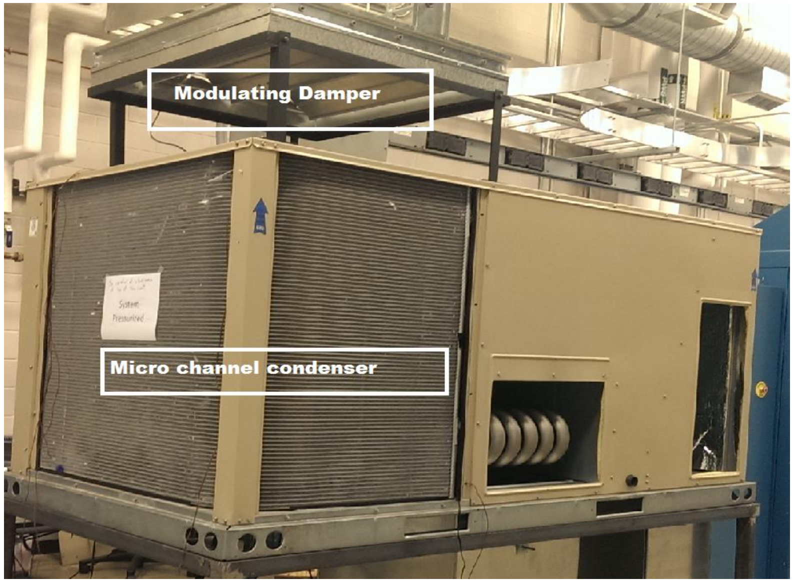
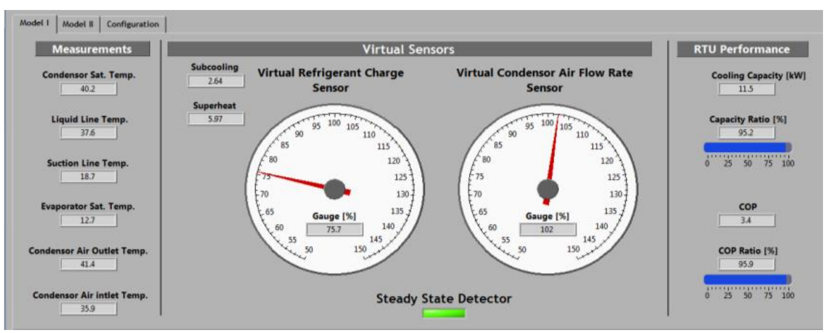
CBEI - Virtual Refrigerant Charge Sensing and Load Metering

2015 Building Technologies Office Peer Review





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Project Summary

Timeline:

Start date: 5/1/2014

Planned end date: 4/30/2016

Key Milestones

1. Accuracy of virtual charge sensor, 4/30/15
2. Accuracy of virtual BTU meter, 4/30/15

Budget:

Total DOE $ to date: **$400,000**

Total future DOE $: **$140,000**

Target Market/Audience:

Commercial buildings with either rooftop units (RTUs) or built-up air-handling units (AHUs)

Key Partners:

CBEI-Purdue
CBEI-UTRC
Lennox

Project Goals:

1. Extend RTU virtual sensor methods for refrigerant charge, cooling capacity, and unit power to RTUs having micro-channel condensers
2. Extend existing method for virtual water-side load metering to air-side virtual load metering

CONSORTIUM for BUILDING ENERGY INNOVATION

Vision:

By 2030, deep energy retrofits that reduce energy use by 50% in existing SMSCB, which are less than 250,000 sq ft

Our Goals:

- **Enable deep energy retrofits** in small to medium sized commercial buildings
- **Demonstrate energy efficient systems** tailored for SMSCBs in occupied buildings – living labs
- **Develop effective market pathways** for energy efficiency with utilities and other commercial stakeholders: brokers, finance, service providers.
- **Provide analytical tools** to link state and local policies with utility efficiency programs

Mission:

