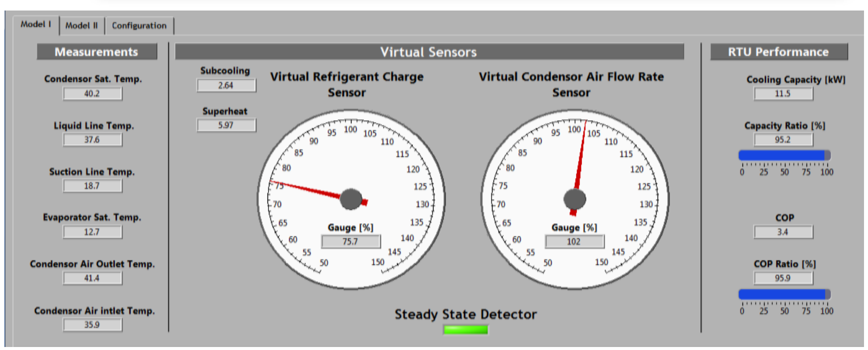
Control and Diagnostics for RTUs

2014 Building Technologies Office Peer Review



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Jim Braun, jbraun@purdue.edu
Purdue University

Project Summary

Timeline:

Start date: 2/1/2011

Planned end date: 4/30/2015

Key Milestones

1. Development and validation of virtual sensors: refrigerant charge, refrigerant flow, capacity, power, etc.: 5/13
2. Demonstration of integrated diagnostic system for RTUs: 9/13
3. Development and initial evaluation of "plug-and-play" learning controller for RTU coordination: 1/14

Budget:

Total DOE $ to date: $600K

Total Cost Share $ to date: $130K

Total future DOE $: $700K

Total future Cost Share: $150K

Key Partners:

Purdue	UTRC
Virginia Tech	Power Insight
Field Diagnostic Services	ORNL

Project Goal:

Development and validation of cost-effective methods for RTU coordination and diagnostics in small commercial buildings

Target Market/Audience:

Market: small commercial buildings utilizing multiple RTUs

Audience: RTU manufacturers; control, monitoring, and service companies

Purpose and Objectives

Problem Statement: Reduce installed costs and improve scalability of optimized controls and embedded diagnostics for RTUs in small commercial buildings.

Target Market & Audience: The market is small commercial buildings that employ RTUs. RTUs provide space conditioning for over 60% of the commercial floor space and account for over 50% of cooling requirements and over 1 Quad of source energy annually. The target audience is: 1) RTU manufacturers for embedded diagnostics and self-learning controls and 2) control, monitoring, and service companies. RTUs tend not to be well maintained and not to have coordinated controls due to high site-specific implementation costs.

Impact of Project: Outputs will include:

1) commercial assessment and demonstration of embedded RTU diagnostics;
2) commercial assessment and demonstration of "plug-and-play" RTU coordination to minimize energy usage.

We will work with market implementers to validate the approaches and assess commercialization potential.

Approach

Approach: 1) reduce the cost of realizing embedded diagnostics through use of "virtual" sensors; 2) reduce the cost and improve scalability for optimal RTU coordination using self-learning "lumped disturbance" models; 3) validate approaches using laboratory, field, and numerical experiments

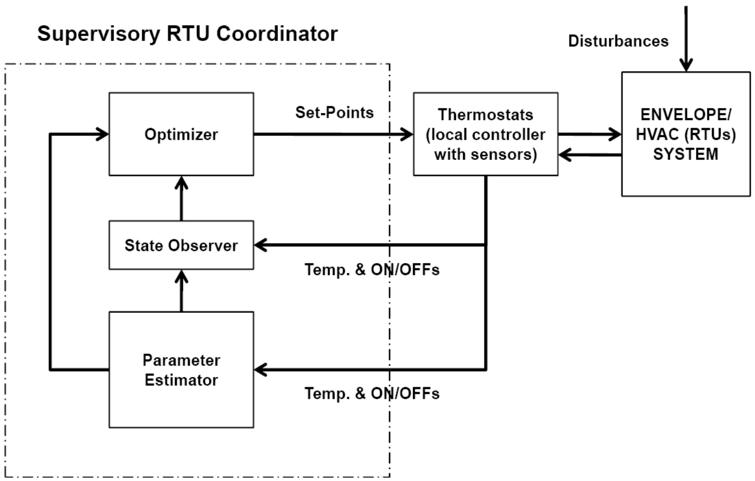
Key Issues: 1) need for plug-and-play software solutions; tradeoff between performance and implementation costs with choice of sensors; 2) overall economic assessment; 3) need for simulation tools to evaluate performance in order to reduce field experiments

