD for meter data management services







ESCO – Energy Services Company

Next Steps

- Integrating the wireless BMS system with microgrid controls
  - Two DoD demonstrations
- Further expanding the EMS software scope for very large installations
- New ESTCP FY18 project
  - Adapt Paragon platform, hardware, software for third parties
  - Eliminates the need for separate ATOs

Conclusions and DoD Benefits

- Modern BMS controls can realistically save 25% building electricity and 45% building gas usage
- The installed cost for our wireless BMS is low enough to provide < 10 year simple payback in even small buildings, allowing use with ESPCs
- Same system provides additional auditing and M&V savings to further justify use with ESPCs and general metering projects
- We are continuing to expand system for both resilience applications, as well as streamlining security for other ICS systems

ESPC – Energy Savings Performance Contract; ICS – Industrial Control System

For additional information, please visit
https://www.serdp-estcp.org/Program-Areas/Installation-Energy-and-Water/Energy/Conservation-and-Efficiency/EW-201410

Speaker Contact Information

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Q&A Session 1

Improving Building Performance Using Virtual Water/Air Flow Meters

Michael R. Brambley, Ph.D.
Pacific Northwest National Laboratory

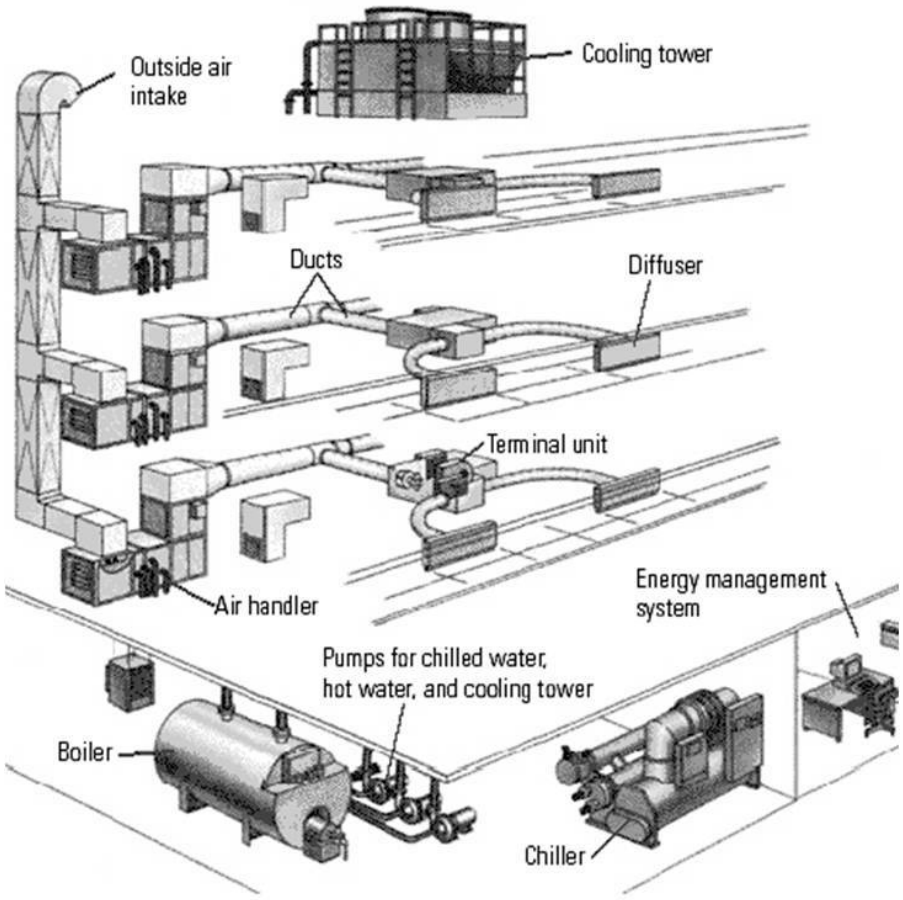
SERDP DOD ▪ EPA ▪ DOE | ESTCP

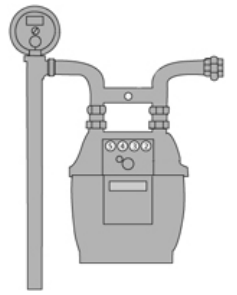
Agenda

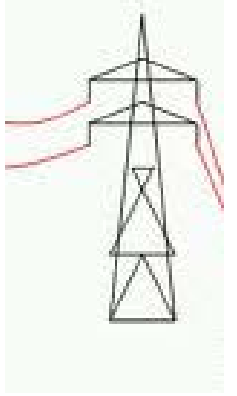
- Problem statement
- Technology description
- Building demonstration results
- Conclusions

High-Resolution Metering Capacity

- Meters at the whole building level are not sufficient







Virtual Meters are the Solution!

- Why?
  - Flow meters are expensive
  - Flow meters are usually intrusive
  - Flow meters require long and straight ducts/pipes
- What?
  - Virtual measurements

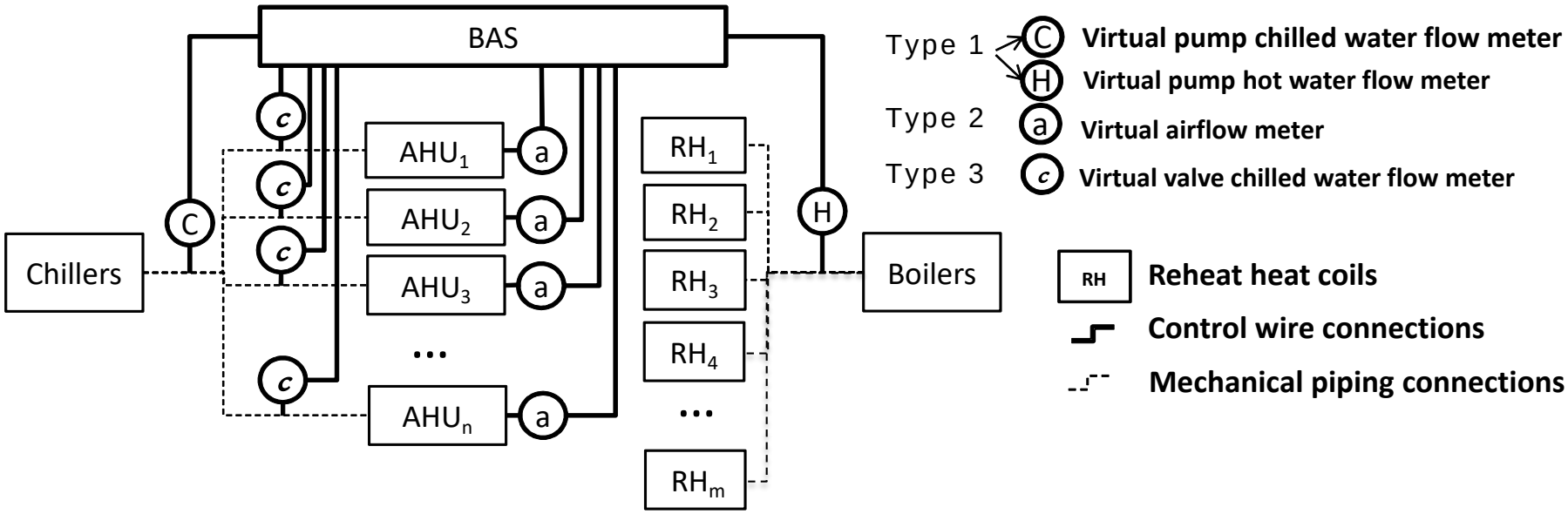
$$Y = f(a_1, a_2, a_3, \ldots a_m, X_1, X_2, X_3 \ldots X_n)$$

