Going Big on Small Buildings: Spotlight on efforts to improve controls for packaged rooftop HVAC units

Eliot Crowe, Nora Hart, John House, Lawrence Berkeley National Laboratory

ABSTRACT

Commercial buildings with a floor area under 50,000 square feet comprise 95% of commercial buildings in the United States, representing almost half of all commercial buildings' energy use. These buildings are typically underserved in terms of energy efficiency programs and are far more likely to be located in rural and disadvantaged communities, when compared with larger commercial buildings.

The past decade has seen significant growth in the array of smart, innovative control technology options available for small to medium buildings, but currently, only 13% of buildings under 50,000 square feet have a building automation system installed. With expected 10% - 20% savings from installing controls, this represents a technical potential of 39 million tons reduction in U.S. greenhouse gas emissions, while simultaneously improving energy affordability for small business owners in disadvantaged communities and improving occupant comfort. Improved controls also enable more advanced performance analysis and building-grid integration.

In this paper, we report on a small building controls needs assessment and recent outcomes of a national owner engagement program designed to accelerate control deployment in existing commercial buildings. The program offers technical assistance, recognizes exemplary control installations, gathers cost/benefit data at scale, and develops resources. We will describe two resources developed under the program to help building owners understand the landscape of current offerings, define their needs, and ultimately select a control product. Lessons learned from these efforts will equip stakeholders such as control vendors, utilities, building owners, and HVAC contractors to equitably scale up building decarbonization.

Introduction

Commercial buildings with floor area of 50,000 square feet or less comprise 95% of the U.S commercial building stock, and 45% of commercial buildings' energy consumption (CBECS 2023). Only 5% of these buildings have smart thermostats, and only 13% have a building automation system (BAS). The combination of relatively low energy bills (compared to large commercial buildings) and typical lack of onsite operations management staff results in significant underinvestment in HVAC controls and maintenance for these smaller buildings. While there has been no large-scale study on the potential energy savings of improved HVAC controls in small commercial buildings, there is a growing collection of case studies and limited-scale reporting that indicates savings of 10% - 20% could be reasonably expected if improved controls were deployed at scale (Table 1 summarizes example study results). This savings assumption, if applied to the portion of U.S. buildings under 50,000 sq.ft. without a BAS, represents the technical potential for a 39 million tons reduction in U.S. greenhouse gas emissions.

Table 1. Example studies on energy savings from small building control improvements

Title / Date	**Summary Results**
Improving Operating Efficiency of Packaged Air Conditioners and Heat Pumps (PNNL 2014)	EnergyPlus simulation study of advanced control strategies for packaged rooftop HVAC units (RTUs) found that multispeed supply fan control combined with DCV resulted in HVAC energy savings (fan electricity energy consumption, cooling electricity energy consumption, and heating gas energy consumption) of 24% to 35% across four building types and 16 locations.
A Low-cost Centralized HVAC Control System Solution for Energy Savings, Load Shedding, and Improved Maintenance (UC Davis 2022)	Implementation of SWARM at UC Davis has resulted in whole building energy savings ranging from -2% to 52 %, with a median savings of 28%.
Small- and Medium-Sized Commercial Building Monitoring and Controls Needs: A Scoping Study (PNNL 2012)	Case study of a controls upgrade for a 20,000 sq.ft. building. Whole-building energy savings of approximately 22% were estimated using empirical models of pre- and post-upgrade building energy use.
Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction (PNNL 2017)	A simulation study was performed using Energy Plus to evaluate the energy savings that could be achieved through various energy efficiency measures (EEMs) implemented in the control system. National savings of 11% ("efficient") to 48% ("inefficient") were found for stand-alone retail buildings, and 4% ("efficient") to 31% ("inefficient") for strip mall retail buildings.
Deep Savings for Small Commercial Direct Install: A Replicable Model for High Volume, Cost Effective Energy Savings (NBI 2016)	By installing highly efficient equipment, addressing multiple measure types, and identifying as many energy savings opportunities as possible, SMUD's Complete Energy Solutions (CES) program was able to reduce customers' total electrical kWh consumption by 19% over baseline.
Small Commercial EMS Scaled Field Placement (kW Engineering 2015)	The study presents the results of the energy performance of small commercial buildings after the installation of a new energy management system (EMS). The mean HVAC energy savings achieved was 18% based on 9 buildings, primarily due to scheduling changes (more unoccupied hours) and setpoint adjustments (higher cooling setpoints and lower heating setpoints).
Scaled Deployment of Advanced Rooftop Unit (RTU) Controls in New York State (Final Report)(Energy Solutions 2019)	Report describes the energy savings achieved through the field deployment of the CATALYST advanced rooftop controller. Average RTU electricity savings of 35% were achieved across 186 units at 24 sites, and 75% of all units achieved at least 30% electricity savings per RTU.

