Pre-commercial demonstration of cost-effective advanced HVAC controls and diagnostics for medium-sized commercial buildings

2015 Building Technologies Office Peer Review

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

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Project Summary

Timeline:

Start date: 05/01/2014

Planned end date: 04/30/2015

Key Milestones

1. Demonstrate that installation method meets commercialization requirements; 10/31/2014
2. Quantify overall installation cost, and ROI; evaluate energy and comfort benefits; 04/30/2015

Budget:

Total DOE $ to date: $450K

Total future DOE $: $0

Target Market/Audience:

Building Automation Systems (BAS) vendors/installers

Key Partners:

CBEI-UTRC	

Project Goal:

Demonstrate cost-effective, scalable installation of advanced building and HVAC control and diagnostic solutions

Demonstrate potential to save 15% HVAC energy with less than 3 years simple payback in the Medium-Sized Commercial Building market.

CONSORTIUM for BUILDING ENERGY INNOVATION

Vision:

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

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

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

CBEI Partners

Bayer MaterialScience

United Technologies Research Center

Industry

DVIRC

PIDC

Ben Franklin Technology PArtners

Economic Development Organizations

Penn State

NJIT

Penn University of Pennsylvania

Drexel University

Carnegie Mellon University

Virginia Tech Invent the Future

Purdue University

Morgan State University

Rutgers

Universities

Purpose and Objectives

Problem Statement: Advanced controls and diagnostics have been proven to reduce energy consumption by >20% and in order to achieve high level of market adoption the cost and length of the commissioning process must be further reduced.

Target Market and Audience: **Commercial buildings with central HVAC** use 1.9 Quads of HVAC energy. **BAS installers and service providers** can enhance HVAC energy efficiency by scalable cost-effective installation and commissioning of advanced controls and diagnostics applications.

Impact of Project:

- short-term: **proof-point demonstrations** of cost effective commissioning of advanced control and diagnostics
- mid-term: **transition to commercialization partners**
- long-term: **wide-scale market adoption** of advanced controls and diagnostics applications via cost-effective, scalable commissioning

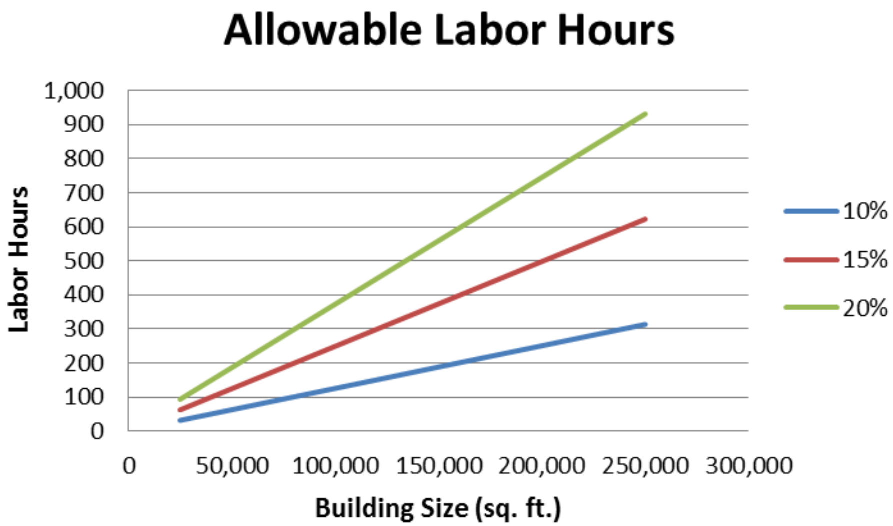
Requirements for cost effectiveness

Current and emerging market solutions

- Focus on large buildings: >250K sq.ft.
- Require metering, customization, and tuning

Market requirements for medium and small commercial buildings

- Return on investment: less than 3 years payback
- Can be deployed with existing industry workforce skillset
- Can be offered as overlay on existing BAS or data management platform with standard HVAC instrumentation