X_i – *the sensed independent device operation variables*

a_j – *represent device characteristics, which can be determined empirically or analytically*

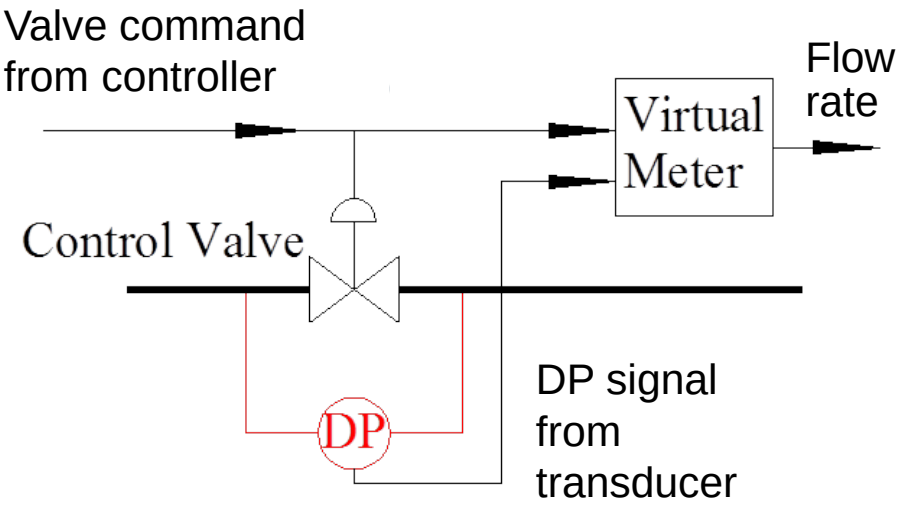
Technology Description

- Uses low-cost sensors to create
  - Fan/pump flow meters
  - Valve flow meters
- Provide
  - Continuous performance monitoring
  - Detection of performance degradation and faults



