CONSORTIUM for BUILDING ENERGY INNOVATION

RETROFIT SOLUTIONS for SMALL/MEDIUM COMMERCIAL BUILDINGS

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DIRECTOR'S LETTER

In early 2010, The Pennsylvania State University (Penn State) developed a collaborative that included more than 20 academic institutions, private sector companies, and economic development agencies focused on transforming the marketplace for energy retrofits in buildings.

This collaborative, which has become the Consortium for Building Energy Innovation (CBEI), was built on existing collaborations that had been established by regional leaders. It also leveraged Penn State energy technology presence in the Philadelphia area through GridStar, a smart grid education and research center, and the Mid-Atlantic Combined Heat and Power Technical Assistance Partnership, both located at The Navy Yard (TNY). When the U.S. Department of Energy (DOE) released its Funding Opportunity Announcement to establish a regional innovation cluster and hub for energy efficiency in buildings, Penn State and its partners were well-positioned to successfully respond.

CBEI's mission is to provide energy efficiency solutions specifically for small and medium commercial building retrofits. Compared to the large commercial buildings market, the smaller building market typically is underserved, includes owners with less knowledge about managing building energy use, and is served by retrofit providers that may not be as specialized. Solutions in this space need to be simple to implement for the owner and the service provider and must have trusted performance. Creating simple solutions that are often integrated packages of technologies and behavioral changes requires a multidisciplinary development approach, which CBEI was designed to provide. CBEI also recognized and emphasized the importance of engaging a broader community and providing education for the entire commercial buildings workforce on how to make these solutions work.

To address these challenges, CBEI engaged with the market and involved all relevant stakeholders to ensure solutions meet their individual needs and that there is trust and buy-in that will strengthen implementation. Over the last five years CBEI has created and simplified design tools; developed prescriptive packages of technologies, including sensors and controls; worked with portfolio owners, utilities, and code developers to create solutions to better understand and manage the energy use in a building portfolio; and created multiple tools and programs that improve the competency of the entire workforce. CBEI developed and tested these approaches in the greater Philadelphia region and has worked with national collaborators to scale these solutions across the country.

Penn State is proud of CBEI's accomplishments over the last five years to advance energy efficiency in an underserved market. This report summarizes the challenges and impacts of this work. However, this is not the end of the journey. Penn State and the other CBEI partners are dedicated to furthering the work described here to continue to reduce the energy use and operating costs for commercial building owners, support regional efforts to curb greenhouse gas emissions, and create a smarter and more efficient buildings workforce.

I would like to thank all the CBEI member organizations, their staff, and our collaboration partners for helping to create lasting solutions for commercial building retrofits.

Martha Krebs, *Director, CBEI*

EXECUTIVE SUMMARY

CBEI was established to develop energy efficiency solutions for the small and medium commercial building market with a focus on buildings less than 50,000 square feet. This market has traditionally been underserved by the energy efficiency industry, which has focused on larger commercial buildings where the scale of an individual retrofit lends itself to the use of sophisticated modeling tools and more advanced solutions. Owners/operators and retrofit providers for larger buildings have a greater level of understanding of and experience with different solutions. In contrast, smaller commercial building retrofits, like residential retrofits, often have owners with less knowledge about energy management and less time to learn about it. This market segment is also served by retrofit providers that are smaller and often focused on particular building systems, e.g. heating, ventilation and air conditioning (HVAC), lighting, roofing, or insulation. The size of a smaller commercial building retrofit does not lend itself, from a cost perspective, to the application of multiple, sophisticated design and modeling tools, which means that they are less likely to have integrated solutions.

CBEI approached this segment of the market recognizing several key drivers are needed for success:

MARKET ENGAGEMENT

Implementation of any solution is much more likely if market players (e.g., owners, utilities) are engaged throughout the solution development process. CBEI projects included relevant market stakeholders in each project, and those stakeholders helped shape the research and move solutions into the market.

SYSTEMS INTEGRATION

Utilizing integrated design tools on commercial buildings requires expertise and expense not accessible to small building owners or service providers. Using these design tools, CBEI assembled pre-packaged sets of technologies tailored to small/medium commercial buildings. CBEI focused on creating HVAC packages to address the largest energy use in these buildings and envelope packages to address an area that has suffered from little attention but has long-lasting benefits. CBEI also focused on developing simple operational solutions, such as integrated sensors and controls that keep the building systems operating more efficiently with little or no involvement by the owners.

