CONSORTIUM for BUILDING ENERGY INNOVATION

FINDINGS

The Consortium for Building Energy Innovation

CBEI is focused on generating impact in the small- and medium-sized commercial buildings (SMSCB) retrofit market. CBEI is comprised of 14 organizations including major research universities, global industrial firms, and national laboratories from across the United States who collaborate to develop and demonstrate solutions towards 50% energy reduction in existing buildings by 2030. The CBEI FINDINGS series highlights important and actionable technical, application, operation and policy research results that will accelerate energy efficiency retrofits when applied by various market participants. CBEI views these FINDINGS as a portal for stakeholders to access resources and expertise to implement change.

Building 101 Testbed

Initially built in 1911 to serve as a U.S. Marine Corps barracks, Building 101 is a three story commercial building that underwent a major renovation in 1999 to accommodate a single tenant. This renovation included adding a forced air heating and cooling system to the formerly hydronically heated barracks. Building 101 currently serves as a multi-tenant office building that is partially occupied. Gross Building Floor Area is 75,156 ft^2 with 69,246 ft^2 of conditioned area.

Building 101 is the principle testbed used to prove the potential for energy savings associated with advanced HVAC controls[1].

Building 101 located at The Navy Yard in Philadelphia

[1] For more information on the Building 101 testbed: http://research.cbei.psu.edu/research-digest-reports/navy-yard-building-101

Research Finding: Building 101 Cost-Effective Advanced HVAC Controls

Through simulation based analysis and demonstration at customer sites CBEI quantified the potential for energy savings of overlay solutions for intelligent building operations such as advanced supervisory controls and diagnostics at 10-30% beyond the benefits of current building automation systems (BAS).

These advanced solutions are not widely adopted due to remaining challenges with scalability. Too often they require prohibitive on-site labor, building specific model and algorithm development, additional sensing, and advanced skill-sets.

The key to wide-spread impact is reducing the installation time and expertise required to implement advanced controls. CBEI is demonstrating one such scalable commissioning process. Focus elements are:

1. Demonstrating the plug-and-play application of advanced controls and other building operations applications.
1. Defining a hierarchical optimization-based control approach with online estimation models that allows for adaptive scalable deployment.
1. Demonstrating sustained energy benefits of forecast-based advanced control algorithms beyond current building automation systems (BAS).

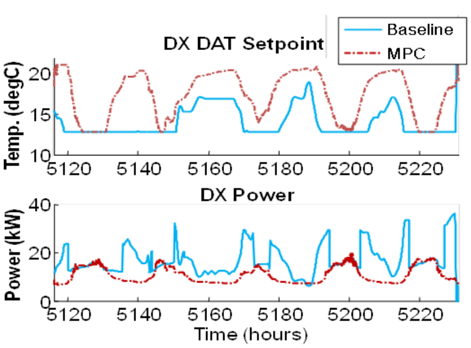
Advanced Control Results

Because of their simplicity, the predominant methods of control for HVAC systems in existing buildings today is on/off and proportional-integral-derivative[2] (PID) control. This simple approach often trades HVAC energy performance for operational robustness. With advances in data storage, computing, and communication devices, it is now feasible to implement advanced control approaches that overcome the inherent inefficiencies in HVAC control. The first step in advancing building HVAC control was to validate and quantify the potential for energy consumption reduction. CBEI demonstrated the benefits of one promising advanced control approach, model predictive control (MPC), for HVAC systems. MPC has the following characteristics:

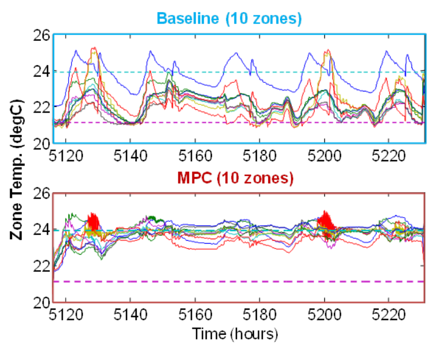
- Use of a system model for anticipatory control actions rather than corrective control;
- Integration of a disturbance model for disturbance rejection;
- Ability to handle constraints and uncertainties;
- Ability to handle time-varying system dynamics and a wide range of operating conditions;
- Integration of energy conservation strategies in the controller formulation;
- Use of a cost function for achievement of multiple objectives;
- Use of advanced optimization algorithms for computation of control actions;
- Ability to control the system at both the supervisory and local loop levels.

In 2012, CBEI created an initial model of Building 101 at the Navy Yard in Philadelphia predicting that MPC could achieve nearly 20% improvement in HVAC efficiency and improved indoor air comfort (see below).