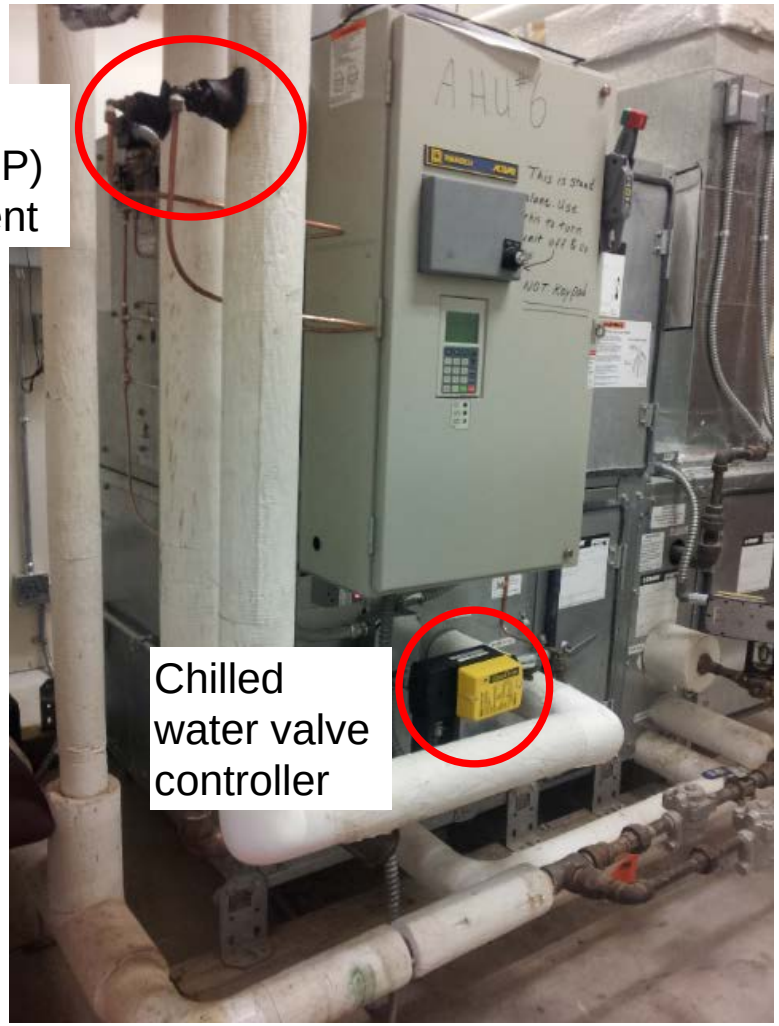
Virtual Energy Meters in an AHU

Virtual flow rate measurement

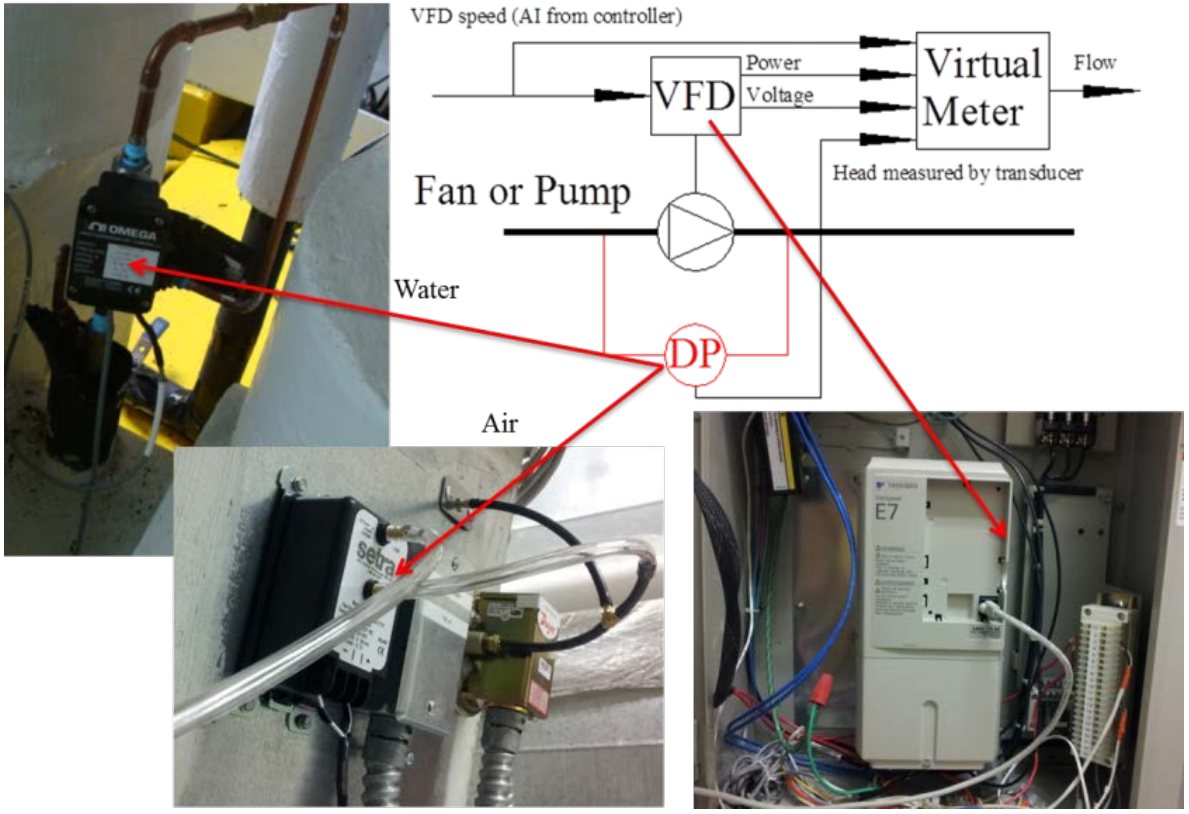


$$Q_x = F_{L,x}(x)\sqrt{\Delta P_{L,x}}$$

$F_{L.x}(x) \equiv$ valve characteristic



Virtual Pump/Fan Flow Meters

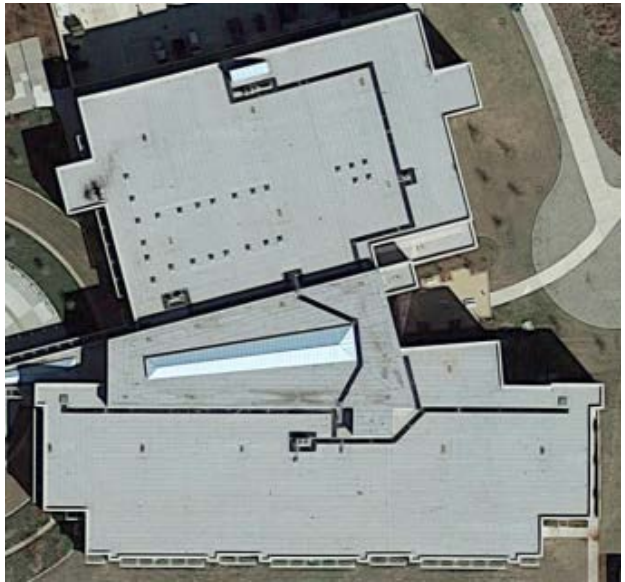


$$Flow\ rate = \frac{Power_{motor} \cdot \eta_{motor}\,(frequency, Voltage) \cdot \eta_{fan\,/pump}\left(\frac{Power_{motor} \cdot \eta_{motor}\,(frequency, Voltage)}{Head^{3/2}}\right)}{Head}$$

$\eta \equiv efficiency$

Performance Validation in a Building

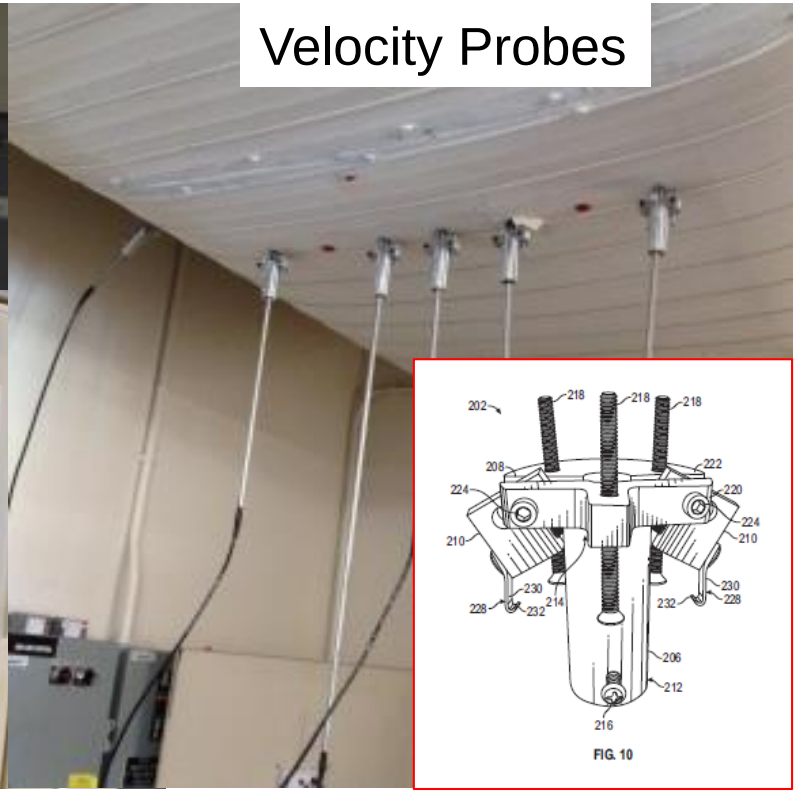
- Three-story medical clinic
  - Floor area 162,000 ft^2
  - 13 single duct AHUs with hot water reheat
- Central plant
  - Two 300-ton chillers and two 3,348-MBH boilers
- Direct Digital Control System (DDC)



Installation and Validation

Fan flow meter

- 13 supply fan flow meters (13 air DP sensors)
- 11 return fan flow meters (11 air DP sensors)