Develop, demonstrate and deploy technology systems and market pathways that permit early progress (20-30% energy use reductions) in Small and Medium Sized Commercial Buildings

CBEI Partners

Industry

- Bayer MaterialScience
- United Technologies Research Center

Economic Development Organizations

- DVIRC
- PIDC
- Ben Franklin Technology PArtners

Universities

- PennState
- NJIT
- Penn, University of Pennsylvania
- Drexel University
- Carnegie Mellon University
- VirginiaTech, Invent the Future
- Purdue University
- Morgan State University
- Rutgers

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Purpose and Objectives

Problem Statement: Low-cost sensing is needed to enable widespread monitoring, automated diagnostics, and advanced controls. Direct sensing methods are too expensive and are not widely utilized.

Target Market and Audience: The target market is commercial buildings having either RTUs or built-up AHUs for cooling. Primary energy for cooling in commercial buildings is about 2.6 Quads per year. Virtual sensors could be brought to market as integrated sensors in manufactured products (e.g., RTUs) or as stand-alone retrofit product for existing systems (e.g., chilled water system)

Impact of Project: Project is demonstrating accuracy within 10% and cost reduction in relation to direct measurement of factor of 5-10

Approach

Approach: 1) Using low-cost sensors and models to provide virtual sensing; 2) Developing and validating low-cost methods for training virtual sensors; 3) Evaluating accuracy using laboratory and field measurements

Key Issues: In order to move this towards commercialization, need to understand and characterize: 1) accuracy of virtual sensors over a range of conditions; 2) potential for cost reduction compared to direct measurement; 3) minimum training requirements for virtual sensors.

Distinctive Characteristics: Unique approach of employing virtual sensors to reduce costs and enable advanced diagnostic and control features

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Progress and Accomplishments

Lessons Learned: 1) difficult to directly measure condensing temperature for RTUs with micro-channel condensers (requires condensing pressure measurement) 2) Sensor health is critical for accuracy of air-side thermal load metering

Summary of Accomplishments:

- Demonstrated low-cost method for training virtual refrigerant charge sensor in open laboratory → could be fully automated
- Accuracy of virtual sensors generally within 10% compared to direct measurements
- Factor of 10 reduction in costs for virtual load sensor compared to direct method based on flow measurement

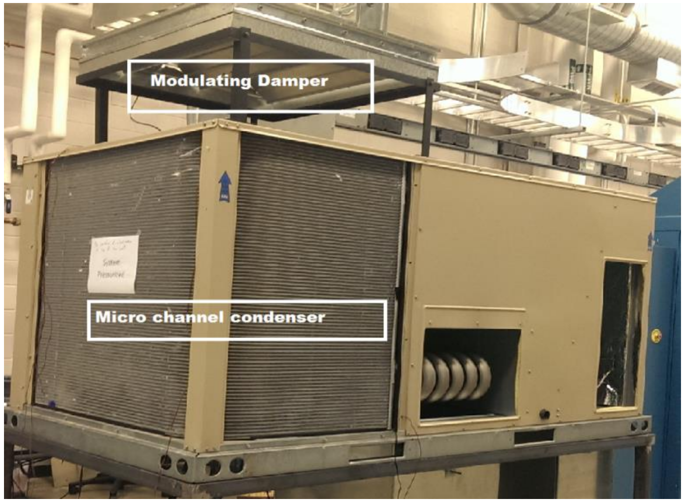
Accomplishments - RTU Virtual Sensor Approach

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

Mathematical
Models

Estimations of quantities that are:
- Difficult to measure
- Expensive to measure

RTU w Micro-Channel Condenser



Virtual Sensor	Approach
Refrigerant Charge	Correlate charge with condenser subcooling & evaporator superheat
Compressor Power	AHRI compressor map with inputs of evaporating and condensing temperatures
Cooling Capacity	AHRI compressor map with inlet density correction

<u>Required Measurements</u>: Evaporating & condensing temp. (or pressure), suction & liquid line temp.

