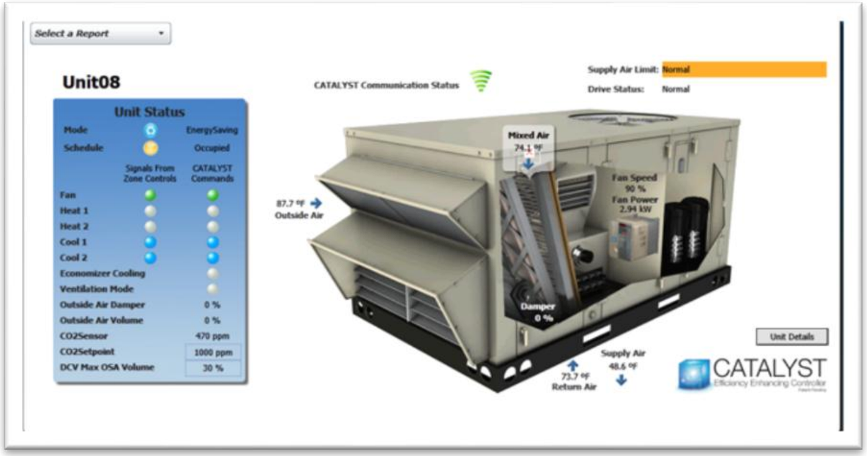
Demonstrations of Integrated Advanced RTU Controls and Automated Fault Detection and Diagnostics (BTO-2.2.2.26)

2014 Building Technologies Office Peer Review



2103 Game-Changing Technology of the Year

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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Project Summary

Timeline:

Start date: 10/1/2010

Planned end date:1/31/2015

Key Milestones

1. Document successful integration of advanced controls and diagnostics and lessons learned in the field; 9/30/2014
2. Document successful demonstration of smart monitoring and diagnostic system in the field and lessons learned; 1/31/2015

Key Partners:

Transformative Wave
NorthWrite
Universal Devices

Budget:

Total DOE $ to date: $2,326K

Total future DOE $: $0

Project Goal:

1) Show that integrating advanced controls and fault detection and diagnostics could result in significant savings and persistence in operations for air conditioners and heat pump units (RTUs).

2) Show that Smart Monitoring and Diagnostic System can be used with RTUs to provide conditioned-based maintenance at very low cost.

Target Market/Audience:

Target market is all commercial building with air conditioners and heat pumps and target audience is energy service providers and control vendors.

Purpose and Objectives

Problem Statement: *Installed operating efficiency of rooftop air conditioners and heat pumps (RTUs) is low due to: 1) lack of advanced controls to improve part load performance and 2) inadequate equipment maintenance*

– Keys to improving operating efficiency and persistence of operations include advanced controls, automated fault detection and diagnostics (AFDD) and conditioned-based maintenance at low cost – the two focus areas under this project will address these problem

Objective: Encourage industry to deploy advanced controls and AFDD technologies and low cost conditioned-based monitoring system on existing RTUs through development and demonstrations

– This will lead to significant increases in the operating efficiency and persistence of operations of installed RTUs, thereby lowering energy use and costs, both for building owners and, at scale, at the national level

Project Focus Areas: This project comprises of two major focus areas:

– **First focus area** is to integrate advanced RTU controls and automated fault detection and diagnostics (AFDD) on a controller – reduces RTU energy consumption significantly (over 50%) and ensures persistence of energy efficient operations; supports California Title 24 and some new ASHRAE 90.1 Standard requirements for existing RTUs

– **Second focus area** is to demonstrate a low-cost smart monitoring and diagnostic system (SMDS) on RTUs – supports low cost conditioned-based maintenance

Target Market and Audience: RTUs are used in about 58% commercial buildings that are cooled, serving over 60% of the cooled commercial building floor space

– The total market size is about 2.6 quads of primary (source) energy annually
– Primary audience is energy service providers, control vendors, and building owners, bill payers and maintenance staff