Installation and Validation

Valve flow meter

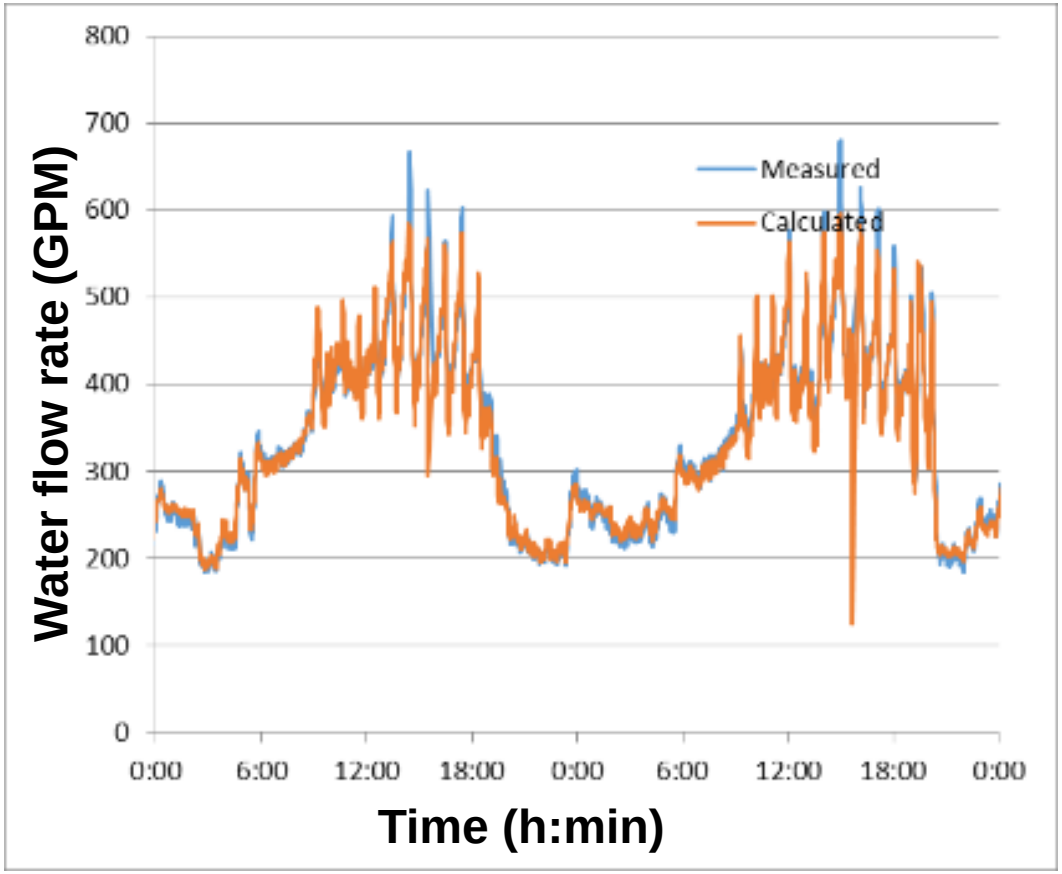
- 13 valve flow meters (13 water DP sensors)

Installation and Validation

Pump Flow Meters

- 3 primary pump flow meters (3 DP sensors)
- 3 secondary chilled-water pump flow meters (3 DP sensors)
- 3 condensing pump flow meters (3 DP sensors)
- 2 secondary hot-water pump flow meters (2 DP sensors)