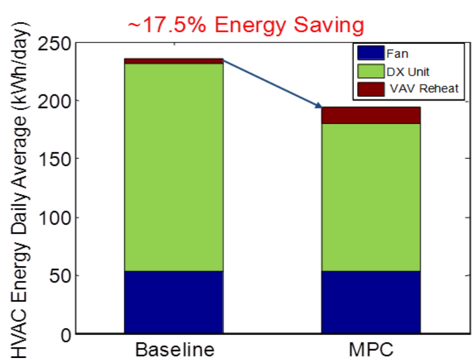
Equipment Optimization



Superior Comfort

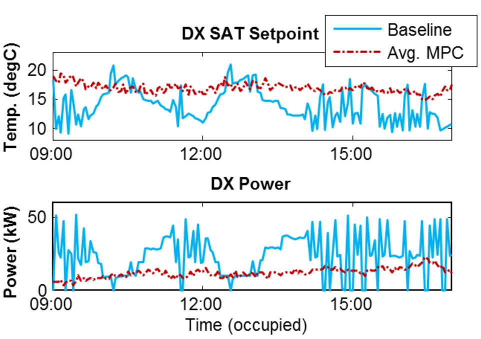


Reduced Energy Usage



During 2013, extensive baseline and advanced control testing were completed at the Building 101 testbed. The measured data below shows improved space temperature control and an average HVAC energy savings of >30% demonstrated over 20 days of testing.

Equipment Optimization



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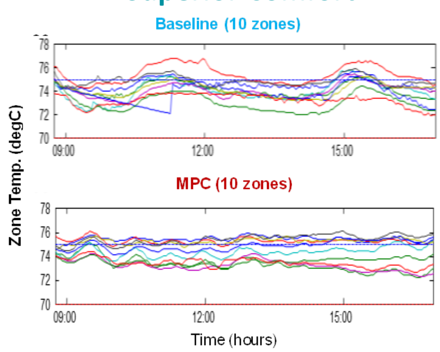
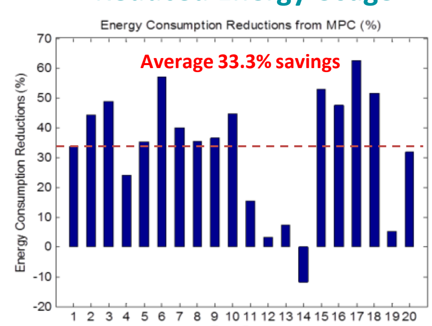
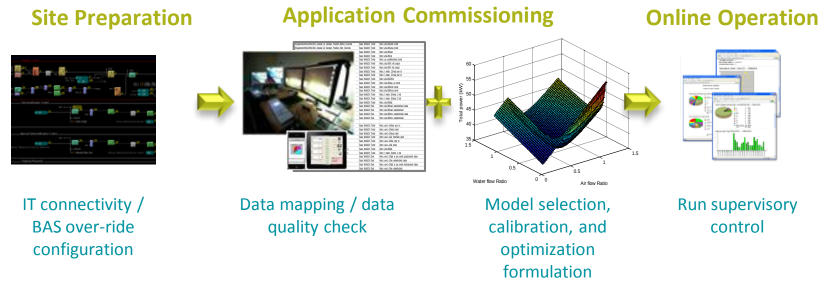


Reduced Energy Usage



[2] A PID controller brings to zero the error difference between a measured process variable and a desired setpoint.

Deployment of Advanced Controls in Existing Buildings with BAS



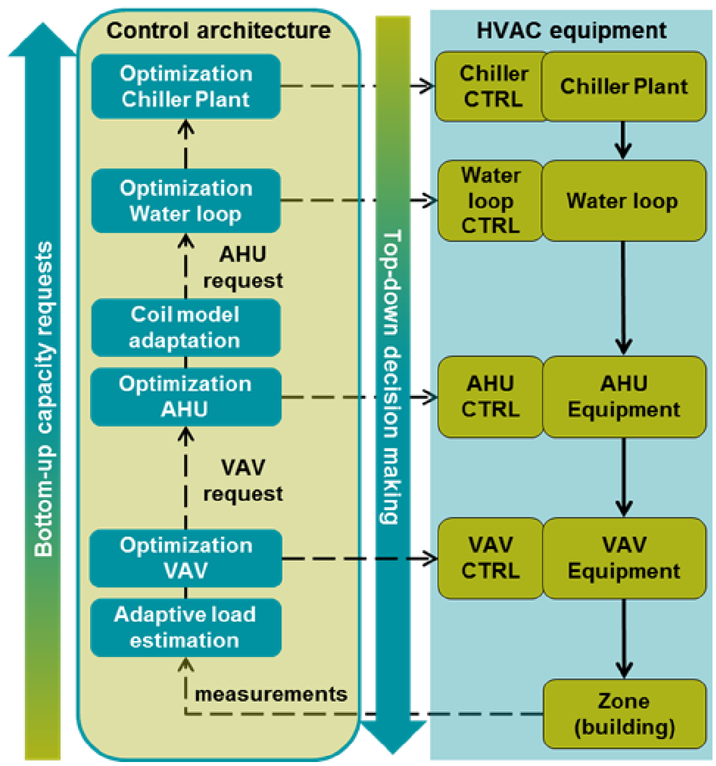
The commissioning of advanced control approaches like MPC at customer sites requires a graduate-level engineering skillset at commissioning time and 2-6 weeks of activity focused on physical connectivity, data mapping, model cccccc configuration and calibration, and operations monitoring. The primary barriers to successful market adoption of cost-effective advanced HVAC controls are commissioning time and cost.