Scaled deployment of improved controls in large commercial buildings has increased pace over the past two decades, and significant energy reduction potential still exists. However, these buildings only comprise just over half of U.S. commercial buildings' energy consumption. In order to meet aggressive national emission reduction goals, increased adoption of improved controls for small to medium buildings comprising 'the other half' of U.S. commercial building energy consumption must be a priority. In this paper, we describe the research underpinning an ongoing effort to increase controls adoption and improve operation in small and medium

commercial buildings (The “Smarter Small Buildings Campaign”). We also describe a resource which categorizes RTU control technology offerings available on the market today along with product selection guidance for small/medium building owners.

Small Building Controls Needs Assessment

In 2016 the U.S. Department of Energy launched the Smart Energy Analytics Campaign, a public-private partnership effort to increase deployment of smart building analytics technologies. The five-year Campaign offered technical assistance, resources, and recognition opportunities to commercial building owners installing energy management & information systems (EMIS) (Kramer 2020). The Campaign did not exclude smaller buildings by definition, but the nature and complexity of most EMIS resulted in the majority of Campaign participants representing large buildings with complex HVAC systems. In 2021 it was proposed to explore the feasibility of a similar Campaign targeted specifically at controls/analytics upgrades in smaller buildings.

As a precursor to developing a small building controls campaign we conducted a needs assessment to gain an initial understanding of the barriers to the installation of controls in small to medium buildings. The needs assessment included a literature review and industry stakeholder phone interviews. Through the needs assessment we reviewed 37 publications and conducted 18 phone interviews (control technology vendors, HVAC contractors, and other industry stakeholders). Table 2 summarizes key challenges and opportunities synthesized from needs assessment literature review and phone interviews. The results of the needs assessment were used to inform the development of the campaign as described in the next section.

Table 2. Summary of key challenges and opportunities relating to increased deployment of small building controls

Challenges	**Opportunities**
- Challenging to sell to smaller portfolios (e.g., <25 sites) - Corporate management more effective prospect than franchisees	- Partner with larger portfolio owners / national accounts - Identify regional partners to support smaller portfolios
- Owner lack of awareness/motivation to reduce energy use - Challenging for small organizations to get beyond pilot stage and deploy at a broader scale, as pilots can be higher cost, and results can vary widely based on the pilot site conditions	- Focus on selling comfort, IAQ, & reliability - Gather data to demonstrate overall benefits when deployed at broader scale (to even out site-to-site variation)
- Selling technology is hard; getting people to use it effectively is even harder	- Technology classification guidance - Raise awareness of benefits - Develop best practice implementation guidance for owners and contractors
- Utility programs can help (cash incentives) or hinder (changing requirements, distorting market)	- Engage utility partners to promote more consistent approaches to programs - Develop standardized product specs, advise on Qualified Product List approach

- HVAC service contracting firms' ability to manage technician time through varying seasonal demands	- Document benefits of remotely assessing HVAC performance for HVAC contractor resource planning; develop & develop Key Performance Indicators
- New technicians' skills/experience do not match up to those retiring	- Include simple solutions in the suite of offerings - Engage with educational institutions
- Perceived contractor job security risk from adding analytics & advanced controls	- Success stories on HVAC contractor firms who have embraced RTU controls/analytics
- Small owners very hard to reach	- Explore potential to support utility programs / trade ally networks through resource & spec development.
-Underserved / Energy Equity and Environmental Justice commercial sector hard to target, partly due to lack of definitions of what constitutes a disadvantaged business/building	- Seek collaboration with existing equity focused program efforts Contract with community-based organizations (CBOs) to support EEEJ-focused demonstration & awareness-raising efforts Partnership & outreach through Historically Black Colleges and Universities (HBCUs) and Community Colleges

Smarter Small Buildings Campaign Overview and Status

In 2023 the U.S. DOE launched the Smarter Small Buildings Campaign (https://smartersmallbuildings.lbl.gov/). The Smarter Small Buildings Campaign (Campaign) is designed to help building owners improve energy performance and occupant comfort through improved HVAC control and monitoring. The Campaign directly interacts with building owners (Campaign "participants"), and partners with industry organizations such as control technology vendors, utilities, and HVAC contractors to promote scaled deployment of improved small/medium building RTU controls.