Distinctive Characteristics: 1) unique approach of employing virtual sensors to reduce costs and combine fault detection and diagnostic steps; 2) including fault impact evaluation to assess need for service; 3) unique simulation platform for assessing RTU coordination control performance

Accomplishments - RTU Coordination

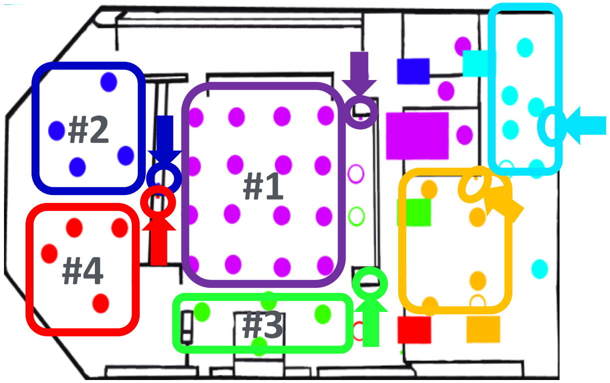
RTU Coordination Overview

- Coordinates RTU on/off cycling to minimize energy consumption while maintaining thermal comfort
- Adaptively learns model for coupled thermostat response to RTU controls
- Eliminates short cycling
- Plug-and-Play software solution: 1) uses only thermostat inputs & outputs; 2) minimal configuration requirements for typical installer (scalable)