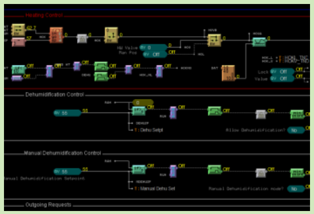
<u>Assumptions:</u>
2003 CBECS Data
All non-mall SMSCB <200k sq. ft.
96 kBTU/sq. ft./year ; $1.69/sq. ft.
Assume 40% HVAC energy consumption;
$82/hour HVAC contractor labor rate;
$0.1/sq.ft application cost
3 year simple payback

Reduce HVAC energy use in ~35% of commercial buildings (1.9 Quads).

Goal: Low-cost Installation of Advanced Applications

Market adoption of advanced application requires **cost-effective** and **scalable commissioning process** to address **building and HVAC system heterogeneity**

Site preparation



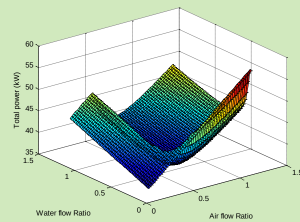
IT connectivity configuration / BAS system interface

2-4 days; HVAC control specialist

Application commissioning

Data mapping/ data quality

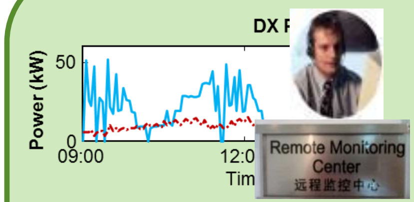
<1 day
HVAC control specialist



Model creation, calibration, and optimization formulation

2-6 weeks
graduate level expertise

Online operation



Monitor system performance
Retraining as required

1 hour/week
graduate level expertise

Current state

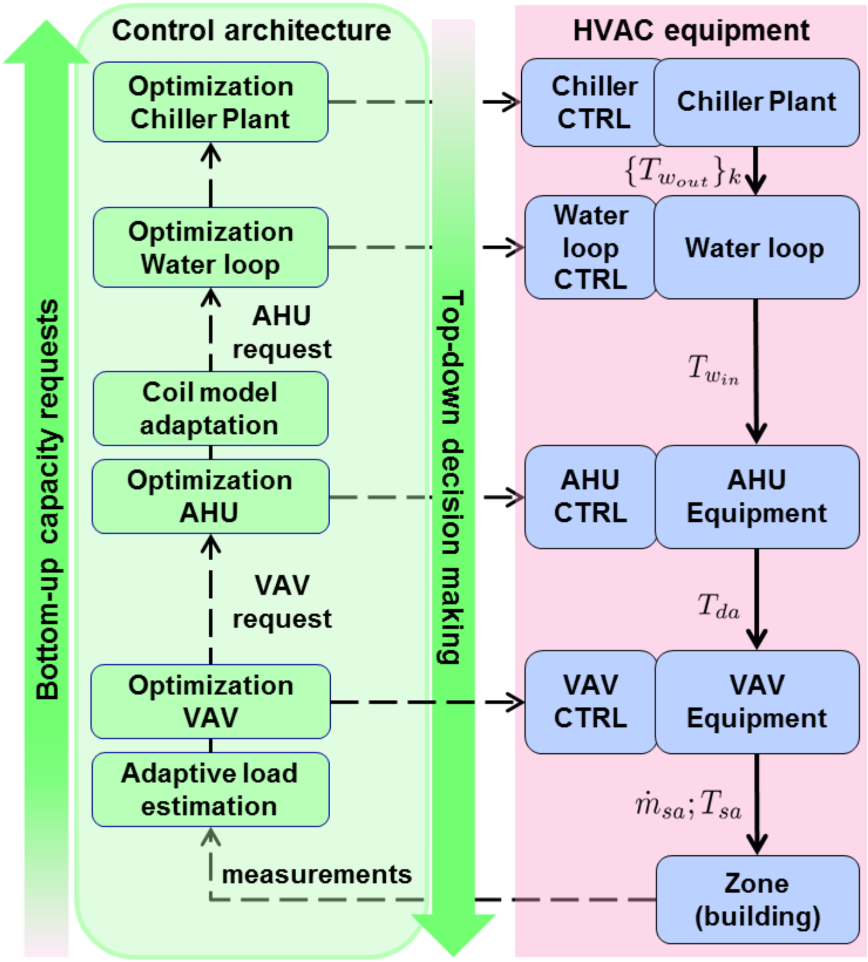
Site Preparation and Interfacing → Technology Installation