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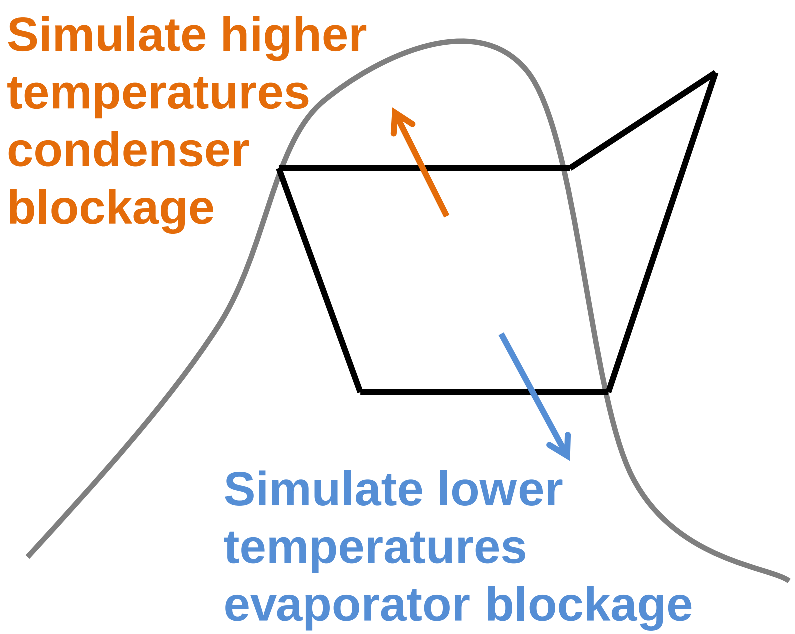
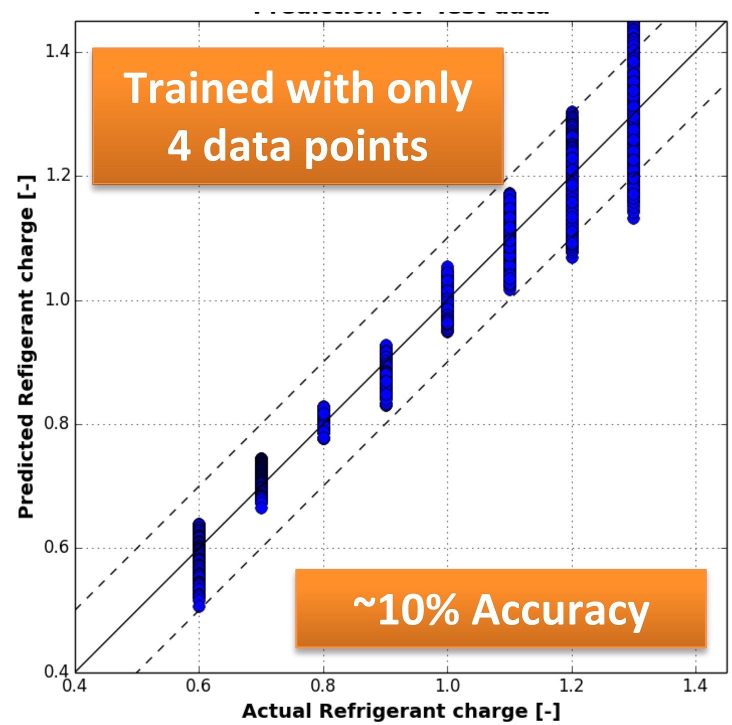
Accomplishments - RTU Virtual Charge Sensor Training