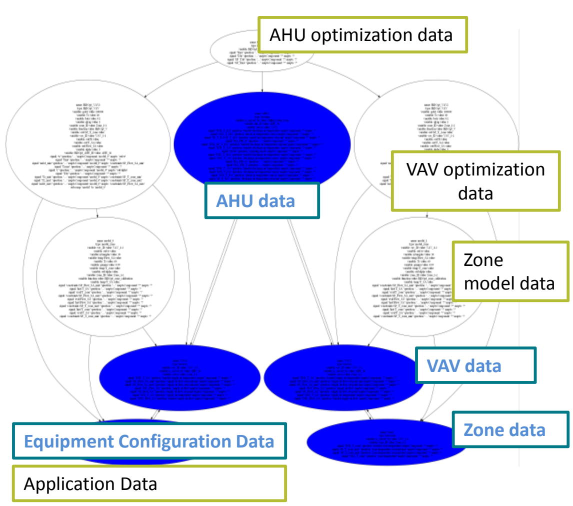
Scalable Deployment of Advanced HVAC Controls

To address the commissioning barrier, CBEI is demonstrating the rapid commissioning of advanced controls using a decentralized hierarchical optimization overlay that mirrors the current control architecture and hardware structure.

The scalability is enabled by the decentralized hierarchical optimization concept. Optimal AHU and VAV set points are computed sequentially to meet loads with minimum energy consumption (thermal and electrical) while accounting for comfort constraints.

In addition, the use of adaptive estimation models eliminates the need for operator assisted HVAC operation model calibration and (re)tuning.





Example of the automatic data and controls composition created by the deployment process

Automated Commissioning Process

The key to applying advanced control technology in existing buildings is low commissioning cost and self-adapting approaches – i.e. plug-and-play solutions. Under this CBEI project, advanced HVAC controls and other applications such as diagnostics are being commissioned using a scalable automated process to demonstrate streamlined commissioning. Based on the HVAC configuration this process automatically determines the data that needs to be mapped and composes the control formulation and sequence of operations. This allows advanced solutions to be installed in a matter of hours once building overrides and data-mapping is complete.

40,000 sq. ft. office building located on the United Technologies Research Center Campus

90,000 sq. ft. Swope School of Music located on the West Chester University Campus

Moving Forward

CBEI is currently demonstrating reduced commissioning effort and scalable deployment for advanced controls (and other applications). The advanced controls application was deployed in August 2014 on an office building at United Technologies Research Center in East Hartford, Connecticut. Beyond defining the HVAC topology and completing the data mapping, no building-specific customization of the controls formulation was required. The long-term performance of the controls will continue to be monitored through 2014. CBEI will also be demonstrating the rapid commissioning of controls and diagnostics at the Swope School of Music in West Chester, PA. The end goal is to demonstrate a cost effective advanced building HVAC control overlay solution that saves a minimum of 15% HVAC energy with less than 3 years simple payback.

The deployment/commercialization pathways and partners including BAS companies and energy service companies are being developed.

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CBEI is a research and demonstration center that works in close partnership with DOE's Building Technologies Office.

Lessons Learned

1. The demonstration of advanced controls as a supervisory overlay on existing building automation systems has reaffirmed the energy-benefit potential, showing the ability to reduce the HVAC energy consumption by 10-30%.
2. Current formulations are not scalable as they require custom model development, functional tests, model calibration, and skilled (graduate level) implementers.
3. To impact the existing buildings market the commissioning of advanced controls must be highly automated.
4. The focus on commissioning cost and complexity of advanced solutions should be commensurate with the focus on energy savings.
5. Demonstrating benefits in the field requires careful back-to-back comparison (accounting for weather, occupancy etc.)
6. Healthy building equipment is a pre-requisite for optimal operation, thus equipment diagnostics is an important complement to advanced controls. Equipment health enables maximization of operating performance and maintenance of required indoor air quality.

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