REAL-WORLD DEMONSTRATIONS

Solutions will only be implemented if the market has confidence that they will work outside of a laboratory environment. CBEI performed demonstrations in a large suite of operating buildings to ensure solutions worked as expected given the complex realities of day-to-day operational situations.

COMMERCIALIZATION

In addition to having deployment partners for new solutions, CBEI also provided support to new technology developers to help them develop and implement business models that would get them traction in the market.

CBEI produced numerous solutions over the last five years. The work can generally be grouped into four categories: solutions to make integrated design and delivery easier and more complete, packages of technologies that in combination result in greater energy reduction, solutions that can be applied on a portfolio-wide basis, and tools and training materials to enhance the energy efficiency competencies of the workforce. A sampling of solutions and their impacts is provided below.

When CBEI was established five years ago, little was known about the needs of the existing small/medium commercial building market. Over the past five years, CBEI has developed a robust understanding of the needs of this market and solutions to help this market segment make significant progress in energy and greenhouse gas reductions. CBEI has demonstrated the power of combining the strengths of capabilities from academia, the private sector, and economic development organizations to provide regional solutions that can scale nationally. Additionally, CBEI has shown how bringing together market players (such as owners/operators, service providers, utilities, regulatory agencies, nonprofits, and financial institutions) can build an ecosystem to develop and implement solutions more likely to succeed. Lastly, CBEI found that education and career development for professional and technical workers is critical for achieving initial, deep energy savings as well as for sustaining the savings.

While much progress has been made, substantial opportunities to improve efficiency in this market space remain. Very simple integrated design tools that can be applied in the field need to be developed to make them cost-effective to use in smaller commercial building retrofits. Robust demonstrations of technology packages in different climate zones would allow incentive programs to create new initiatives and the finance industry to be more comfortable with lending. Analytical tools are needed to take advantage of the increasing availability of building energy use data so that portfolio owners/operators can better manage their building stock, and additional training solutions targeted at those working on small/medium building retrofits are necessary to achieve greater impact in this market segment.

EXAMPLES OF SOLUTIONS AND IMPACT

Integrated Design

3 new modules developed for and embedded in the OpenStudio, EnergyPlus, and Radiance modeling suite; BIM Datahub created to allow seamless sharing of data between design and modeling software tools.

Technology Packages

20+ technology packages developed, achieving 10%-50% system savings; 2 new control/automated fault detection and diagnostics technologies developed and demonstrated, achieving 10%-20% HVAC savings and on the path to commercialization.

Portfolio Solutions

8 approaches/guides and 2 tools developed and/or demonstrated to improve portfolio energy transparency, management, and benchmarking in collaboration with 17 utilities, 21 cities/regional governments, and 27 portfolio owners/tenants.

Workforce Development

Career development paths for 4 key job types developed in collaboration with the Department of Labor and professional associations for deployment; 4 training programs developed/expanded and piloted, and 2 certificate programs developed, all are on the path for national deployment.

MISSION

Develop, demonstrate, and deploy technology systems and market pathways that permit early progress (20-30% energy use reductions) in small/medium commercial buildings.

VISION

By 2030, deep energy retrofits will reduce energy use by 50% in existing small/medium buildings, which are less than 250,000 square feet.

CBEI

The CBEI partnership was developed in response to a Funding Opportunity Announcement (FOA) in 2010 jointly published by the U.S. Department of Energy, U.S. Department of Commerce's Economic Development Administration and National Institute of Standards and Technology/Manufacturing Extension Partnership, U.S. Department of Labor, U.S. Department of Education, Small Business Administration, and National Science Foundation.

The FOA called for the establishment of a consortium to develop, expand, and commercialize innovative energy efficient building systems technologies, designs, and best practices in a regional setting for national and international deployment.

In the early years of the partnership, CBEI was also referred to as the Greater Philadelphia Innovation Cluster (GPIC) and the Energy Efficient Buildings Hub (EEB Hub).