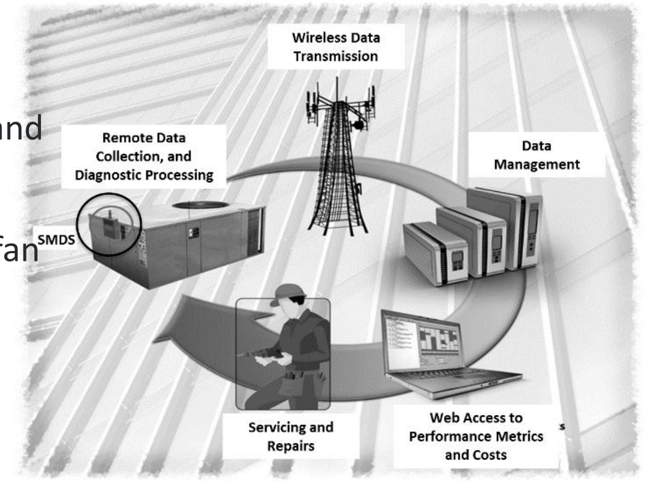
Impact of the Project

- The goal of the project is to significantly increase the operating efficiency of the RTUs in the field through
  - Development, demonstrations and deployment of retrofitable solutions
- For advanced controls retrofit solution, there are already at least three manufacturers offering the solution
  - With over several 100s of installations
  - We anticipate as more organizations and utilities join the campaign over the next five years, there will be an exponential growth in installations
- For conditioned-based maintenance solution, the current demonstration partners are willing to take the technology to the market after successful completion of demonstrations
  - In a year from now we anticipate there will be at least one manufacturer who will be offering conditioned-based monitoring as a service
  - Over the next five years we anticipate there will be more service providers willing to offer this service, especially the Cloud-based approach
- If all existing RTUs are retrofitted with advanced controls, it could lead to over 1.3 tBtus of savings annually (technical potential)

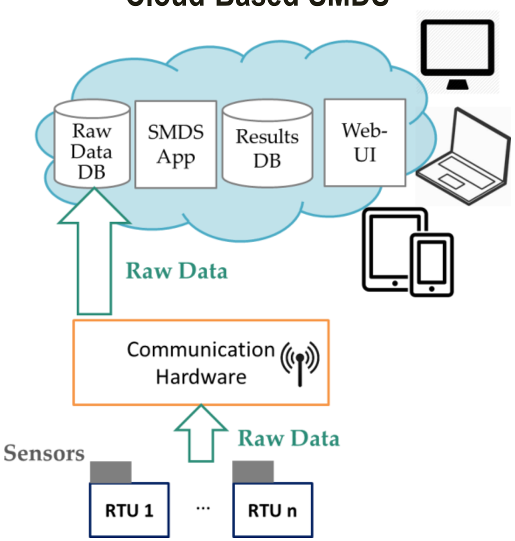
Focus Areas

- Integrated advanced controls and diagnostics
  - Small improvement in operational efficiency through use of advanced controls can lead to significant reduction in energy use and carbon emissions
    - integrated economizers controls, variable or multiple speed fan controls and demand controlled ventilation
    - Operational efficiency can be sustained by use of AFDD technologies
- Smart Monitoring and Diagnostics System (SMDS)
  - Servicing, when done at all, is generally performed on a semi-annual basis but often is inadequate to correct all important faults
  - A low-cost SMDS has been developed
    - Retrofitable to existing and new packaged units
    - Provides continuous condition monitoring and fault detection, so owner and service provider decisions about servicing the equipment
    - Identifies and quantifies degradation in performance and increases in operating cost (and savings from repairs)
    - Provides results via the web on any device with a web browser (cell phone, tablet, laptop, desktop)

Custom Hardware-Based SMDS



Cloud-Based SMDS



Approach: Integration of Advanced Controls and Dx (IACDx)

Approach:

- Leveraging previously estimated potential savings from use of advanced control strategies with RTUs through detailed simulations* and with extensive field tests to demonstrate the control strategies; also leveraging AFDD methods developed for air-handling units and RTUs
- Currently, integrating the advanced controls and AFDD technologies on to a single "retrofit-able" RTU controller
- Will demonstrate the integrated technology on a number of RTUs to validate integrated advanced controls and AFDD features and prepare the technology for more widespread market deployment