Pump Flow Meter Accuracy



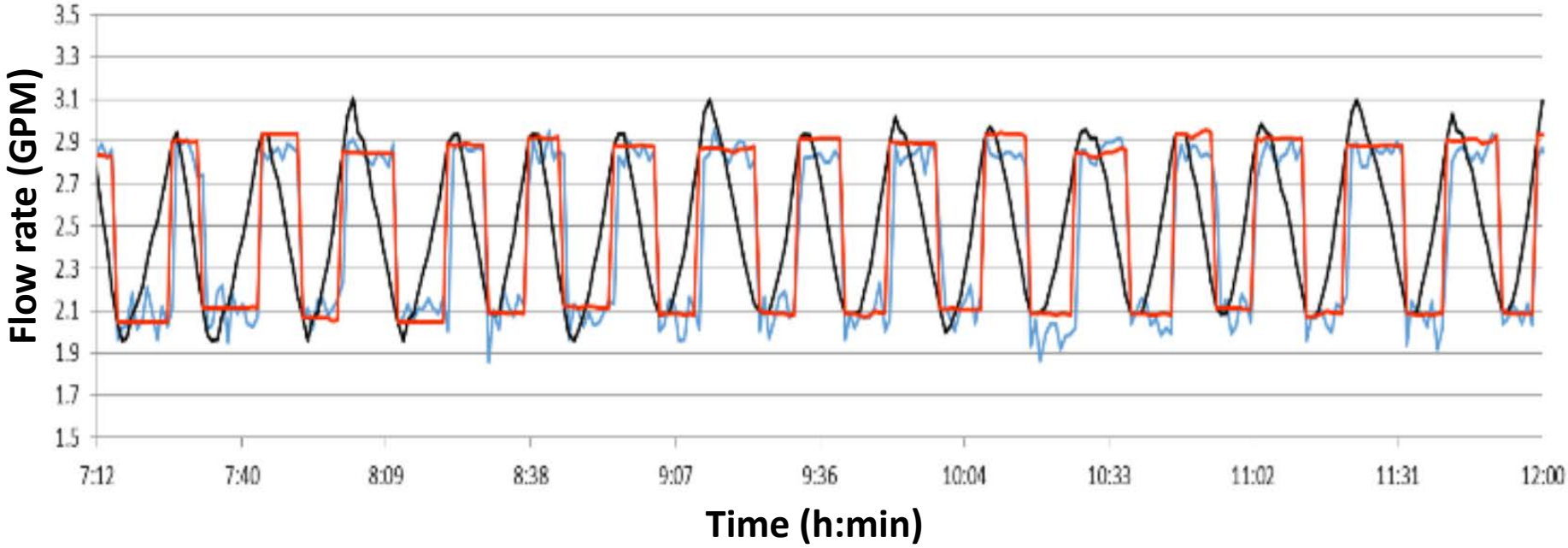
Blue: Measured flow rate

Orange: Calculated flow rate – virtual

Valve Flow Meter

Accuracy Improvement

- Uncertainty reduced from 10.37 to 3.95%



Legend

Blue: Ultrasonic meter measurement

Black: Calculation using original algorithms

Red: Improved device design

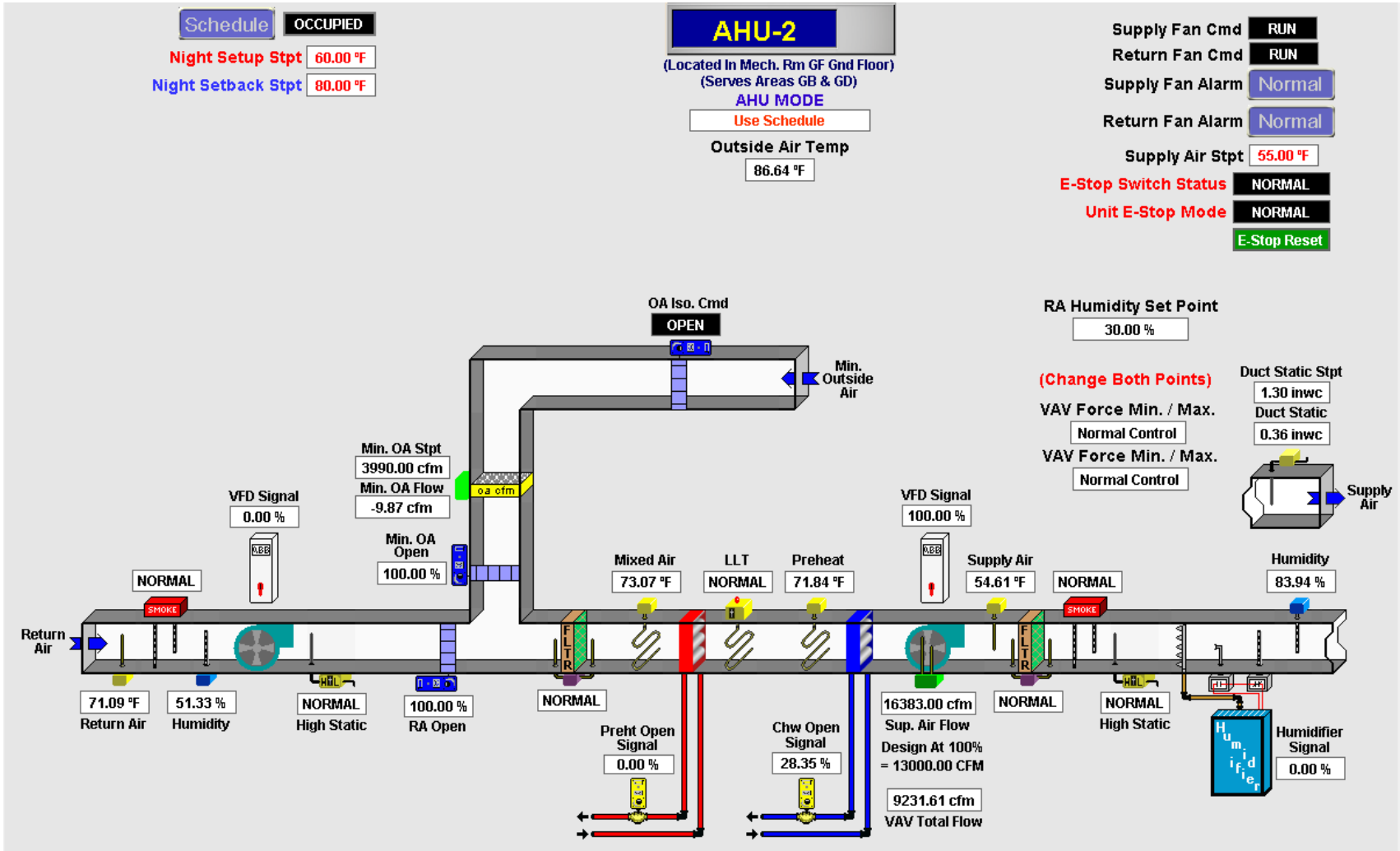
Fault Types Detectable

with Virtual Meters

- Outdoor airflow control faults
- Fan operation faults
- Reheat control faults
- Pump operation faults