Automated Training In Open Laboratory



Possible to train VRC sensor with minimal data



Significant reduction in costs required to train virtual sensors

Significant reduction in time required to train virtual sensors

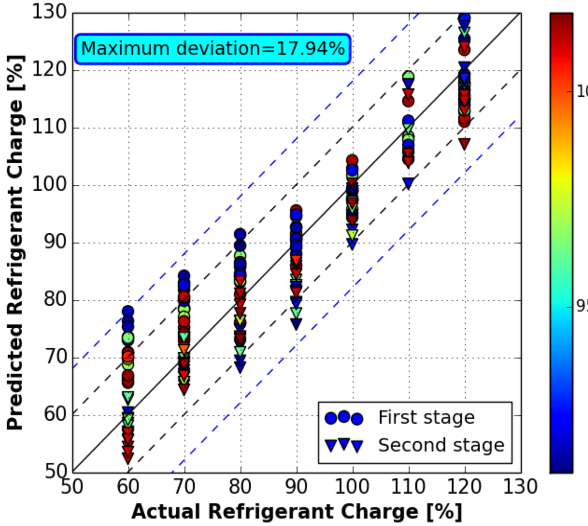
Accomplishments - RTU Virtual Sensing Testing

Charge level	Stage of operation	Ambient Conditions [F]	Indoor air flow reduction	Outdoor air flow reduction
60% - 120%	First	67;82;95	3 levels	3 levels
60% - 120%	Second	82;95;108	3 levels	3 levels

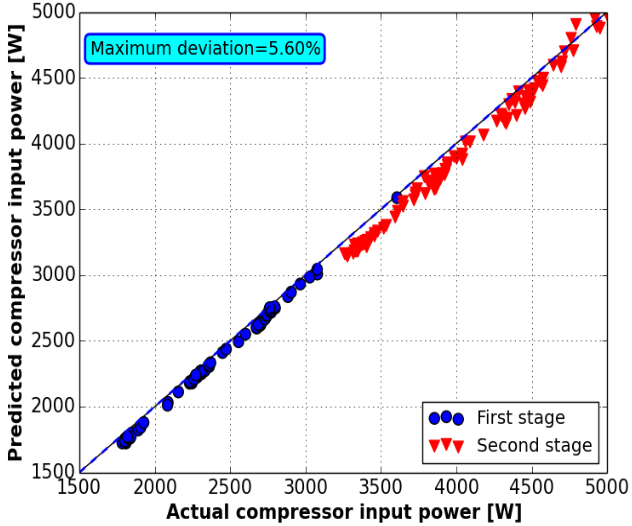
- Total test cases = 232.
- The test scenarios include testing the micro-channel unit at different charge levels, indoor air flow reduction levels, outdoor air flow reduction levels and combinations of all three at different ambient conditions for two stages of compressor operation.

Accomplishments - RTU Virtual Sensing Accuracy

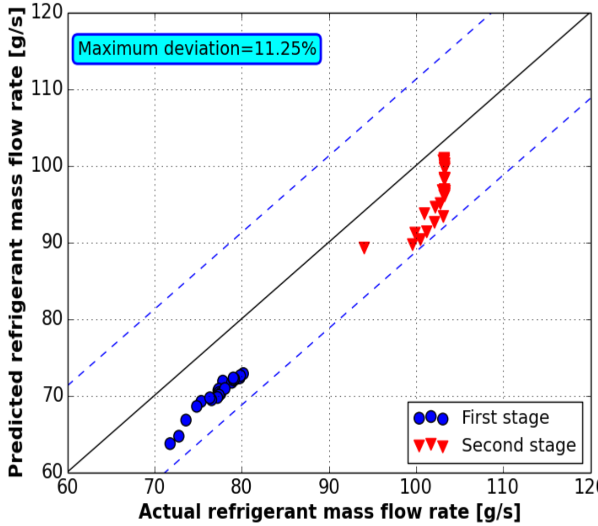
Virtual Charge



Virtual Compressor Power



Virtual Refrig. Mass Flow



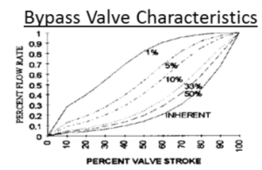
- Charge sensor trained at a single ambient condition (open lab testing)
- Accuracy is better when trained with a separate set of coefficients for the individual compressor stages
- Virtual refrigerant mass flow rate sensor and virtual compressor power sensors are based on AHRI compressor map for the micro-channel RTU