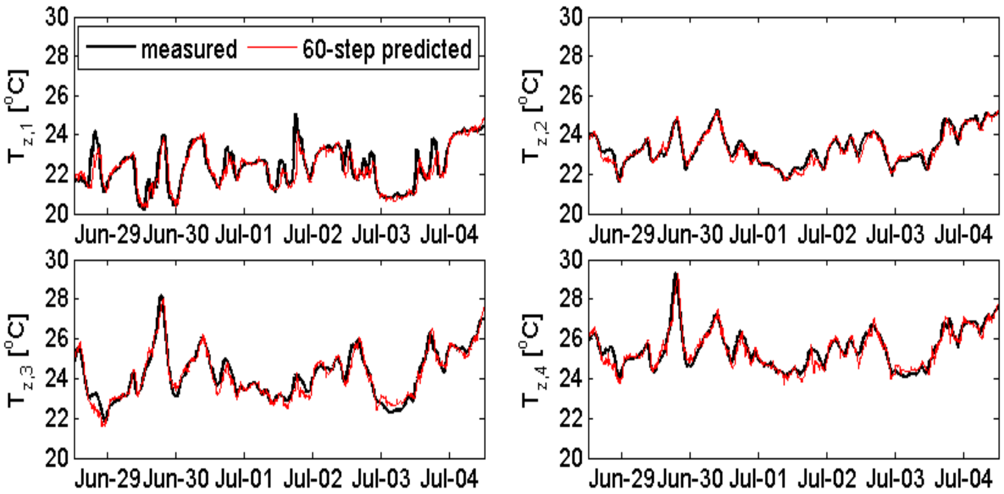
Multiple RTUs

Locations of diffusers and thermostats



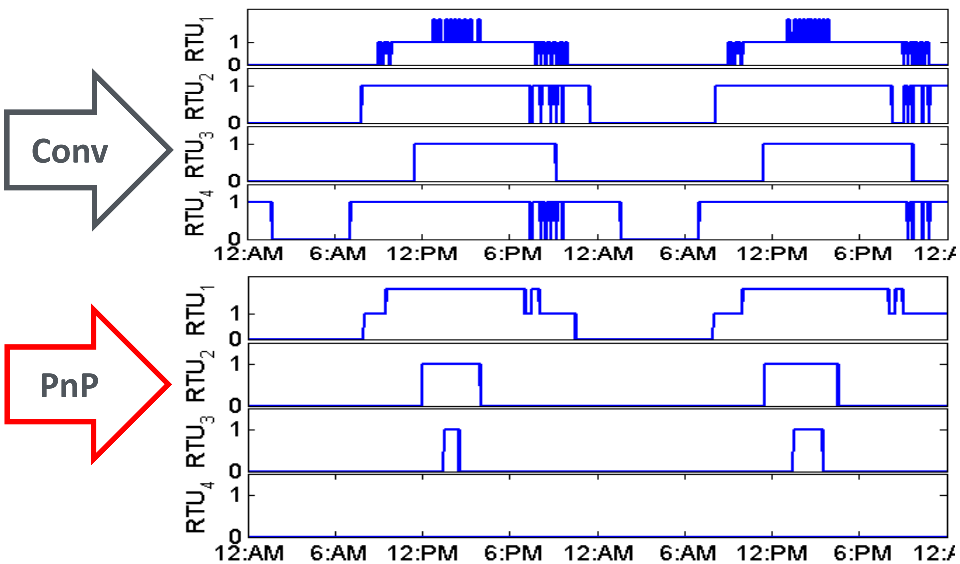
Harvest Grill Restaurant in Glenn Mills, PA.

Sample model valuation: 1-hour predicted values compared to measured data (with three-day training data)

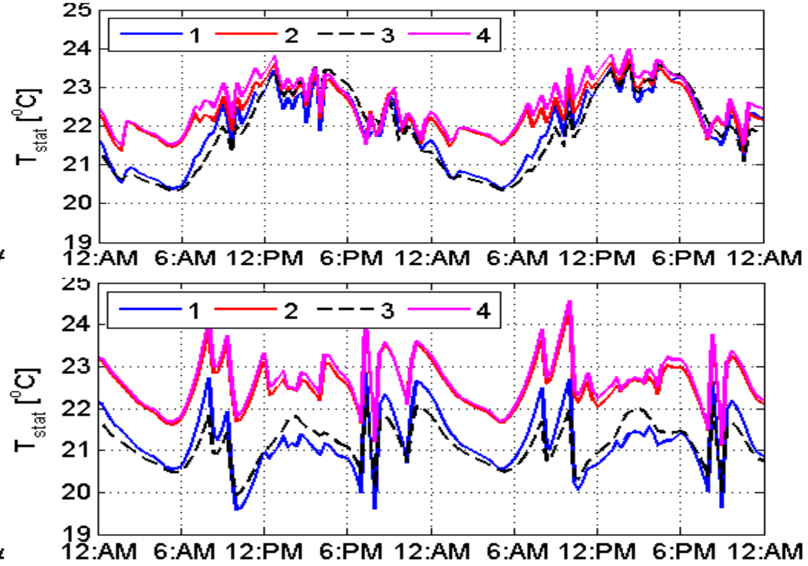


Accomplishments - RTU Coordination

RTU Staging



Thermostat Temperature Profiles



Control Algorithm	Energy Consumption [kWh/day]
Conventional	362.315
Plug & Play	281.72 (**22.2**% saving w.r.t conv.)