The Campaign is a multi-year effort (no end date defined), and as of May 2024 has enrolled 30 building owners (participants) and 71 industry partners. Participants represent a diverse set of building/owner types, including K-12 schools, retail chains, universities, county government, state agencies, and other organization types. Almost half (32) of the industry partners are technology vendors, largely because a key early Campaign activity was to research and demystify the wide array of available RTU control technology options. The partner list also includes 4 utilities and 14 HVAC contractors. The "Other Partners" list (21) includes third party utility program implementers, regional energy efficiency organizations (REEOs), industry trade associations, and other organizations.

The Campaign developed a simple framework to communicate three general levels of functionality available to building owners beyond the use of standalone non-communicating thermostats (considered the status quo in most cases) for small buildings, as shown in Figure 1.

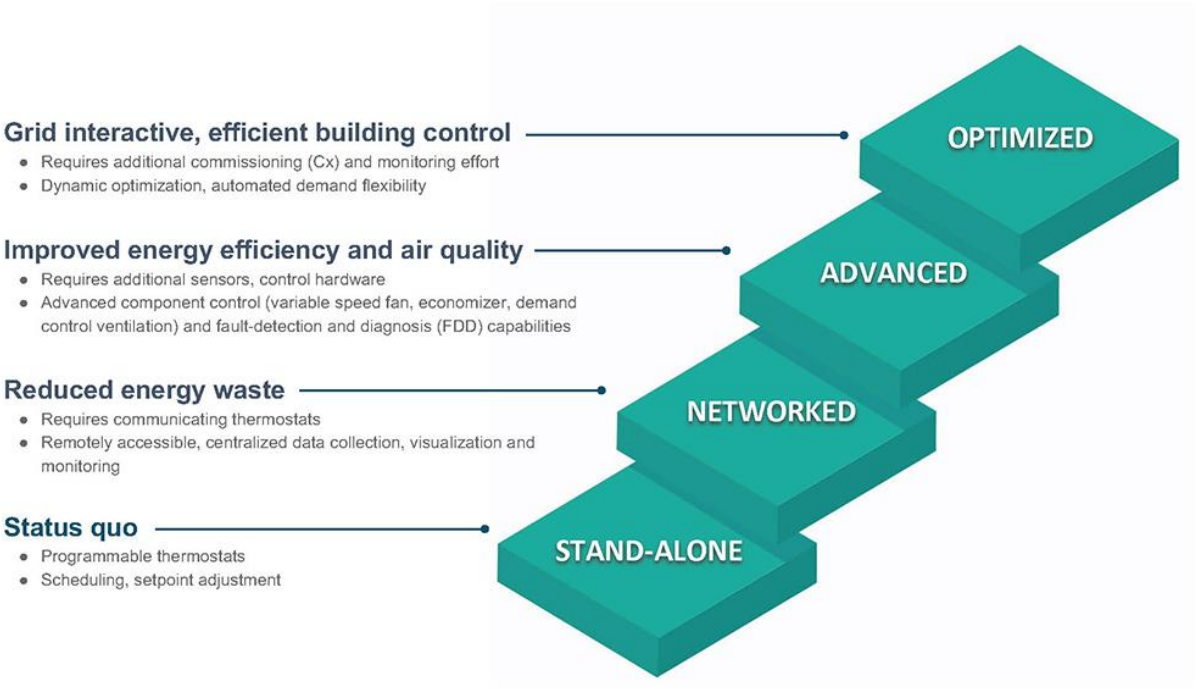

Figure 1. Control functionality levels available for RTU-equipped commercial buildings

The control functionality 'steps' shown in Figure 1 (beyond stand-alone) represent incrementally increasing levels of benefits, cost, complexity, and effort to configure and operate, and a building owner may choose an option based on their unique needs and resources. The step up from Stand-Alone to Networked control presents significant benefits by simply assuring that HVAC schedules and space temperature setpoints are correct and maintained.