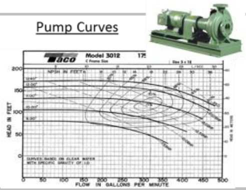
BTU Virtual Meter Approach

Challenge: Cost of BTU thermal submetering (~$10K/point) prohibitive, inhibiting uptake of energy monitoring and analytics

Collect pump & valve data

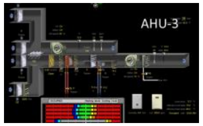
- Collect catalogue pump and valve performance maps

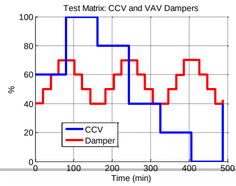




Run functional tests

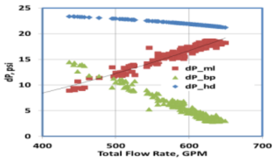
- Run functional tests to infer system flow characteristics

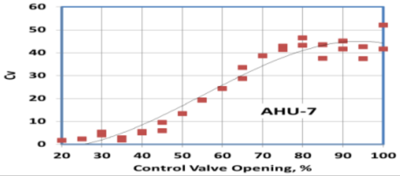




Flow rate estimation

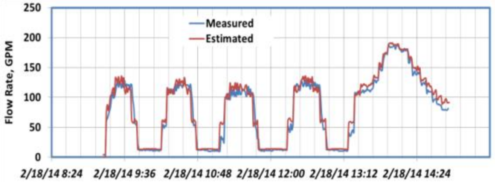
- Infer terminal valves' flowrate as a function of system settings





Thermal load calculation

- Combine with temperature measurements to estimate thermal load



Virtual thermal metering project aims to achieved ±10% accuracy at >5X cost reduction

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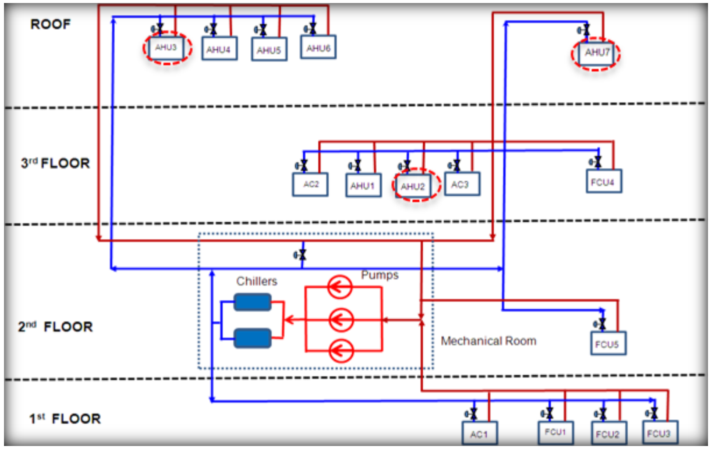
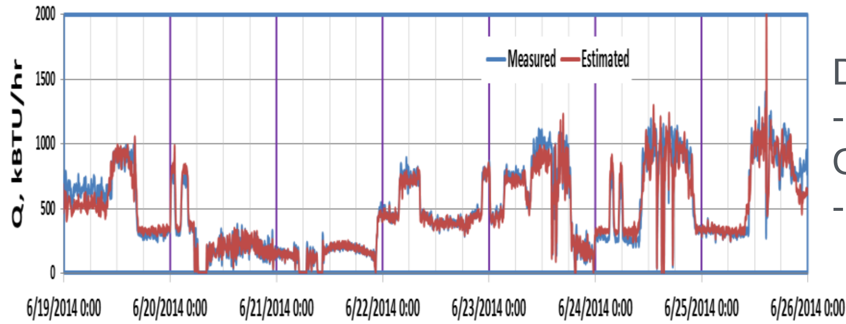
Accomplishments – Water-Side Load Metering