Plug-n-Play Controller Performance

- Uses learned behavior and optimization to maximize use of most efficient RTU_1
- Reduces short cycling and maintains comfort

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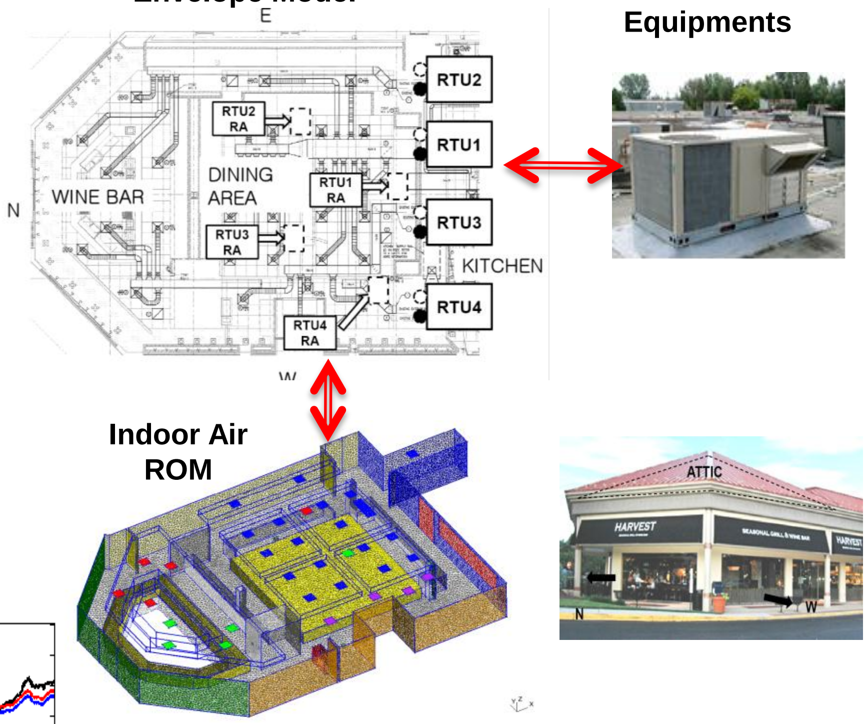
Accomplishments - RTU Control Assessment Simulator

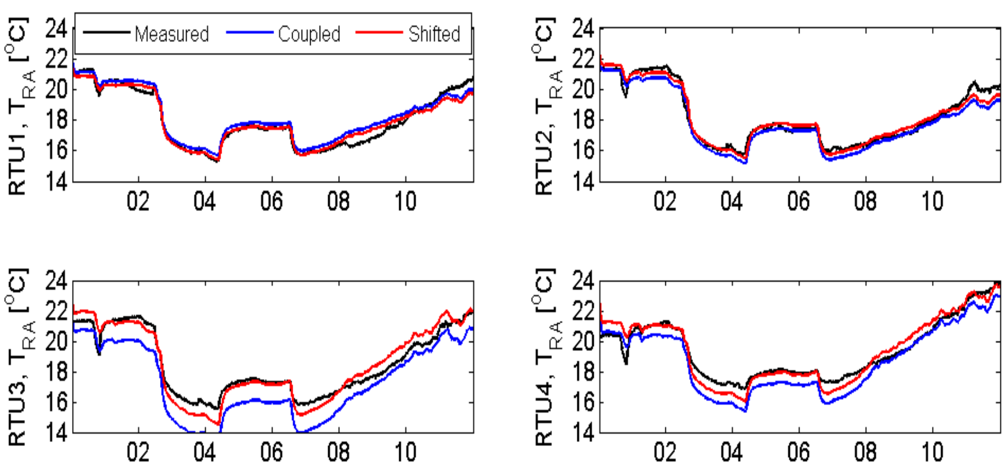
Overview

- Need for tool to allow control assessment of both energy and comfort performance for small/medium buildings that utilize rooftop units (RTUs) to serve open spaces (retail, restaurant, etc.)
- Approach for generating“fast” reduced-order models that couple building envelope and indoor air