Key Issues:

- Through integration and field demonstrations, show that significant savings and persistence of savings are possible with advanced controls and AFDD technologies on a single retrofit controller for existing RTUs
- Also, show that the integrated technology being developed and demonstrated in the project will meet California Title 24 and some ASHRAE 90.1 Standard mandatory requirements for RTUs

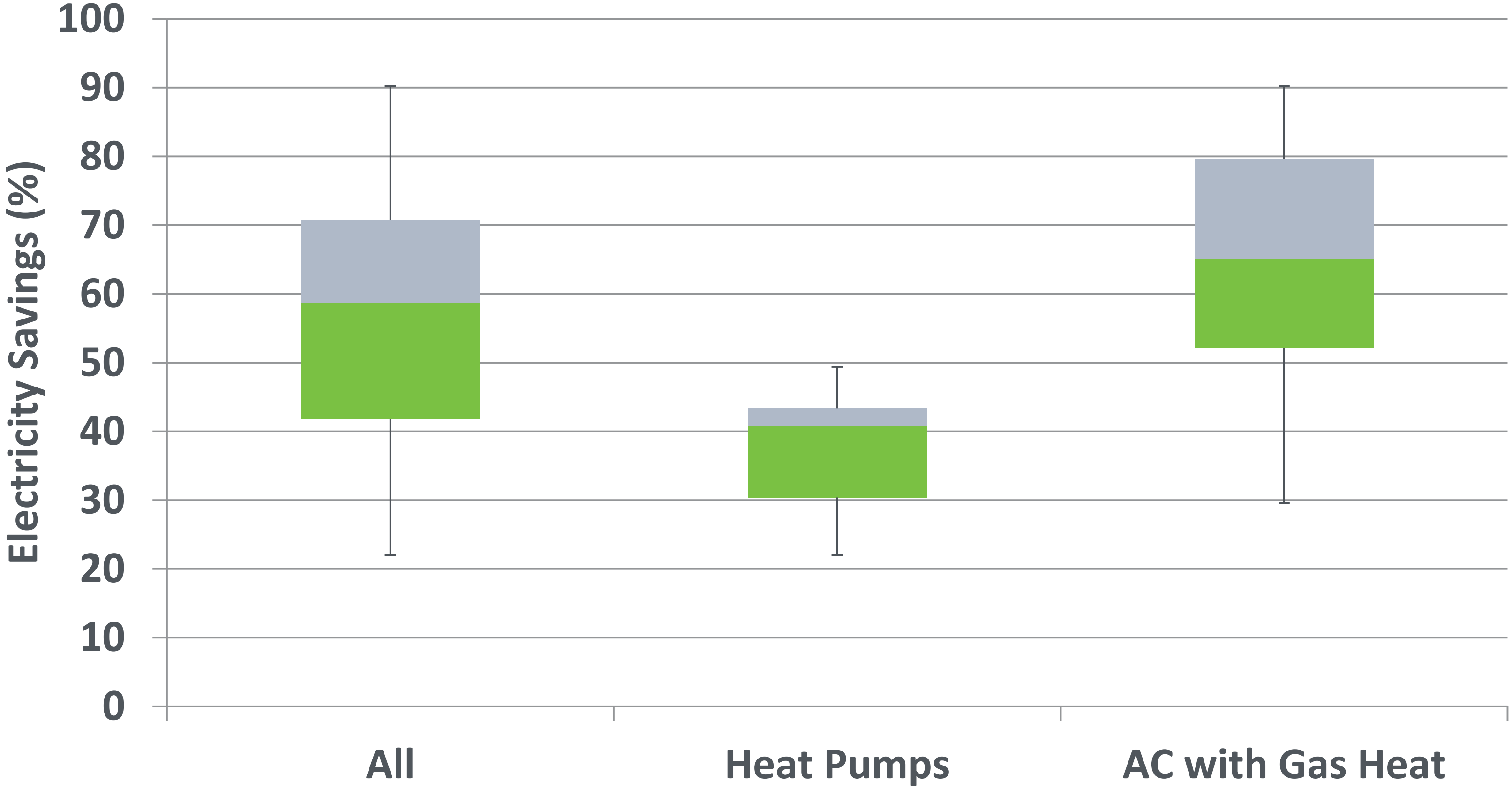
Distinctive Characteristics:

- Leveraging previously developed technologies and working with partner to create an immediate market for the technology

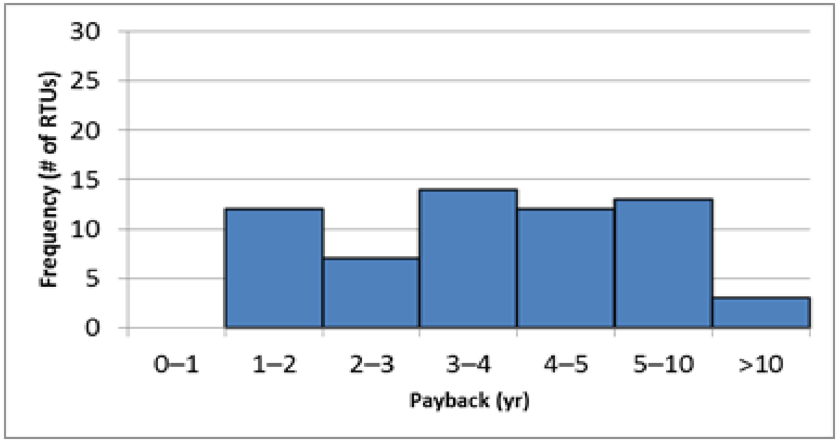
*http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20955.pdf
*http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-21944.pdf
*http://www.pnl.gov/main/publications/external/technical_reports/PNNL-22656.pdf

IACDx: Electricity Savings (%) from Field Measurements

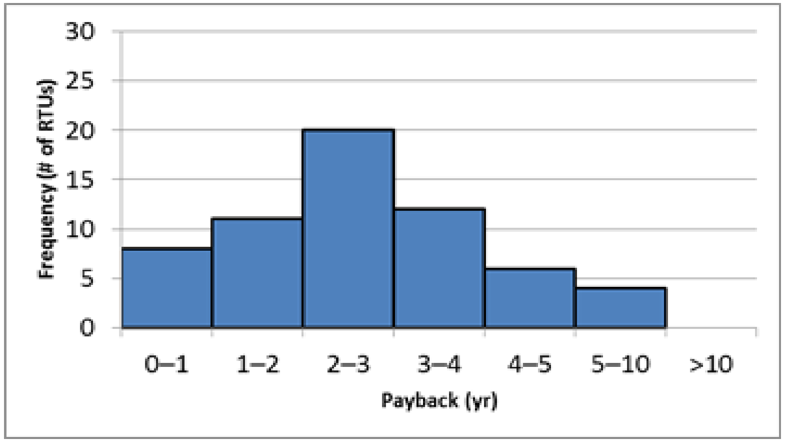
- Electricity consumption from 61 RTUs was compared under "standard" and "advanced" control modes
  - 16 heat pumps and the rest are air conditioners with gas furnaces