Swope School of Music



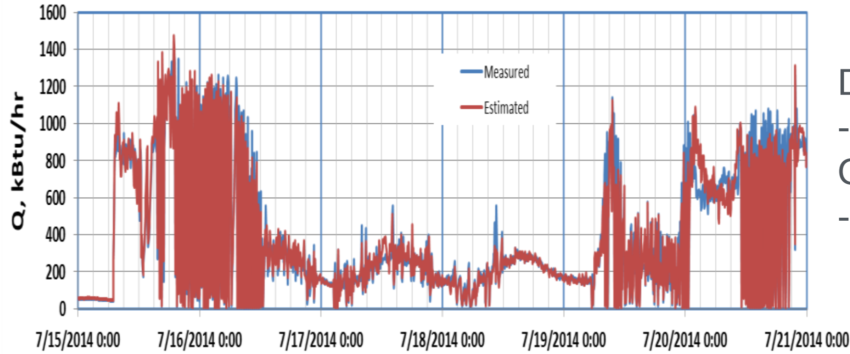
Cooling Season Results (AHU-7)

June 19 – June 26, 2014 (Period 1)



Daily
-6.5%~ 5.4%
Overall
-1.3%

July15 – July 21, 2014 (Period 2)



Daily
-2.6%~ 2.0%
Overall
-0.5%

Field test achieved ~3-6% accuracy on daily hydronic thermal loads
Key learning on system requirements (system definition)

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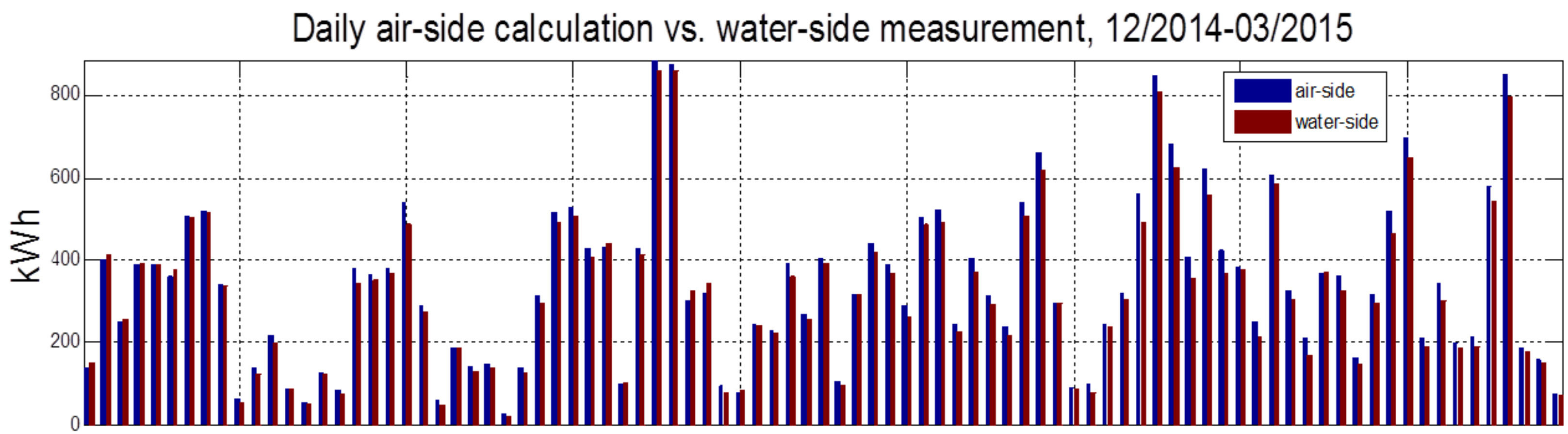
Accomplishments – Air-Side Load Metering