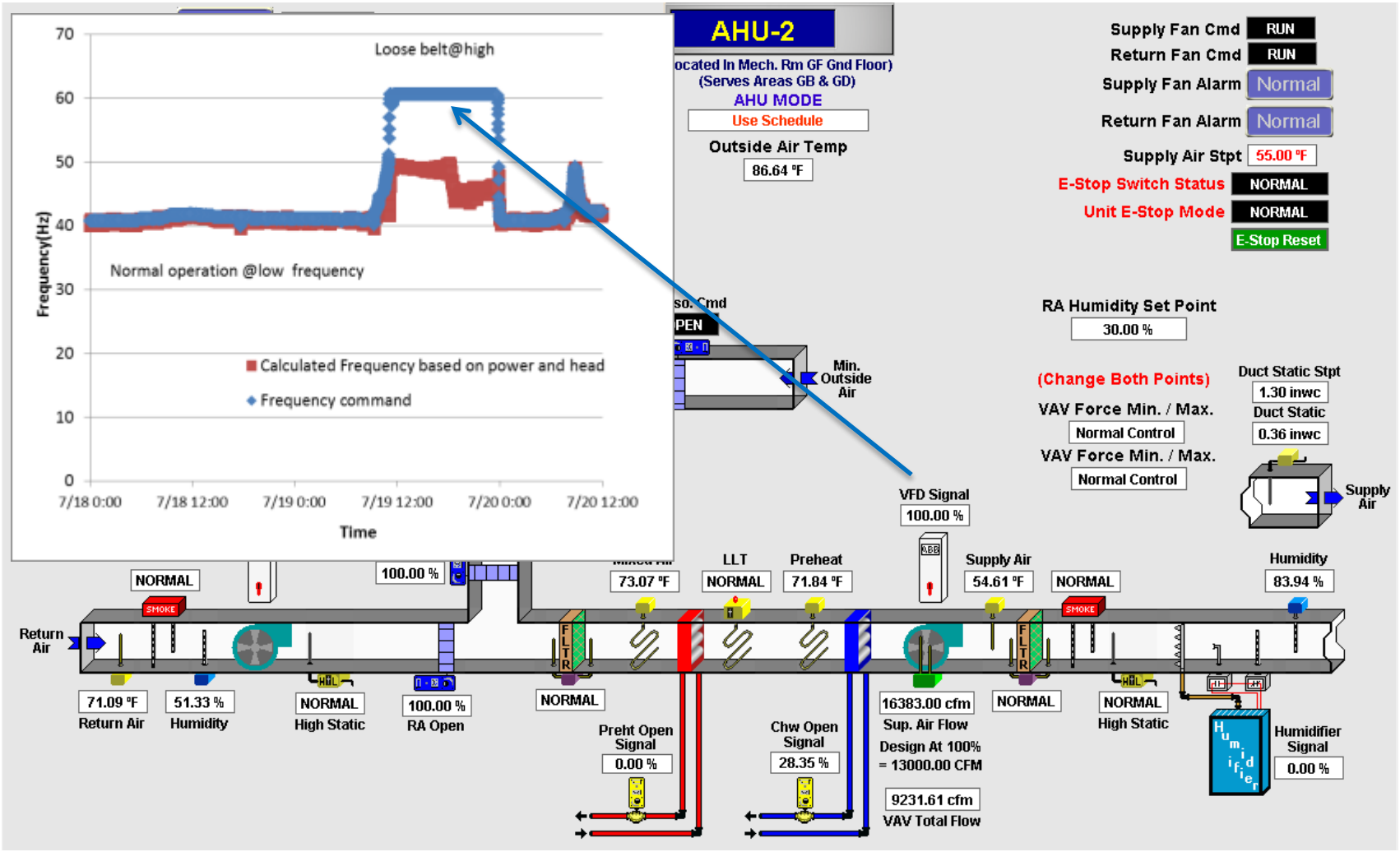
Identify an AHU Fan Fault

Loose Belt



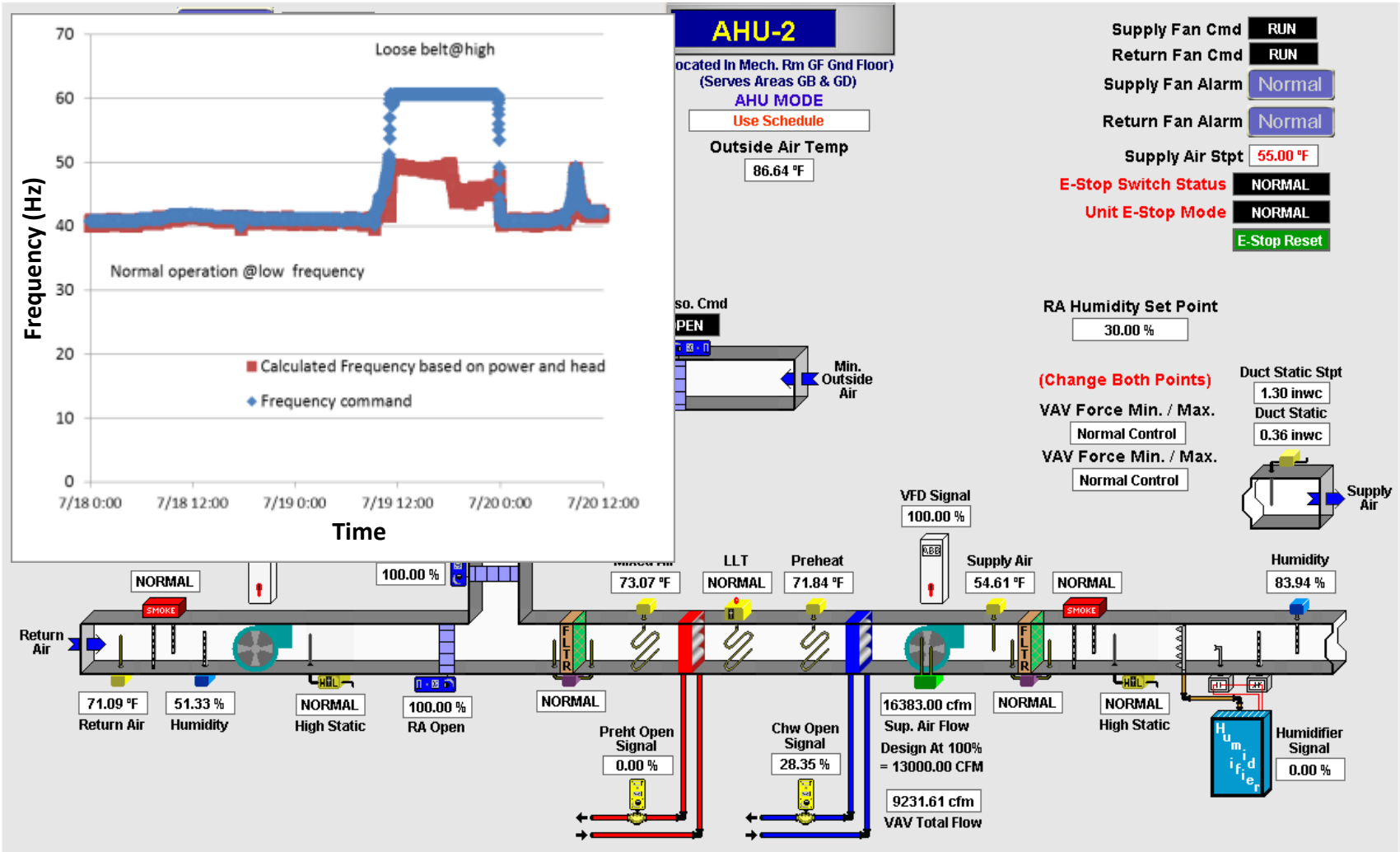
Identify an AHU Fan Fault

Loose belt



Identify an AHU Fan Fault

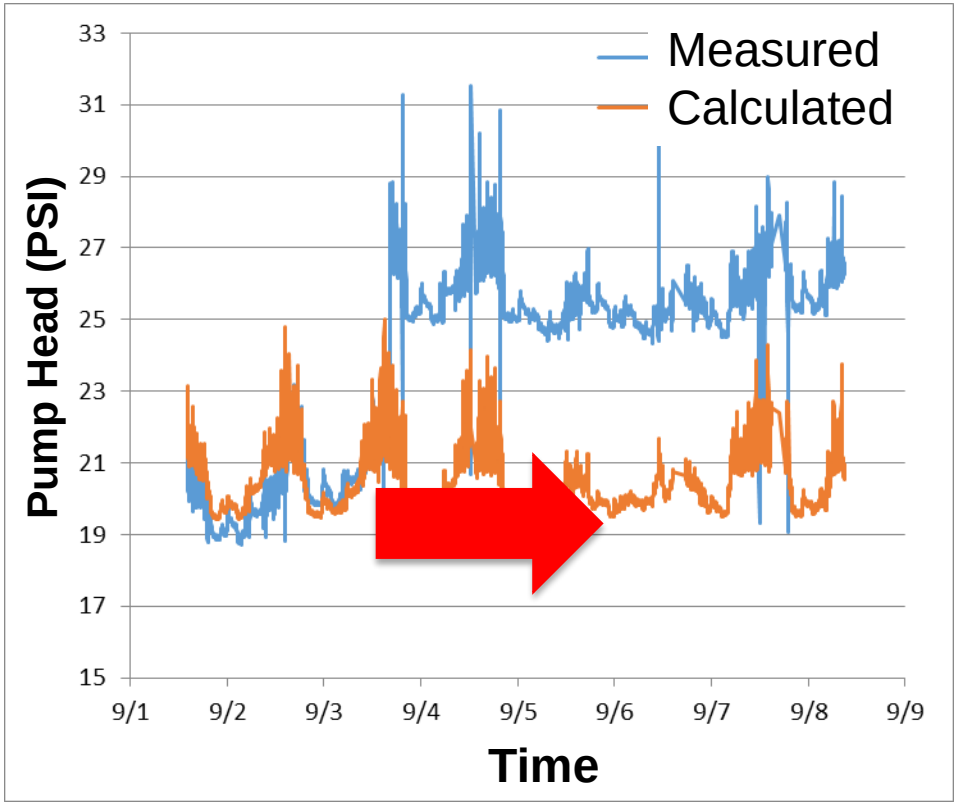
Loose belt