Approach



Initial Validation



Accomplishments - RTU Virtual Sensors

Low-Cost
(e.g., temperature)
Measurements

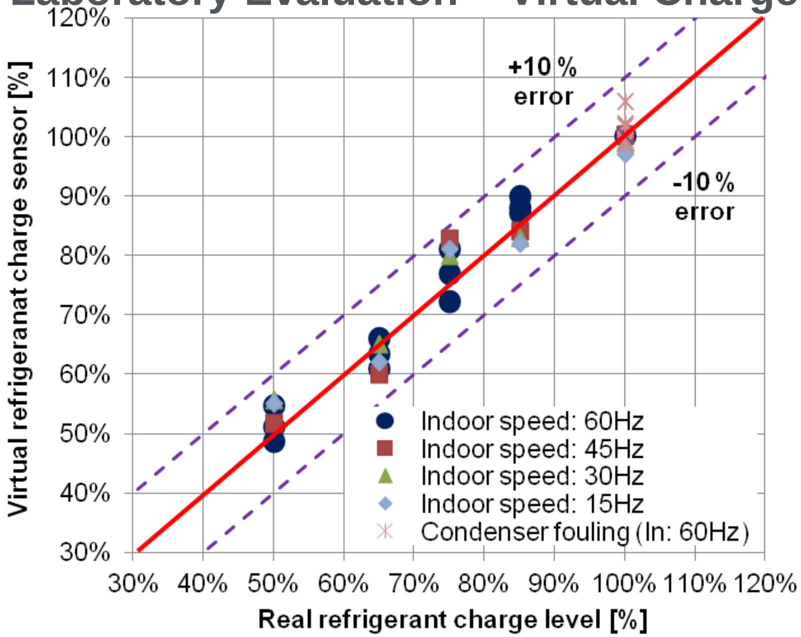
Mathematical
Models

Estimations of quantities that are:

- Difficult to measure
- Expensive to measure

Use them as inputs to diagnostic tools.

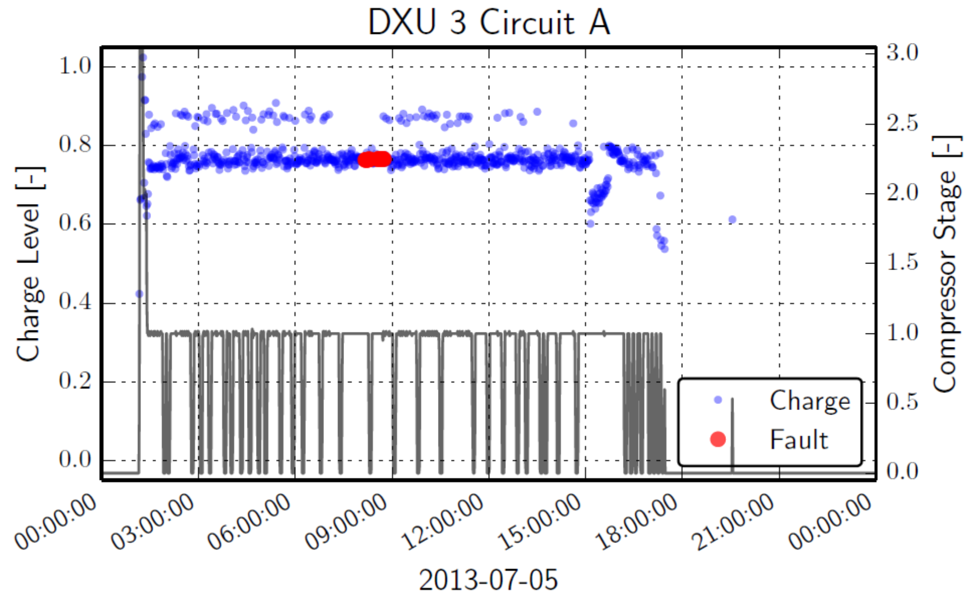
Laboratory Evaluation – Virtual Charge



Examples

- RTU capacity
- Refrigerant mass flow rate (3-ways)
- Refrigerant charge
- Compressor power
- Evaporator and condenser air-flow rate
- Supply fan power
- Outdoor-air fraction