Heating Season Results (AHU-7)



Error (%)	Daily	Weekly	Monthly
Mean	6.8	5.3	5.2
Std Dev	5.3	2.4	2.7

Field test achieved ~7% accuracy on daily hydronic thermal loads
Key learning on system requirements (sensor calibration)

Accomplishments – Virtual Load Metering Costs

The cost of an installed BTU meter on AHU7 in Swope Building:

Material - $2,800
Installation - $6,000
Mapping to BMS (or BAS) - $240
Total - $9,040

Estimated Virtual Sensor Costs:

Information Gathering - $200
Temperature Sensor Installation - $300
Functional Testing - $200
Application Software Integration - $500
Total - $1200

Path to >5X cost reduction via scalable commissioning framework

Progress and Accomplishments

Market Impact: Future impact could be dramatic increase in the use of load, power, capacity, and refrigerant charge sensing that enables 10-20% reduction in energy usage for cooling due to improve controls and fault detection. Working with partners to evaluate next steps towards commercialization

Project Integration and Collaboration

Project Integration: Purdue is working with Lennox to assess the potential for embedded virtual sensing for RTUs. . UTRC is working with ALC and their development partners to assess next steps towards commercialization of virtual load metering.

Partners, Subcontractors, and Collaborators: Purdue is responsible for developing and assessing the RTU virtual sensors, while UTRC is focused on water-side and air-side load metering for systems with built-up AHUs. Lennox has provided support for implementation and testing for an RTU with micro-channel condensers

Communications: The virtual RTU sensing work was presented at a workshop for RTU Diagnostics that was held in summer, 2014.

Next Steps and Future Plans

Next Steps and Future Plans:

- Implement RTU virtual sensors within a small controller and demonstrate in order to assess practical requirements and costs

- Develop and demonstrate fully automated and low-cost system (hardware and software) for training RTU virtual sensors → training kit is important for improving the overall economics of applying virtual sensors for a whole RTU product line

REFERENCE SLIDES

Project Budget

Project Budget: $400,000
Variances: None
Cost to Date: $400K

Budget History					
CBEI BP3 (past) 2/1/2013 – 4/30/2014		CBEI BP4 (current) 5/1/2014 – 4/30/2015		CBEI BP5 (planned) 5/1/2015 – 4/30/2016	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
		$400,000	$45,000	$140,000	$15,556

CBEI – Consortium for Building Energy Innovation (formerly EEB Hub)
BP – Budget Period

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Project Plan and Schedule

- Go/No-Go completed on October 20th, 2014

Project Schedule												
Project Start: **5/1/2014**		Completed Work										
Projected End: **4/30/2016**		Active Task (in progress work)										
	◆	Milestone/Deliverable (Originally Planned) use for missed milestones										
	◆	Milestone/Deliverable (Actual) use when met on time										
	BP3 (2013-14)				BP4 (2014-15)				CBEI BP5 (2015-16)			
Task	Q1 (Feb-Apr)	Q2 (May-Jul)	Q3 (Aug-Oct)	Q4 (Nov-Apr)	Q1 (May-Jul)	Q2 (Aug-Oct)	Q3 (Nov-Jan)	Q4 (Feb-Apr)	Q1 (May-Jul)	Q2 (Aug-Oct)	Q3 (Nov-Jan)	Q4 (Feb-Apr)
Past Work												
Water-Side Virtual Load Meter Evaluation for Heating					◆							
Preliminary Virtual Charge Sensor Results						◆						
Cooling -Side Load Meter Evaluation						◆						
Air-Side Load Meter Evaluation							◆					
Overall Virtual Meter Assessments								◆				
Current/Future Work												
Automated System for Training RTU Virtual Sensors												
RTU Virtual Sensor Implementation												
Demonstration												
Final Specification and Performance Evaluation												

BP – Budget Period for Consortium for Building Energy Innovation (formerly EEB Hub)