PARTNERS

Universities

- Penn State
- Carnegie Mellon University
- Drexel University
- Morgan State University
- NJIT New Jersey Institute of Technology
- Penn University of Pennsylvania
- Purdue University
- Rutgers
- Virginia Tech Invent the Future

Industry

- covestro
- United Technologies Research Center

Economic Development

- Ben Franklin Technology PArtners Southeastern Pennsylvania
- DVIRC
- PIDC

FORMER PARTNERS

- Balfour Beatty
- Collegiate Consortium
- IBM
- Lawrence Livermore National Laboratory
- Massachusetts Institute of Technology
- Pennsylvania College of Technology
- PPG
- Project Based Learning, Inc.
- Princeton University
- University City Science Center
- University of Pittsburgh

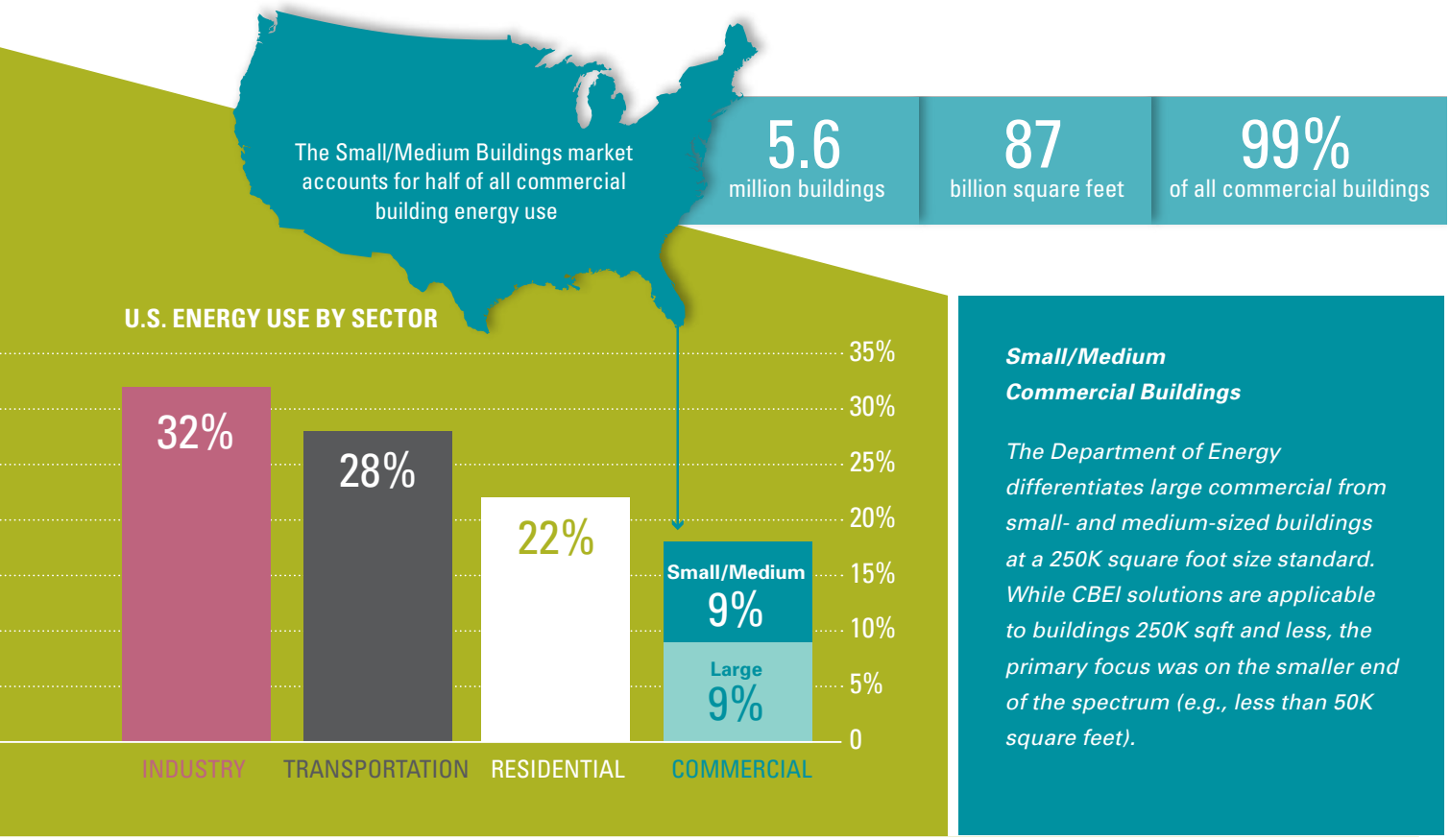
Challenges for Small/Medium Commercial Buildings

This market accounts for 99% of all existing commercial buildings and approximately half of all commercial building energy use.

This underserved market is challenging to reach because there are so many individual owners and the market is fragmented. The owners are often small businesses focused on business growth, and they lack in-house expertise to manage energy use and plan for energy efficiency improvements. However, energy generally accounts for a larger fraction of their operating expenses than for large commercial building owners. Building operational and equipment improvements are smaller in scope than for large commercial buildings, and therefore are often serviced by providers that are smaller and less likely to provide integrated, full-service solutions.