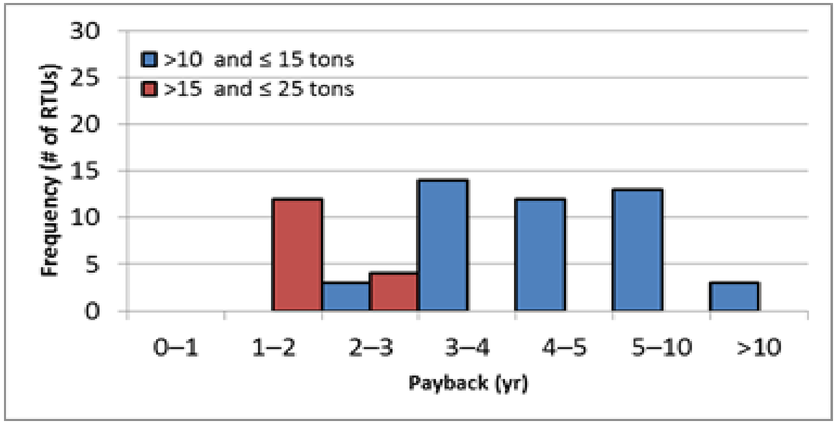
Advanced RTU Controller Simple Payback



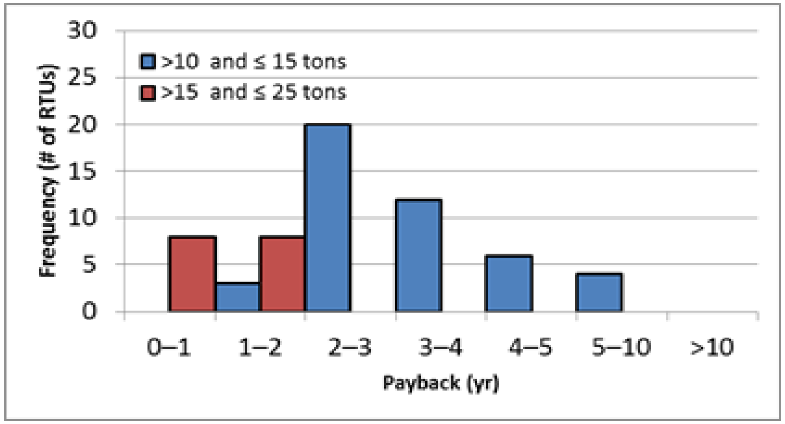
(a)



(b)



(c)



(d)

Histogram charts showing the frequency of units at varying payback periods for <u>(a) all capacities at a $0.10/kWh utility rate</u>; (b) all capacities at a $0.15/kWh utility rate; (c) 2 capacity ranges at a $0.10/kWh utility rate; and (d) <u>2 capacity ranges at a $0.15/kWh utility rate</u>

Progress and Accomplishments: IACDx

Lessons Learned:

- Even in cases when the expected payback periods for advanced control retrofit are less than 3 years, some building owners have difficulty justifying the retrofit because of capital requirements and split incentives also make it difficult

Accomplishments: FY13 and before,

- Showed advanced controls for RTUs can save over 50% of total RTU energy and electricity cost
- Showed AFDD can be deployed on RTUs to identify operation problems that impact energy consumption
- Participated in a number of seminars and conferences to highlight the savings from advanced controls
- Published an article in ASHRAE Journal http://bookstore.ashrae.biz/journal/download.php?file=2014March036-043_Katipamula.pdf
- In FY14, recruited a project partner to help in deployment and demonstration of a new integrated controls and diagnostics solution
- Completed the development and deployment, currently in the test phase of the project

Progress and Accomplishments: IACDx

Planned Contribution to Energy Efficiency:

- A path to significantly improving energy efficiency of the existing RTU stock through deployment of integrated advanced controls and AFDD on a single retrofit RTU controller with simple payback between 1 and 3 years
- Because PNNL is partnering with a deployment partner to develop and demonstrate the advanced features, we anticipate immediate deployment opportunities
- With a concerted DOE market transformation efforts, other deployment partners will be created for significantly more impact
- Since the technology being demonstrated meets certain California Title 24 requirements and ASHRAE 90.1 Standard requirements, it provides another option for legacy RTUs
- In the long-term, we expect these options will be part of the new RTUs. For example, DOE's RTU Challenge unit already has some of these features

Market Impact:

- There are three manufacturers of the retrofit product, with one manufacturer clearly ahead with a mature product
- Although the technology has high rate of return, many utilities are providing incentives, which makes the technology look even better
- Promoting the technology through the DOE Advanced Rooftop Unit Champaign will increase the market penetration even further

Awards/Recognition: Based on this DOE funded work, E-Source recognized the advanced retrofit control technology for RTUs as the top "**Game-Changing**" technology for 2013 - http://www.esource.com/email/ENEWS/2014/Top5-Tech

Project Integration and Collaboration: IACDx

Project Integration: Project staff

- Are actively involved in Better Buildings Alliance, RTU Advanced Retrofit Champaign
- Regularly participate in Consortium for Energy Efficiency (CEE) workshops
- Are part of ASHRAE Special Project Committee 207P - Laboratory Method of Test of Fault Detection and Diagnostics Applied Commercial Air-Cooled Packaged Systems
- Regularly have discussions with other stake holders, such as, utilities and E-Source