Detect a Secondary Chilled-Water Pump Operation Fault

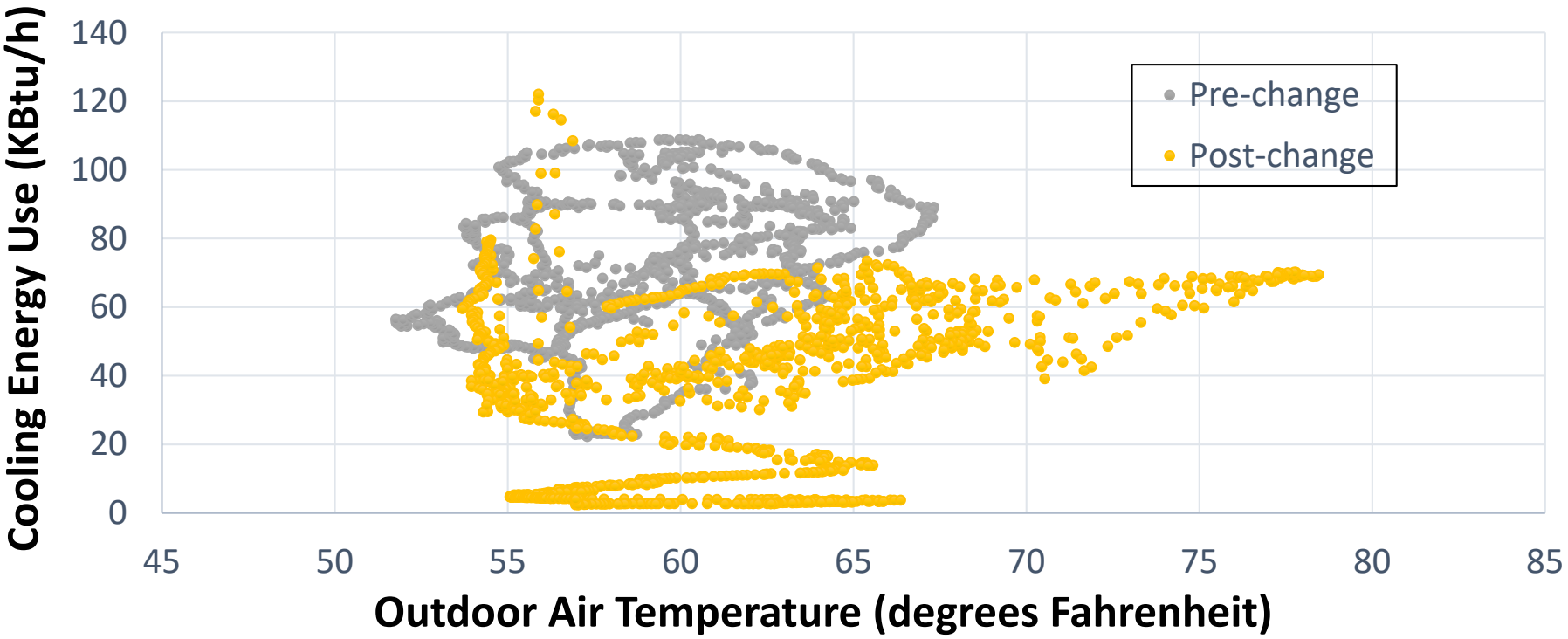
Differential pressure set point override

- The calculated pump head deviated from measured one when the control set point was overridden to a higher value