Scalable installation of advanced applications

Site Preparation and Interfacing → time & cost reduction

Target: technology installation reduction to < 1 day with existing workforce

Approach: 1. Hierarchical Decentralized Optimization

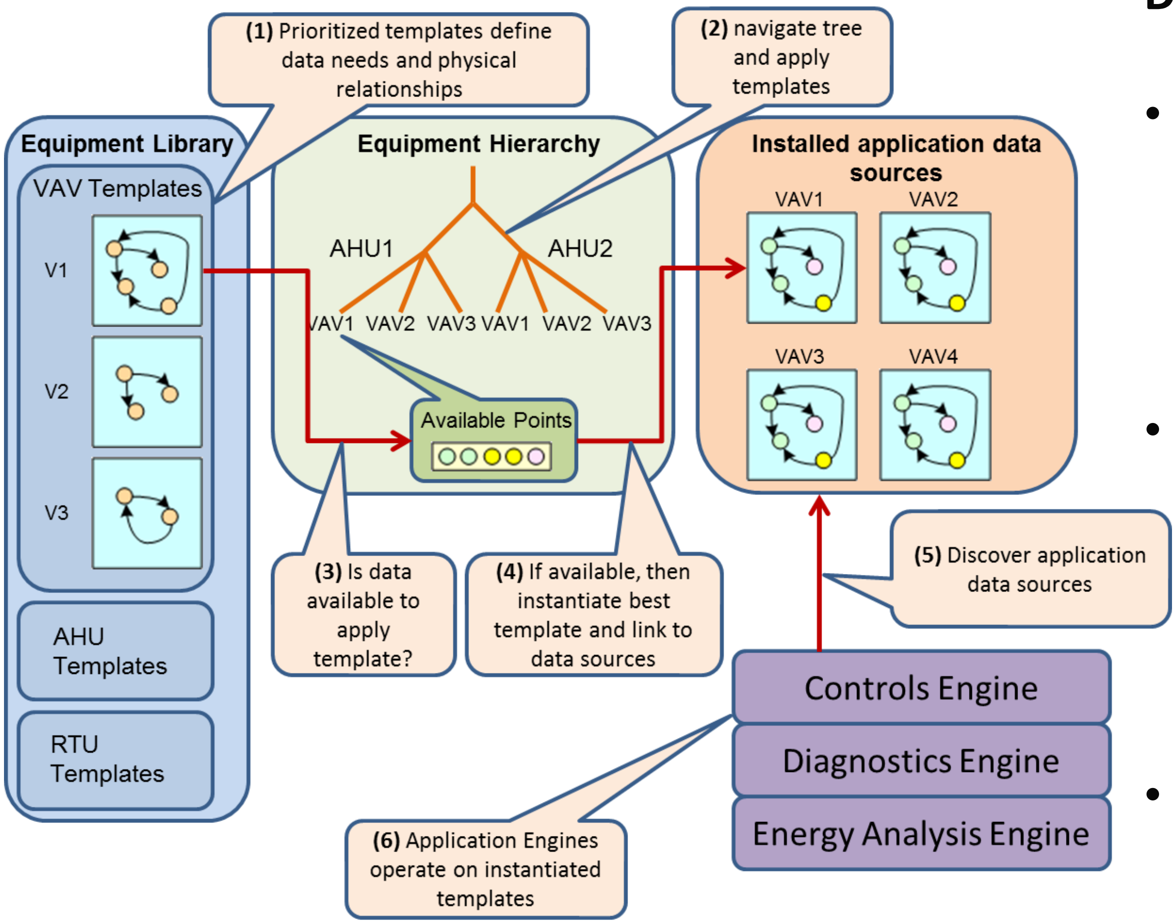


Distinctive characteristics:

- Composability: automated composition of optimization approach based on current control architecture and HVAC system structure
- Self-calibration: Online load estimation models eliminate the need for manual model calibration and (re)tuning
- Adaptability and Robustness: to variations in load, building usage conditions, slow equipment degradation

Decentralized formulation allows for automated composition

Approach: 2. Automated Commissioning



Distinctive characteristics:

- Data Needs: Based on building HVAC configuration the data needs of advanced applications are automatically determined
- Automated Composition: The hierarchical control problem is automatically composed for a given HVAC configuration and available sensing
- Automated Execution: The available engines are executed as needed

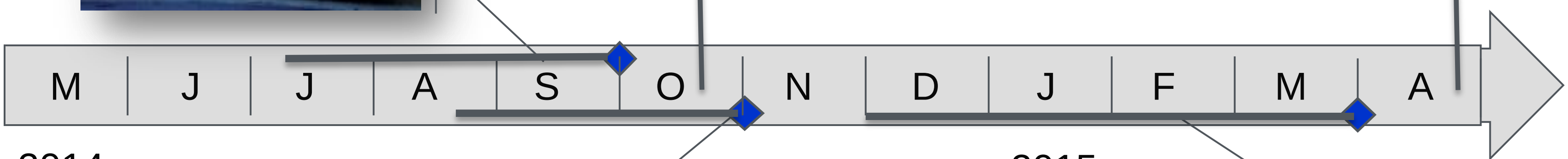
Automatically map applications onto data sources and manage execution

Project Timeline

9/2014:
Commissioned advanced building controls at UTRC office building

Review:
Evaluation results, market opportunity, and demo plan

Review:
Evaluate energy and comfort benefits, overall installation cost and ROI



2014

2015

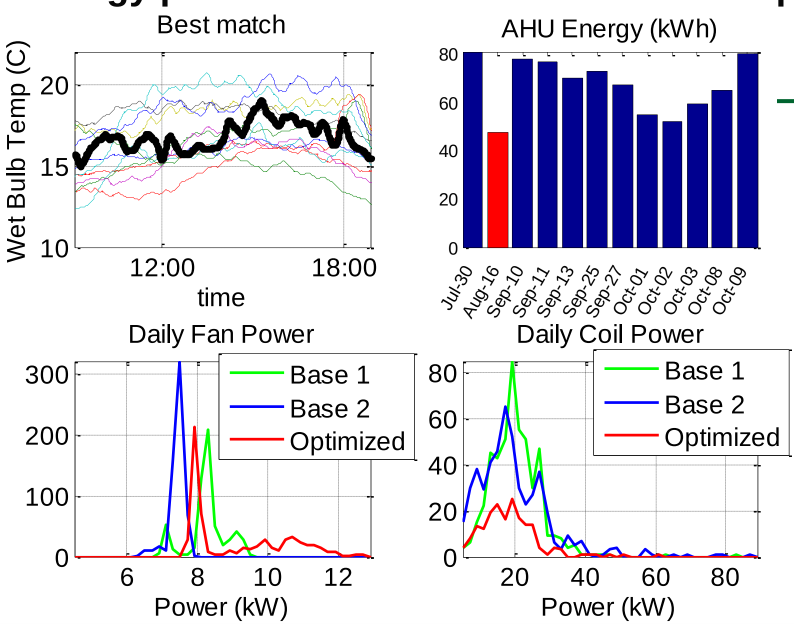
10/2014:
Commissioned advanced building diagnostics at Swope School

