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 for 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/or expertise to implement change.

Gaining Control

Buildings consume over 40% of the total energy in the U.S. Over 90% of the buildings are less than 50,000 square feet in size. These buildings currently do not use building automation systems to monitor and control their building systems. This lack of control generally results in wasted energy and increased operating expenses. So, if money can be saved, why isn't everybody gaining control of these buildings mechanical systems?

The answer is also money; it costs too much to fix this problem through an energy efficiency retrofit. The Harvest Seasonal Grill testbed was developed to demonstrate that by using web enabled thermostats and HVAC system knowledge, an effective multiple-input and multiple-output (MIMO) control algorithm can be developed that saves energy at a low installed cost.

Research Finding: Harvest Grill –Predictive Controls

Driving down the cost of building rooftop package HVAC control systems is now achievable by using internet-connected accessible thermostats and software.

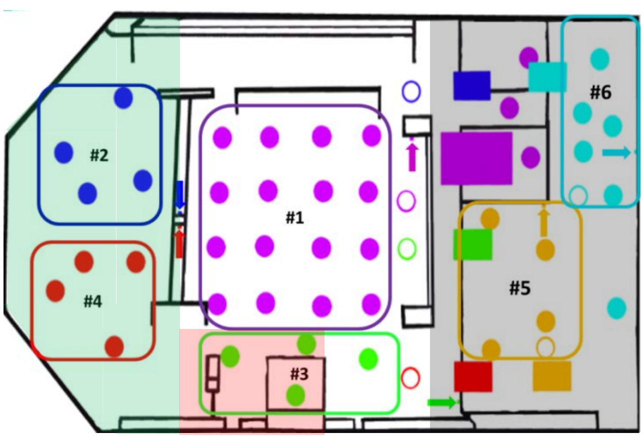
A multiple-input and multiple-output (MIMO) control algorithm has been developed providing predictive control of multiple RTUs providing conditioned air to a single space.

Adding RTU measured power to the MIMO control algorithm creates the ability to optimize multiple RTUs by managing runtime of high efficiency systems versus lower efficiency systems while maintaining space temperatures.

The future will offer small and medium sized buildings a modest cost connected solution combining optimization and demand response.

The Testbed

The Harvest Seasonal Grill and Wine Bar is known for the kitchen's working relationship with over 75 area farmers, great meals and its ambiance. It is also known by its upscale interior. This former GAP store is a very successful restaurant and gathering place. Like most businesses, Harvest Seasonal Grill is known for their product and not their energy footprint. The site is a 6,040 square foot end unit in a strip mall. The restaurant is divided in two major areas: the front of the house: bar (green shade), dining room (white) and reception (rose) and the back of the house (gray). The site is served by six rooftop units (RTUs) which are color coded (bottom right of sketch and aerial photo). Each RTU's supply diffusers are shown below (solid circles and return diffusers are hollow circles). Thermostat locations are indicated with arrows. The dining room served by four RTUs is similar to most buildings less than 50,000 square feet served by multiple RTUs. Results from these tests are expected to have wide applicability across approximately 12 billion[*] square feet of these buildings served by RTU systems across the country.



Economic Implication

Recently, controls are being added to building HVAC systems to allow building owners and operators to participate in demand response markets. Essentially, by allowing the HVAC systems to be turned off during high peak electricity times, the utility provides compensation to the user. While this is not the focus of this work, demand response algorithms could work in conjunction with the CBEI MIMO predictive control and building RTU optimization algorithm to save even more money while increasing energy efficiency.

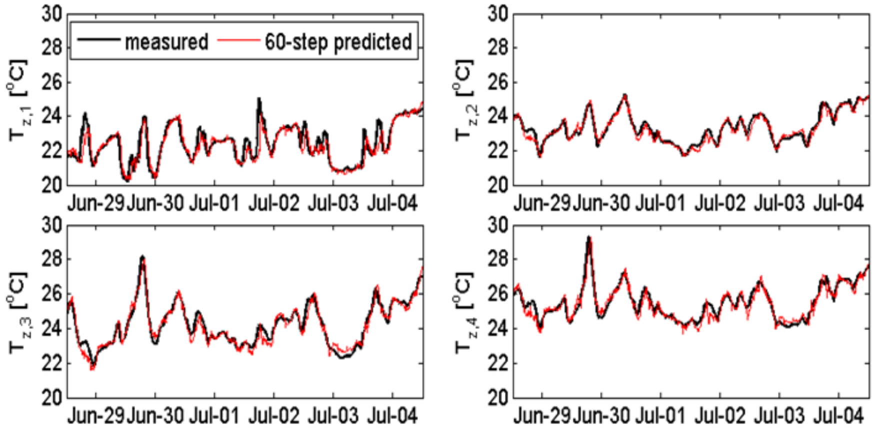
The economic implications of optimizing performance at this testbed building, with energy costs of 9.97 cents per kWh of electricity and $5.50 per MMBtu of natural gas, are significant. The project energy cost savings for applying RTU optimization algorithm is an annual savings of $1,000.

An installed cost of $1,000 for four new internet connected thermostats and an annual $300 per year service charge for optimization control would yield a first-year cost of $1,300.

This creates a reasonable economic payback period of just over 1 year for installing addressable thermostats without any utility incentives. If the utilities provide incentives through their demand side management programs, the installed cost can be higher and still have a one-year payback.

Gaining Control

An addressable thermostat that is powered from the RTU provides space temperature, RTU on/off status and cooling and heating stages. From this thermostat data alone, CBEI researchers have developed a predictor modeling algorithm that successfully provides one-hour ahead predictions of the future space temperatures based on the on/off cycling of the four RTUs servicing the dining/bar area and the recent history.