Building 101 – Virtual Charge



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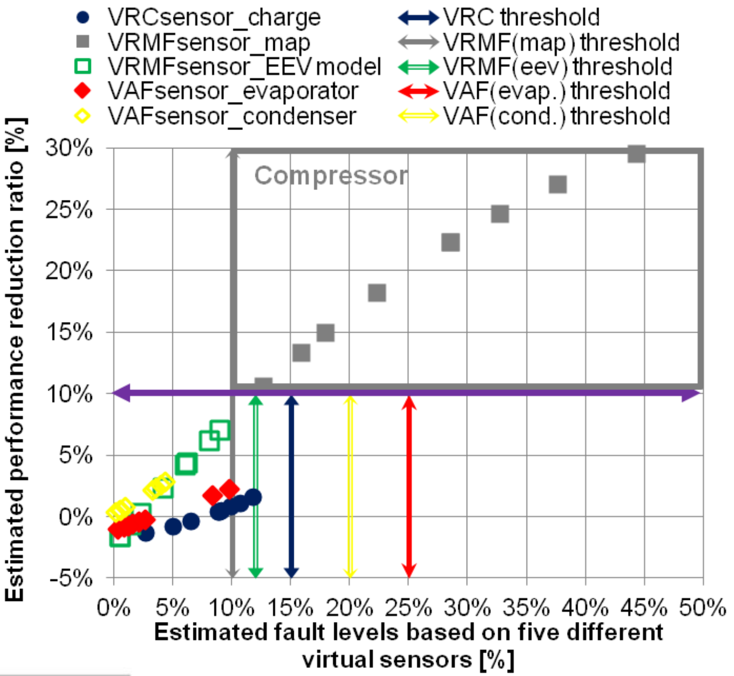
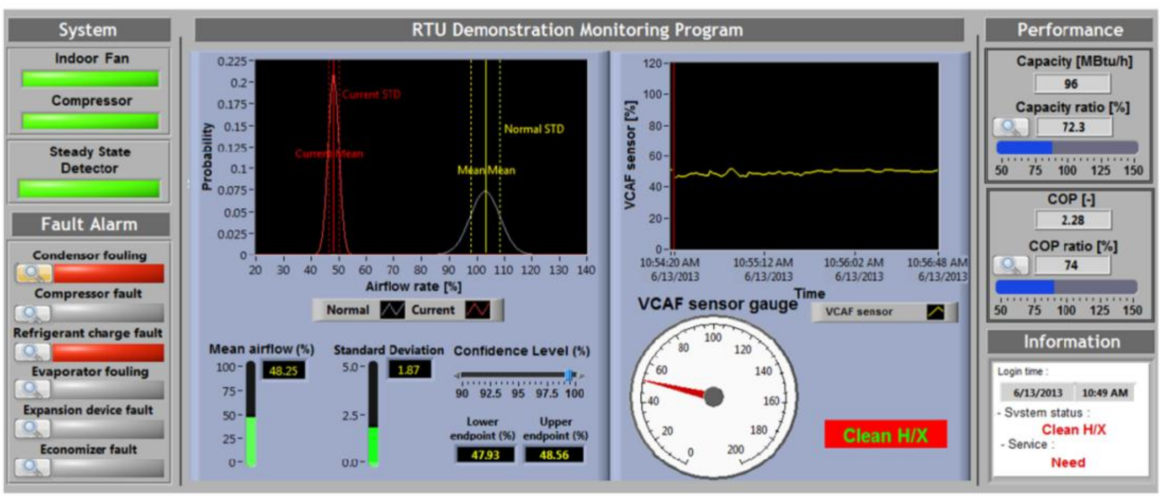
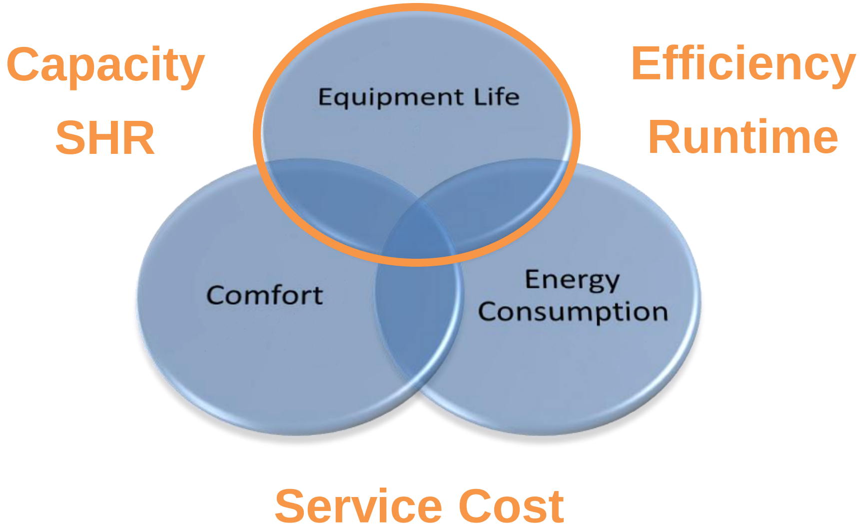
Accomplishments - Integrated Diagnostics for RTUs