Campaign participants, once enrolled, receive one-on-one technical assistance (TA) over an extended period (1+ years) to help alleviate the challenges that can derail implementation and best practice operations. Examples of TA offered to Campaign participants to date includes:

- Assistance with best practices for data collection and analytics
- Support selecting a product by providing feedback on vendor questionnaire
- Attending vendor demonstrations and providing suggestions on additional questions for clarification
- Facilitation of peer exchange calls for participants experienced with controls implementation to share lessons learned with participants early on in the process
- Development of a product specification document for an owner to set minimum requirements for any replacement thermostats/controls for RTUs

The majority of TA support to date has been on the early stages of implementation, such as defining internal requirements, gaining buy-in from internal stakeholders, and in supporting the owner's outreach to technology vendors to get product information (the Campaign is technology-agnostic and does not make any endorsements of recommendations on specific products). The following section describes two resources that resulted from the Campaign to date: RTU Controls Categorization, and Product Selection Guidance. Future resources of the

Campaign will focus on best practice operations to support owners that already have controls installed.

Collecting data from participants on cost of controls and operational savings along with recognizing participants in various categories (innovation, impact, O&M best practices, and equity) is integral to the Campaign design, but at the time of writing this paper we have not completed a data collection or recognition cycle. Representative examples of recognition from a prior campaign resulted in 24 case studies (U.S. DOE 2020) and a 'showcase' report summarizing recognition highlights (Crowe 2020). Currently the Smarter Small Buildings Campaign website (Berkeley Lab 2023) features two success stories based on University of California, Davis' successful "SWARM" program that has added networked/advanced RTU controls across over 100 small buildings (Fauchier-Magnan 2022). Additional case studies will be developed throughout the Campaign.

RTU Controls Categorization and Product Selection Guidance

A critical early objective of the Smarter Small Buildings Campaign was to categorize the range of solutions offered by vendors for RTU controls as this could apply to 42% of the buildings below 50,000 sq. ft. (CBECS 2023). Vendors tend to offer multiple solutions and configuration options that result in different capabilities. Understanding product differences and being able to conduct technology research is a significant challenge faced by small building owners with limited resources. In contrast to the functionality options illustrated in Figure 1, the product categorization research was oriented around the different means of achieving those functional objectives; for example, certain products may offer advanced control functionality for single-zone RTUs that is not applicable to multi-zone RTU applications.

Through a series of calls with technology vendors and a detailed spreadsheet-based survey, we gathered information on technology capabilities from vendors. Based on this detailed information we developed four high level technology categories, iterated based on internal review and external feedback from technology vendors. When reaching out to technology vendors we explained the classification scheme and which category their product would fall under (allowing for a single product to meet the criteria for multiple categories). The final technology classification is shown in Table 3.

Table 3. RTU control product categorization description

Product Categories	**Criteria**
Networked Thermostatic Control	Solution uses networked thermostats communicating to a software platform to enable remote access, monitoring, and control (e.g., setpoint and schedule changes) of multiple single-zone RTUs from one or more buildings through a single interface of a web or mobile app.
Advanced RTU Control	Solution adds control capability that enhances RTU energy efficiency, reduces electrical demand, and/or improves occupant well-being. Examples are demand controlled ventilation, economizer control, variable speed fan control, and dynamic multi-unit coordination. These capabilities can be implemented through the addition of hardware components (e.g., controllers, actuators, sensors) and associated software, or through software alone. Solution also enables remote

	monitoring of multiple RTUs from one or more buildings through a single interface of a web or mobile app.
Light Commercial BAS - Integrates with Multiple-Zone HVAC Systems	Solution provides Advanced RTU Control and can integrate and control more complex HVAC equipment and systems such as RTUs with VAV distribution systems.
Light Commercial BAS - Integrates with Other Energy End Uses	Solution provides Advanced RTU Control and can integrate and monitor other energy end uses and provide on/off control of lighting, pumps, fans, and other equipment.

To date 26 RTU control products have been classified under the criteria shown in Table 3, and are posted on the Campaign website. This information is provided for illustrative purposes and does not constitute an "approved" list of products. We will continue to collaborate with technology vendors and add to the product list.