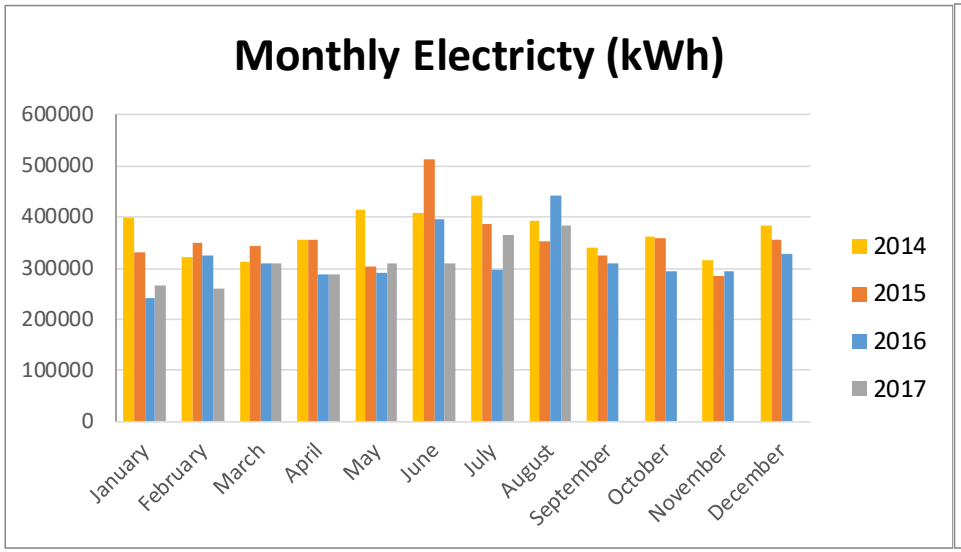
Energy Performance Comparison

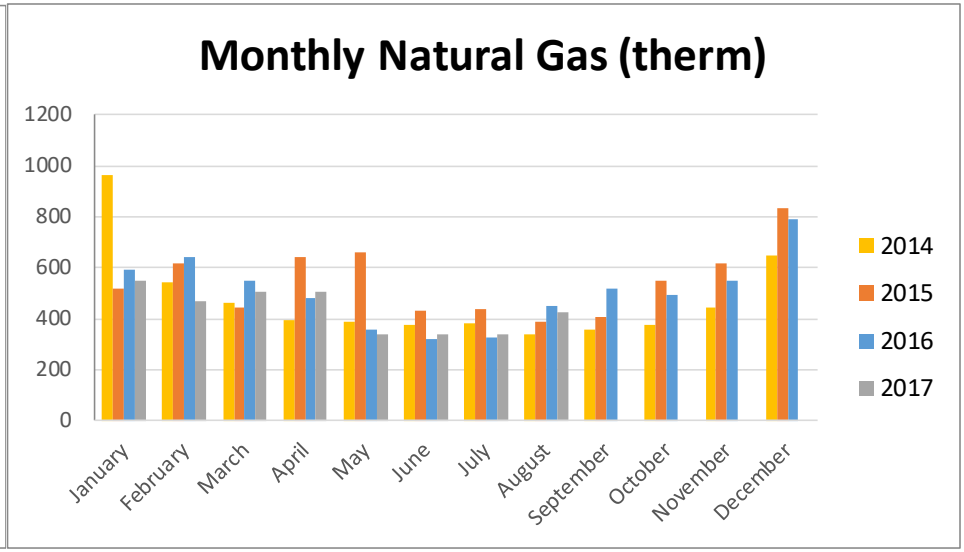
After Fault Corrections for an AHU



Monthly Utility Bill Comparison

from 2014 to 2017



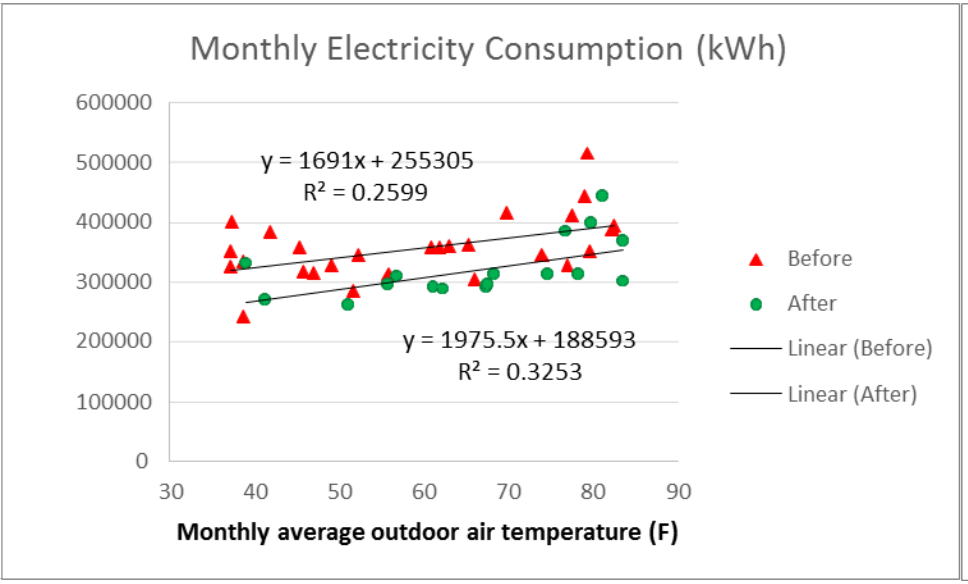


Monthly Utility Bills

Reduction in electrical and natural gas use

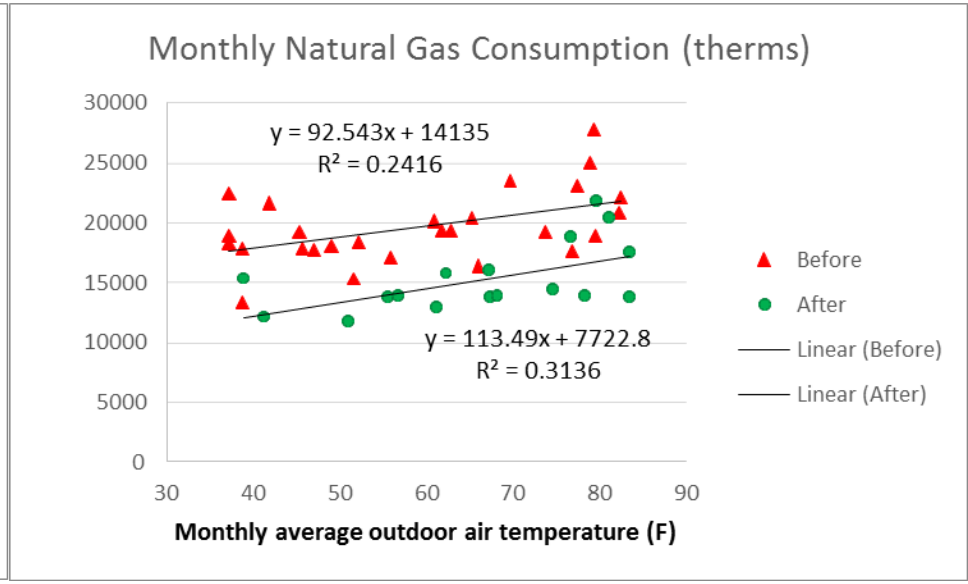
Electrical

(Average 13% Reduction)



Natural Gas

(Average 25% Reduction)



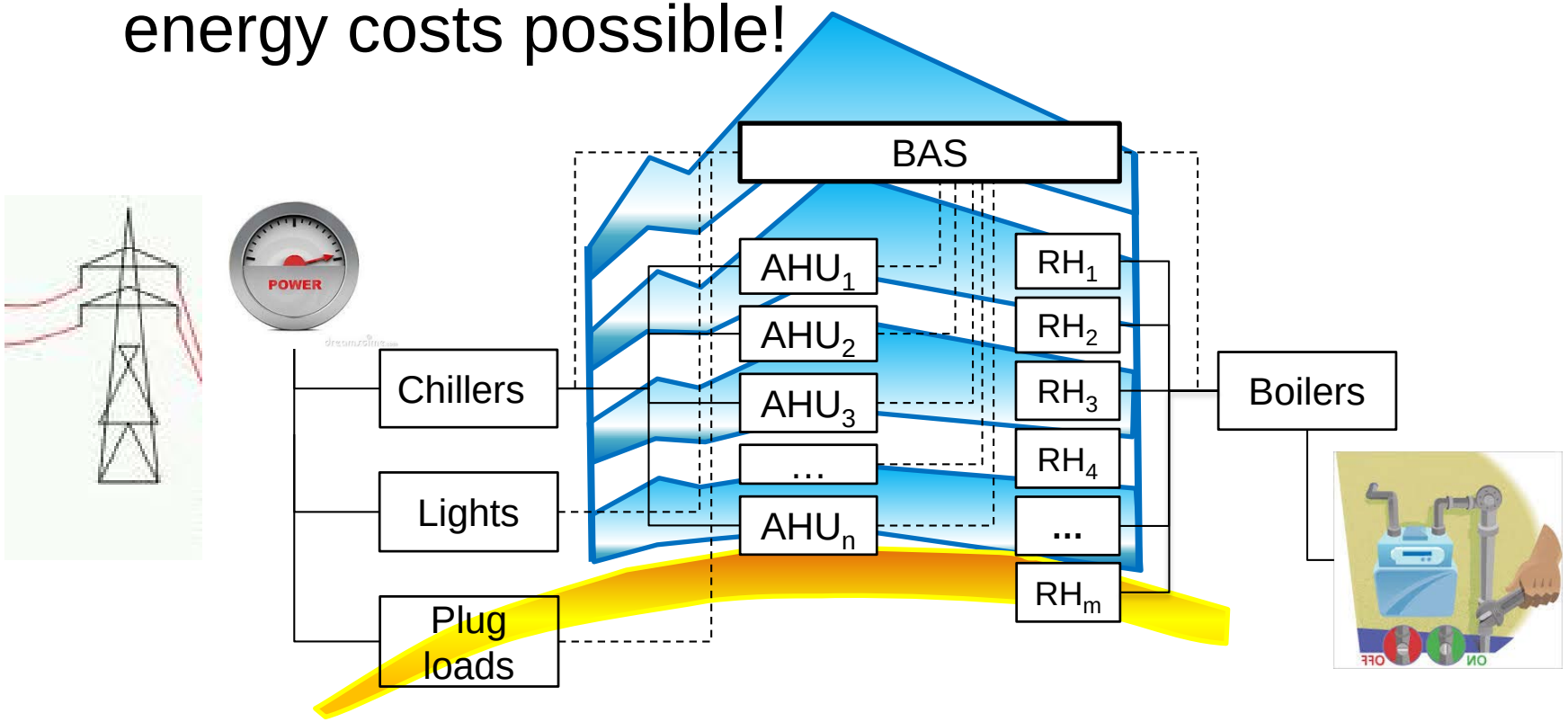
Conclusions and DoD Benefits

- Benefits of virtual meters
  - Low cost
  - Do not need space for installation
  - Improve monitoring capacity in buildings
  - Enable energy efficient building operations
- 16% of whole building annual energy use was obtained for a LEED silver building

Low Cost Virtual Meters

Enable High-Resolution Monitoring in Buildings

- Make cost-effective fault detection and diagnosis, greater energy efficiency, and lower energy costs possible!



For additional information, please visit
https://www.serdp-estcp.org/Program-Areas/Installation-Energy-and-Water/Energy/Conservation-and-Efficiency/EW-201407

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SERDP DOD • EPA • DOE | ESTCP

Q&A Session 2

The next webinar is on
August 9, 2018

Energy Sustainable Wastewater Treatment Systems for Forward Operating DoD Installations

SERDP DOD ▪ EPA ▪ DOE | ESTCP

Survey Reminder

Please take a moment to complete the survey that will pop up on your screen when the webinar ends