- Use virtual sensors along with statistical classifier to isolate faults
- Primary focus is embedded diagnostics that would be included with manufactured RTU
- Estimate fault impacts using virtual capacity and power sensors
- Only diagnose faults that have statistically significant fault levels and impacts
- Developed laboratory and Building 101 demonstrations

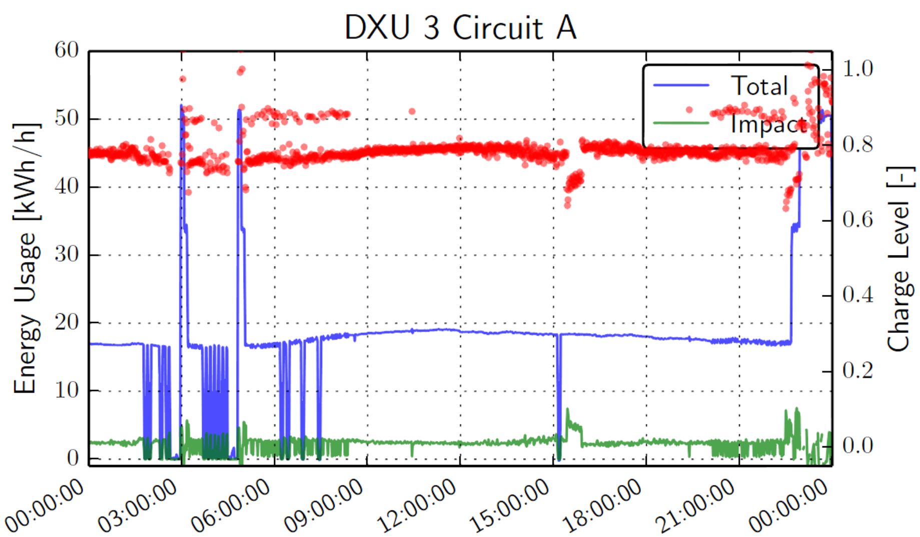




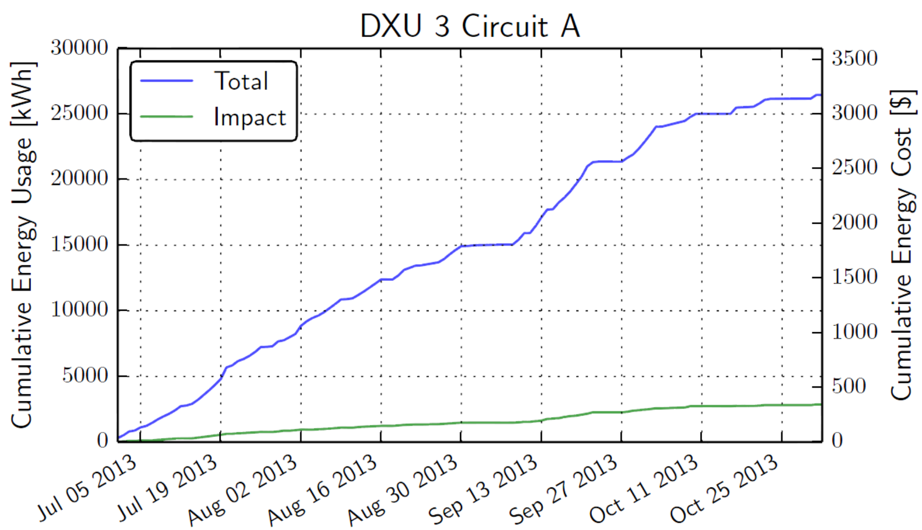
Accomplishments – RTU Fault Impact Evaluation