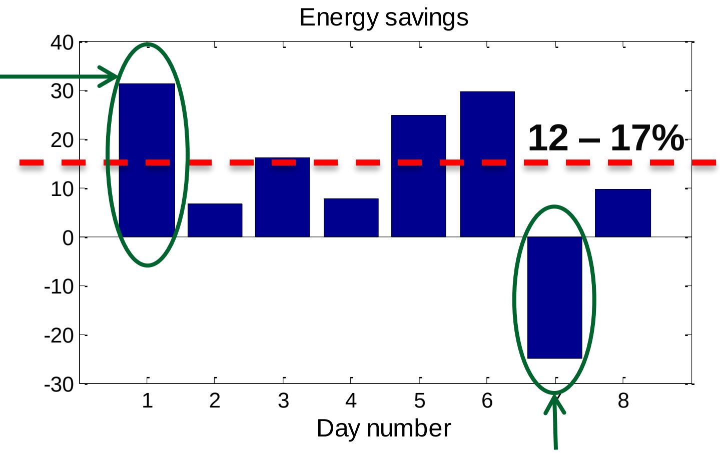
03/2015:
Commissioned advanced building controls at Swope School

Rapid Deployment Demo: Controls results

- Demo Site: UTRC office building ~40,000 sq ft. in East Hartford Connecticut; AHUs served by district chilled and hot water
- Baseline supervisory: Trim-and-respond based on heating and cooling requests
- Automated Deployment: Time to configure 1 hour (excluding point mapping)
- No manual tuning or retuning
- Cooling season experiments: Aug – Sept 2014

Energy performance calculated for each optimized day relative to baseline days with similar load





Simultaneous heating and cooling was activated by logic switches in the local control resulting in excessive cooling during the afternoon

Time to commission controls: 1 hour. HVAC energy savings 12-17%.

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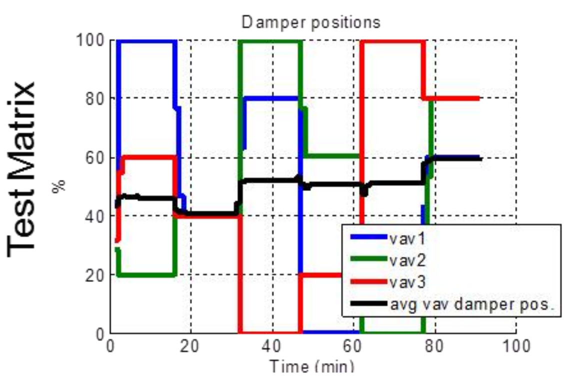
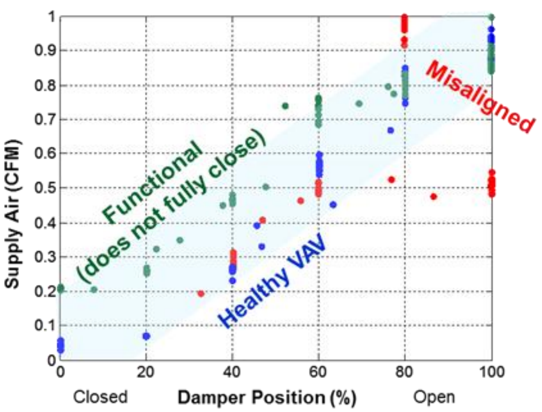
Rapid Deployment Demo: Diagnostics - VAV dampers

- Demo Site: West Chester University, Swope School of Music Building and Performing Arts Center; LEED Silver Rating; ~88,000 sq ft.; AHUs served by chiller plant and boilers
- Automated Deployment: Automated construction and remote execution of functional tests enabled health of 51 VAVs to be evaluated in <3 hours: Time to configure < 4 hours (excluding point mapping)
- Functional test experiments: August 2014
- Diagnostics application detected all observable injected faults, with no false detections.