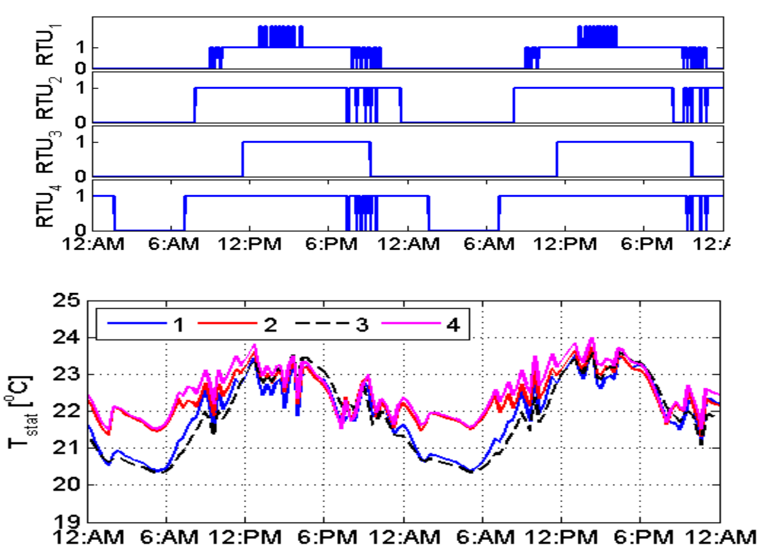


More than Gaining Control – Optimizing

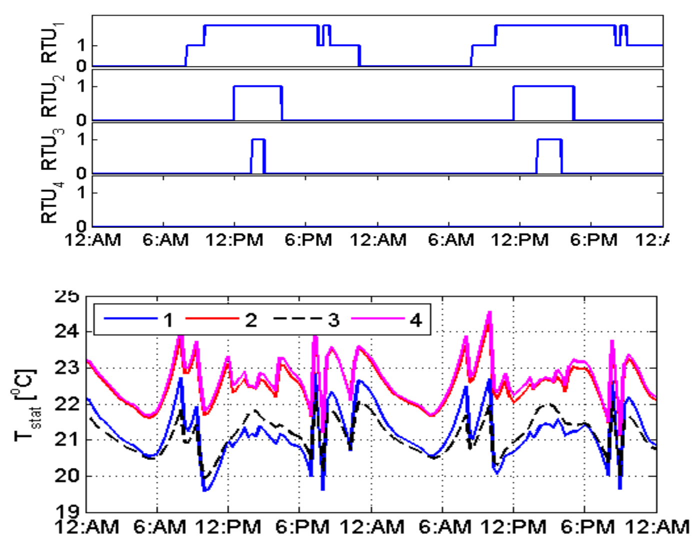
The testbed RTUs are of different capacity, age and performance. This is quite typical of most existing facilities where systems degrade differently over time. In this case, RTU #1 performance is about 35% better than the others. This means if RTU #1 operation can displace other units, without significantly sacrificing comfort, then the owner saves money.

Having mastered predictive performance from the thermostat data above, then an optimization algorithm can be developed to control the four RTUs to deliver greater building level performance. CBEI researchers employed their MIMO predictive control and building RTU optimization algorithm at the testbed resulting in shifting the RTU operating sequence (figure below) from the upper left figure to the upper right figure (Note RTU #4 did not even run under optimized conditions). Thermostat space temperatures served by RTUs 1 & 3 were slightly reduced. Most importantly, RTU power was reduced by 22%.

Independently Controlled RTU Performance



Web Enabled Optimized RTU Performance



Lessons Learned

Currently, most small and medium sized buildings are set point-based with a predefined control scheme that is executed based on the thermostat sensor data. Multiple RTUs serving the same space, (from quick service restaurants to big box retailers) using this decentralized control strategy, operate inefficiently and RTUs can be found fighting each other.

Many of the recently available advanced thermostats can be connected via the Internet, allowing for remote control. These advanced features also allow for some advanced control concepts like optimal control and agent-based or learning-based controls. However, even the most sophisticated thermostats are very rarely integrated into a single network allowing for managing and monitoring from a central location. Therefore, most of the advanced features of these devices are rarely used in practice.

A MIMO control algorithm was successfully implemented at the testbed, demonstrating that predictive control of multiple RTUs providing conditioned air to a single space is possible.

Adding RTU measured power to the MIMO control algorithm creates the ability to optimize multiple RTUs by managing runtime of high efficiency systems versus lower efficiency systems while still maintaining space temperatures.

Moving Forward

According to the Pacific Northwest National Laboratory, over half (55%) of the energy consumption in buildings less than 50,000 square feet is from HVAC equipment.

The CBEI MIMO predictive control and building RTU optimization algorithm is in the validation stage of development. During this time, the algorithm is being shared with prospective market players to develop business models.

Further exploration of low cost optimization techniques is being considered including:

- Using a single building level addressable current transformer (<$200) in conjunction with individual RTU operational sequence and space temperature to determine RTU efficiency for optimization.
- Using RTU design data and predetermined performance degradation curve to approximate RTU efficiency.
- Using RTU control system data to wirelessly transmit efficiency information through a low cost wireless transmitter.

The CBEI MIMO predictive control and building RTU optimization algorithm is in validation mode and early stage product development discussions. Additional stakeholders will be sought out and provided with a new understanding of the "art of the possible" with respect to gaining control of the buildings and saving energy. In particular, CBEI is planning to work with utilities, public utility commissions, and state and local energy officials to understand this new and cost effective means of delivering energy efficiency.

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