Partners, Subcontractors, and Collaborators:

- Transformative Wave (TW) is one of the companies that makes an advanced retrofit controller for RTUs, PNNL is working with them to integrated advanced controls and AFDD technology
- After the integrated technology is demonstrated and validated in the field, TW will deploy the technology, especially in the state of CA
- PNNL developed AFDD technology will be available for any other company that wants to integrate AFDD with advanced controls

Communications: PNNL will continue to participate

- in relevant ASHRAE forums to promote the concept
- CEE workshops and E-Source forums

Next Steps and Future Plans:

- Help BTO and Commercial Buildings Integration (CBI) team to promote the use of integrated advanced controls and AFDD technologies thru RTU replacement campaign initiated by CBI
- Continue to promote the technology to CEE, utilities and other potential deployment partners
- Provide technical support and assistance for other manufacturers willing to integrate advanced controls and AFDD

Purpose and Objectives: SMDS

Planned Contribution to Energy Efficiency: Second focus area outcomes include

- <u>A field-verified smart monitoring and diagnostic system (SMDS) compatible with retrofit on existing RTUs and installation during manufacture on new units</u>
- Two deployable versions: 1) custom hardware based with on-site processing and 2) Cloud-based processing with off-the-shelf sensors
- Users access results from any device with a web browser (cell phone, tablet, computer)
- <u>Savings potential 10% to 20% of RTU energy consumption from condition-based maintenance</u>
- Automatically detects performance degradation of RTUs plus operational faults (e.g., supply fan running when the building is unoccupied) and provide energy cost impacts for owner use in making maintenance-service decisions
- <u>Uses just two sensors, total RTU power and outdoor-air temperature, minimizing hardware cost and the time requirement and cost for installation (3 sensed data points for multi-speed units)</u>
- Communication service costs, which were ~$50/month just 1 year ago are now ~$10/month per building (multiple RTUs) and likely to decrease in the future
- Retrofit installations will have payback periods of 1 to 5 years, dependent on the location, climate and capacity of the RTU. New RTUs should have much lower cost and shorter paybacks
- <u>Immediate commercialization is planned by deployment partner upon completion of demo</u>
- The hardware manufacturer also expects to independently pursue commercialization
- <u>The methodologies developed for detection of performance degradation and other operation faults will be publically available</u>

Approach: Smart Monitoring and Diagnostics System

Approach:

- Developed the novel two-sensor, self-configuring, SMDS system prior to FY14. Methodology tested on measured data from 90 operating RTUs, offline
- Began testing hardware SMDS version in FY13, found communication issues, completed revisions by end of Dec. 2013, and began testing final hardware systems in Jan. 2014
- Field demonstrations of hardware SMDS in Baltimore and Puerto Rico planned to verify field performance through August 2014
- Verified performance of Cloud SMDS on historical data for approximately 40 RTUs
- Plan field demonstrations of Cloud SMDS version with NYSERDA in New York through August 2014 to verify field performance
- Immediate commercialization by partner upon successful completion of demonstration
- Public release of performance and fault detection methodology and software code

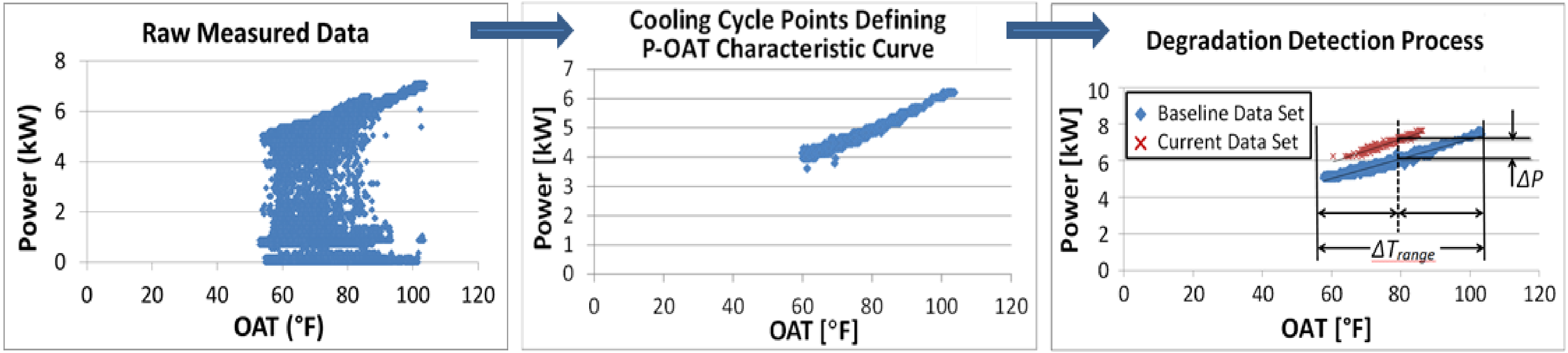
Key Issues:

- Use of Zigbee wireless for local communication outdoors on rooftops with rotating equipment proved difficult—required special measures to ensure long-term uninterrupted operation
- Field testing in Baltimore will verify successful adaptation of Zigbee to rooftop environment

Distinctive Characteristics:

- Uses only two sensors, total RTU power use and outdoor-air temperature
- Is self-configuring, requiring no user input of information to start operation after installed
- Low hardware and installation costs (~$200 and 1 hour)

SMDS Performance Degradation Detection Method



Degradation is detected when $\Delta P > \Delta P_{alarm\ threshold}$

Followed by energy use change calculation, which determines the sign and magnitude of the degradation (or improvement).

Progress and Accomplishments: SMDS

Lessons Learned:

– Testing of low-power wireless communications (e.g., Zigbee) in realistic environments with rotating electrical equipment for extended times is critical to verify performance during development before field deployment of full systems for demonstration

Accomplishments:

– Developed a novel two-sensor, self-configuring, performance degradation detection method for the SMDS system, disproving the widely-held belief that such an indicator was not possible

– Proved that the empirical model underlying the methodology for performance degradation detection fits data for RTUs very well through application to data from about 120 RTUs

Market Impact:

Leveraging:

– Cost sharing with NYSERDA project for field testing/demonstration of Cloud-based SMDS

Ensure/Accelerate Impact:

– Collaborating with two private-sector companies which plan to commercialize the technology upon completion of the demonstration

Project Integration and Collaboration: SMDS

Project Integration:

- Entire effort from development through demonstration has been highly integrated and collaborative
  - Joint development of system requirements by all organizations
  - Methodology and initial programming by PNNL followed by user interface programming and firmware development by the commercial partners using the PNNL code
  - Development of SMDS custom hardware by partner with testing by PNNL
  - Recruiting of test sites and arrangement of installations by commercial partner
  - Field support, troubleshooting and solution development by integrated full team
  - Close coordination with test-building staff and service providers for installations and updates
- Participate on ASHRAE Standards Project Committee SPC-207P – Laboratory Method of Test for Fault Detection and Diagnostics Applied to Commercial Air-Cooled Packaged Systems
- Participate in Western HVAC Performance Alliance Fault Detection & Diagnostics Subcommittee

Partners, Subcontractors, and Collaborators:

- NorthWrite Inc. (www.NorthWrite.com) – company providing building energy management solutions via the web
- Universal Devices (www.universal-devices.com) manufacturer of affordable, Internet accessible, energy management systems for residential and small commercial buildings

Communications:

- ASHRAE Seminar on “Fault Detection, Diagnostics and Control for Packaged Commercial Rooftop and Split Residential Units: What’s New?” Seminar 15, ASHRAE Winter Meeting, New York, January 19, 2014

Next Steps and Future Plans: SMDS

- **Next Steps and Future Plans**:
  - Complete demonstrations of the hardware SMDS and Cloud SMDS
  - Publish report on and disseminate findings of the demonstration
  - Encourage and support commercialization of the SMDS technology by the commercial project partners and other companies
  - Publish SMDS methodology and software code for open use in the open literature, on a web page, and by posting as appropriate in the DOE BTO resource data base
  - Increase awareness of SMDS technology, potential savings, and opportunity for commercialization and end use by presentations at trade organization and building owner and management events
  - Present and disseminate information on the SMDS technology to the Better Buildings Alliance
  - With DOE agreement, provide technical support to commercializers