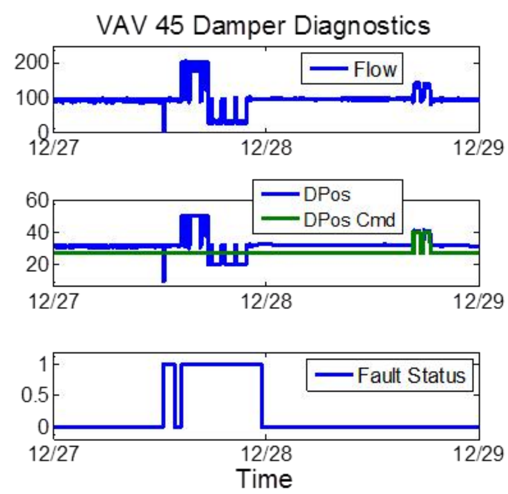
VAV Functional Testing



VAV damper health evaluation



VAV damper fault detection



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Rapid Deployment Demo: Controls results

- Demo Site: West Chester University, Swope School of Music Building and Performing Arts Center; LEED Silver Rating; ~88,000 sq ft.; AHUs served by chiller plant and boilers
- Baseline supervisory: Dead-band control on AHU return air temperature
- Automated Deployment: Time to configure 1 hour (excluding point mapping)
- No manual tuning or retuning
- Heating season experiments: March – April 2015

Preliminary analysis

The optimized coordination scheme demonstrates consistent performance enabled by tradeoffs between the AHU fans and coil operation.

Progress and Accomplishments

Lessons Learned:

- Baseline control typically involves switching mechanisms in the enabling local control loops that have to be managed carefully during the coupling with the supervisory control decisions
- Data point mapping done exclusively by human operators was an error prone and time consuming step: large opportunity for standardization and automation

Accomplishments:

✓ Proof-point demonstrations of cost-effective and low-touch commissioning of advanced control and diagnostics: < 1 day installation and commissioning

✓ Demonstrated 12 - 17% HVAC energy reduction beyond state-of-the-art trim and respond supervisory HVAC control, with no additional hardware and sensors, based on adaptive optimal approach

Market Impact:

✓ Demonstration of scalable installation and commissioning that can meet commercially viable deployment by current market workforce will unlock energy reduction potential in medium scale commercial buildings

Awards/Recognition: None.

Project Integration, Collaboration and Next Steps

Project Integration:

- Engagement with manufacturers and installers to explore pre-commercial demonstration at customer sites

Partners, Subcontractors, and Collaborators: UTRC performed this project in collaboration with CBEI demonstration sites and Radius Systems

Communications:

- Conference publication at 2014 Purdue Conference on High Performance Buildings
- Journal publication in ASHRAE Science and Technology for the Built Environment special issue on "Recent research on high performance buildings“, 2015 – accepted.
- Presentation accepted for the 2015 SIAM Conference on Control and its Application (Society of Industrial and Applied Mathematics)
- Journal paper on performance measurement and verification approach – in preparation

Next steps and future plans:

- Evaluate commercialization path with controls companies

REFERENCE SLIDES

Project Budget

Project Budget: $450K
Variances: None
Cost to Date: $440K
Additional Funding: None

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
$0	$0	$450K	$112.5K	$0	$0

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

BP – Budget Period

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Project Plan and Schedule

Go/no-go decision points:

- **(10/2014) Market analysis and other industry efforts in this area; Viability of scalable installation process; Results evaluation, market opportunity and demo plan**
- **(04/2015) Final report of cost and benefit analysis, commercialization path, overall installation cost and ROI**

Project Schedule												
Project Start: 05/01/2014	■ (light blue)	Completed Work										
Projected End: 04/30/2015	■ (dark blue)	Active Task (in progress work)										
	◆ (red)	Milestone/Deliverable (Originally Planned) use for missed										
	◆ (black)	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												
Engage with CBEI and key stakeholders					■ ◆							
Commission advanced controls at UTRC building					■	■ ◆						
Commission advanced diagnostics at Swope building					■	■ ◆						
Commission advanced controls at Swope building							■	■ ◆				
Evaluate and report demonstration results								■ (dark) ◆				

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