A related area of research has led to the development of product selection guidance for building owners to use when establishing their operational needs and in requesting proposals from technology vendors. The guidance can also be found on the Campaign website, and covers the following key considerations:

- **Control Capabilities**: What control capabilities does the product offer and what hardware is required?
    - Centralized monitoring of zone temperatures, setpoints, schedules, equipment status, and critical alarms
    - Centralized adjustment of setpoints and schedules
    - Centralized data collection and visualization (multi-building and multi-site)
    - Remote access and configuration
    - Variable speed fan control
    - Economizer control
    - Demand-controlled ventilation
    - Optimal start/stop
    - Automated grid-responsive strategies (e.g., load shedding and shifting)
    - Coordination of units to limit peak demand

- **Accessibility:** Will users be able to access devices through a web-based platform and / or a mobile interface or app?
- **Scalability:** Is there a limit to how many building sites can be accessed through the central interface?
- **Compatibility:** Can the control components be integrated with components from another manufacturer? For instance, can thermostats be accessed via an open protocol such as BACnet? Can data be accessed via a web API? Will this control solution work for the full range of HVAC systems and other energy end uses in my building(s)?

- **Trending:** How far back are historical data stored? Are there subscription options to increase this? Can historical data be viewed directly through the user interface?
- **Analytics:** Does the product provide fault detection & diagnostics (FDD) or other analytical capabilities? Can the product provide feedback of equipment status and operating parameters such as fan status or status of heating/cooling stages?
- **Ongoing Services:** Does the manufacturer or vendor of the product also offer services such as remote monitoring, periodic performance reporting, etc.? Are there subscriptions that are required with the product, or that provide enhancements to the base offering?
- **Delivery Model:** Who sells the control solution, and who installs and services it?
- **Cost Implications:** Does the product fall under utility rebates in my jurisdiction? Is there a cost for additional users? What is the cost of data storage?

Product selection guidance is designed as a tool for owners to determine their needs and communicate with tool vendors, as opposed to being a recommend set of minimum performance criteria.

Conclusions and Next Steps

Small-to-medium commercial buildings comprise the vast majority of the U.S. commercial building stock. Improved HVAC controls for these buildings has the potential to cut energy waste by 10% - 20% and improve occupant comfort. A wide array of control technology solutions exist, but scaled deployment faces many challenges. The Smarter Small Buildings Campaign, launched in 2023, is a multi-year effort targeted at addressing some of those challenges, through development of best practice guidance and resources, recognition of owners' implementation successes, the gathering and reporting of participant's costs and benefits, and through broad industry partnerships. Resources developed to date by the Campaign include a product categorization matrix and product selection guidance, to address a need for owners to understand the array of options available and to make informed choices based on their needs.

Beyond the Campaign, complementary industry efforts may include utility programs and financing, broader adoption of building performance standards, and training for building operators and HVAC contractors.

Acknowledgements

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Office, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

References

Adams, Josiah, Alexi Miller, Cathy Higgins. 2016. "Deep Savings for Small Commercial Direct Install: A Replicable Model for High Volume, Cost Effective Energy Savings." 2016 ACEEE Summer Study on Energy Efficiency in Buildings.

Berkeley Lab. 2023. Smarter Small Buildings Campaign website. https://smartersmallbuildings.lbl.gov/

Crowe, Eliot, Hannah Kramer, Jessica Granderson. 2020. “EMIS Applications Showcase.” Lawrence Berkeley National Laboratory. https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/EMIS_Showcase_2020oct8_Final.pdf

Fauchier-Magnan, Nicolas, Joshua Morejohn, Marco Pritoni. 2022. “A Low-cost Centralized HVAC Control System Solution for Energy Savings, Load Shedding, and Improved Maintenance.” 2022 ACEEE Summer Study on Energy Efficiency in Buildings.

Fernandez, N., et al. 2017. “Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction.” Pacific Northwest National Laboratory.

Gartland, Lisa, Peter Pollard, Magdalena Brum. 2015. “Small Commercial EMS Scaled Field Placement.” Pacific Gas & Electric.

Katipamula, Srinivas, et al. 2012. “Small- and Medium-Sized Commercial Building Monitoring and Controls Needs: A Scoping Study.” Pacific Northwest National Laboratory.

Katipamula, Srinivas, Weimin Wang, Mira Vowles. 2014. “Improving Operating Efficiency of Packaged Air Conditioners and Heat Pumps.” Pacific Northwest National Laboratory.

Kisch, Teddy, et al. 2019. “Scaled Deployment of Advanced Rooftop Unit (RTU) Controls in New York State (Final Report).” Energy Solutions.

Kramer, Hannah, Claire Curtin, Guanjing Lin, Eliot Crowe, Jessica Granderson. 2020. “Proving the Business Case for Building Analytics.” Lawrence Berkeley National Laboratory.

United States Energy Information Administration. 2023. “2018 Commercial Buildings Energy Consumption Survey final results.” https://www.eia.gov/consumption/commercial/