REFERENCE SLIDES

Project Budget

Project Budget - AFDD
Cost to Date: $38K, as of 3/14/2014
Projected Cost to Date through 4/30/14: $90K
Additional Funding: $0K (Project complete at the conclusion of FY2014)

Budget History					
FY2011– FY2013 (past)		FY2014 (current)		FY2015 – Q2 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$655K	$100K	$300K	$20K	$0K	$0K

Project Budget - SMDS
Cost to Date: $88K, as of 3/14/2014
Projected Cost to Date through 4/30/14: $100K
Additional Funding: $0K (Funding required to complete FY2015 scope will be carried over from FY2014)

Budget History					
FY2011– FY2013 (past)		FY2014 (current)		FY2015 – Q2 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1,671K[1]	$225K	$142K	$0K	$0K	$0K

[1]$897K provided to NorthWrite, Inc. ($704K for the development of the SMDS technology; $193K for demonstration efforts.)

Project Plan and Schedule

- Couple of milestones/deliverables for the SMDS project have been delayed
  - Early field test findings required moving FY13 SMDS milestones and deliverables to FY14 extending into Q2 of FY15
  - Additional SMDS milestones and deliverables were added in FY14 to accommodate addition of offline testing and field demonstrating the Cloud-based SMDS

Project Plan and Schedule

Project Schedule		
Project Start: 10/1/2010	(light blue)	Completed Work
Projected End: 1/31/2015	(dark blue)	Active Task (in progress work)
	◆ (red)	Milestone/Deliverable (Originally Planned)
	◆	Milestone/Deliverable (Actual)

	FY2013				FY2014				FY2015			
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												
Q1 Milestone: Energy Savings and Economics of advanced Control Strategies for Packaged Heat Pumps (AFDD)	◆											
Q1 Milestone: Presentation of preliminary results to CEE members (AFDD)	◆											
Q3 Milestone: Participate in CBEA Efficiency Forum (AFDD)			◆									
Q3-Q4 Milestone: Complete monitoring of data and data analysis (AFDD)			◆	◆								
Q4 Deliverable: Completed final Advanced Rooftop Control (ARC) Retrofit: Field-Test Results technical report (AFDD)				◆								
Q4 Deliverable: Draft Case Study (AFDD)				◆								
Q4 Milestone: Presentation of final results and discussion of potential FY14 activities (AFDD)				◆								
Current/Future Work												
Q2 Deliverable: Document automated fault detection and diagnostic (AFDD) algorithms, including flow charts (AFDD)						◆						

Project Plan and Schedule

Project Schedule													
Project Start: 10/1/2010	(light blue)	Completed Work											
Projected End: 1/31/2015	■	Active Task (in progress work)											
	◆ (red)	Milestone/Deliverable (Originally Planned)											
	◆	Milestone/Deliverable (Actual)											
	FY2013				FY2014				FY2015				
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)	
Current/Future Work													
Q3 Milestone: Complete implementation of AFDD algorithms on the controller (AFDD)						■	■ ◆						
Q4 Milestone: Complete deployment of advanced controllers in the field (AFDD)							■	■ ◆					
Q4 Milestone: Field data collection completed (SMDS)								■ ◆					
Q4 Deliverable: Final report documenting the performance of AFDD algorithms in the field (Resource Database) (AFDD)								■ ◆					
Q1 Deliverable: Draft technical report on the SMDS demonstration providing all results and discussing conclusions based on them. CD or DVD with field data (SMDS)									■ ◆				
Q2 Deliverable: Final technical report on the SMDS demonstration (after peer review and receiving DOE review comments) (SMDS)										■ ◆			
Q2 Milestone: Field data collections completed for NYSERDA cost-share task for Cloud SMDS (SMDS)										■ ◆			
Q2 Milestone: Data analysis completed for applications of Cloud SMDS to May-Oct data for "40 RTUs w/ Transformative Wave Technologies (SMDS)										■ ◆			