- Service decision can result from tradeoff between energy, equipment life, and service costs
- Can estimate energy impact using virtual sensors
- Additional work needed to develop simple overall impact indice



Cooling Season Impact (11% penalty)



Summary of Progress and Accomplishments

Accomplishments:
- developed scalable plug-and-play software solution for RTU coordination
- demonstrated 20% savings for optimal coordination of RTUs for a restaurant
- developed simulation tool for assessing RTU controller performance
- developed and validated a number of virtual sensors for RTUs
- demonstration and evaluation of complete RTU diagnostic system

Market Impact: working with RTU manufacturers' to assess commercial potential for RTU virtual sensors and diagnostics; working with control implementers for small commercial buildings to assess RTU coordination controller

Awards/Recognition: 'Very Highly Commended Paper' award for refrigerant charge impact paper published in the International Journal of Refrigerant in 2012/2013; best poster award for virtual

Project Integration and Collaboration

Project Integration: Purdue is working with UTRC/Carrier to assess the potential for embedded RTU diagnostics and Field Diagnostic Services, Inc. (FDSI) and Power Insights (PI) to assess RTU control coordination potential.

Partners, Subcontractors, and Collaborators: Purdue is responsible for algorithm development; Virginia Tech is developing reduced-order indoor air modeling; UTRC is providing implementation feedback and will perform RTU diagnostic commercialization evaluation; FDSI, Power Insights, and ORNL will provide access and support for field site demonstrations and assessments.

Communications: organized and presented work at Intelligent Building Operations Workshop (Summer, 2013); organizing workshop on FDD for RTUs (Summer, 2014); presented work at DOE Sensors and Controls Review (Spring, 2013); published a number of papers on controls and diagnostics work

Next Steps and Future Plans

- Further develop and demonstrate optimal RTU coordinator for multiple field sites
- Further develop and validate testbed for evaluating controls for small commercial buildings with open spaces served by multiple RTUs → utilize to evaluate and compare alternative RTU coordinators
- Develop an integrated fault impact estimation methodology for RTUs that can be used to determine optimal service scheduling
- Develop and assess complete diagnostic system for RTU that meets DOE Advanced RTU specification
- Perform commercial assessment of RTU diagnostics for advanced RTUs
- Perform commercial assessment of RTU coordinator control

REFERENCE SLIDES

Project Budget

Project Budget: Annually funded as part of EEB Hub. Total DOE budget to date $595K.
Variances: No project budget variances to date.
Cost to Date: $600K (46%) of DOE funds expended to date

Budget History					
2/1/2011– FY2013 (past)		FY2014 (current)		FY2015 – 4/30/2015 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
250K	60K	350K	70K	700K	150K

Project Plan and Schedule

- RTU Coordination Go/No-Go: 1) assessment of alternative approaches using data (6 months); 2) assessment of performance and cost savings (10 months)
- RTU FDD Go/No-Go: 1) laboratory implementation of fault emulation for advanced RTU (6 months); 2) evaluation of FDD performance and economic

Project Schedule												
Project Start: 2/1/2011		Completed Work										
Projected End: 4/30/2015		Active Task (in progress work)										
		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												
Initial assessment of RTU coordination algorithm												
Initial demonstration of embedded RTU FDD												
Current/Future Work												
Set up evaluation of RTU coordination approaches with ORNL												
Evaluate RTU FDD commercialization readiness for Adv. RTU												
Set up FDD experimental evaluation												
FDD commercialization workshop												
Test RTU coordination implementation for two test sites												
Design of diagnostics & optimal servicing for Adv. RTU												
Performance and cost assessments for controls & diagnostics												