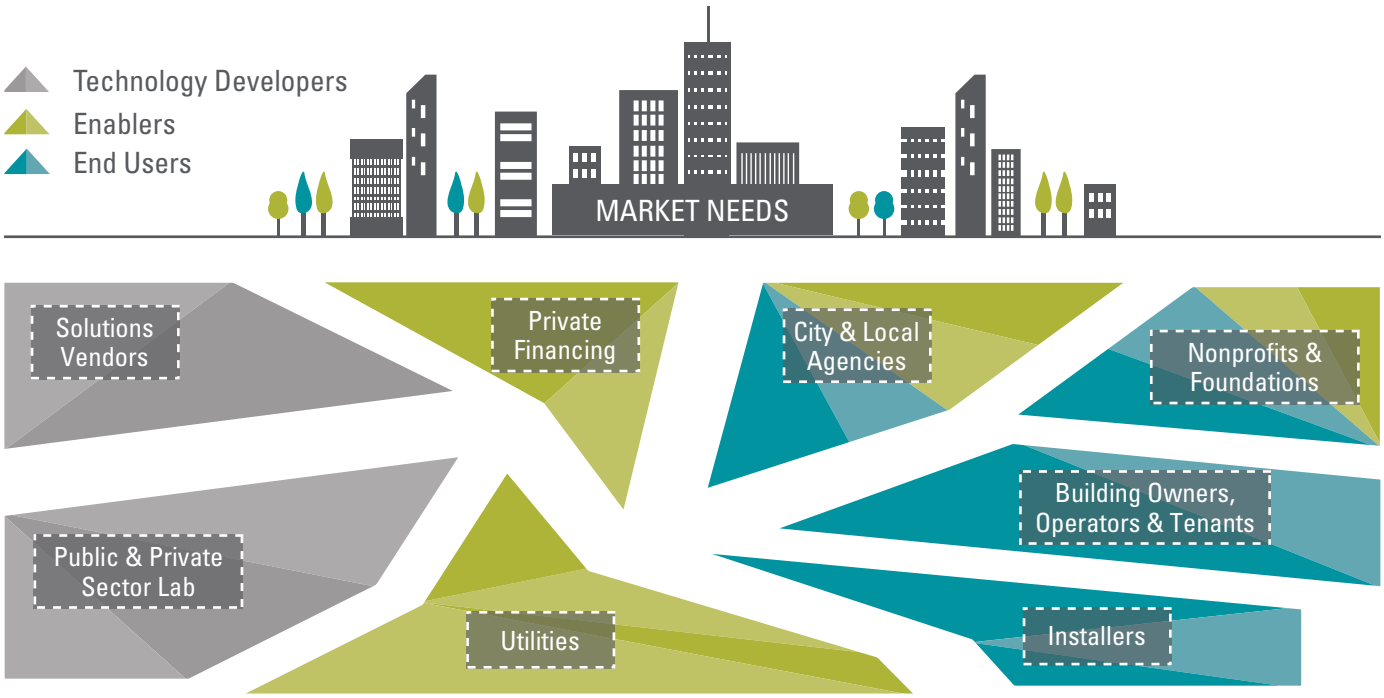
Energy use improvements for buildings are more likely to be adopted if solutions are simple to implement. One simplifying approach is to have pre-proven technology packages for common building types and uses, making retrofits more standard and therefore less costly. This market sector is also better served by having automated solutions for detecting when systems are not operating properly and adjusting their operation to improve energy use.

While building-level solutions are needed for this market sector, there are stakeholders in the market — primarily cities, states, and utilities — that have a strong influence on energy use in buildings this size. They influence or drive retrofits through carrots such as financial incentives for retrofits or sticks such as regulatory actions (e.g., building codes).



Small/Medium Commercial Buildings

The Department of Energy differentiates large commercial from small- and medium-sized buildings at a 250K square foot size standard. While CBEI solutions are applicable to buildings 250K sqft and less, the primary focus was on the smaller end of the spectrum (e.g., less than 50K square feet).



Associations and other nonprofits and economic development agencies also are influential as trusted, independent entities that have non-energy missions but recognize the value that energy efficiency can have to smaller commercial building owners, such as how reducing energy costs can make regions more competitive. However, this diverse set of stakeholders is fragmented, often working in silos, even though they have similar goals.

Adding to the challenge for retrofits in this market sector is the uneven level of understanding and awareness about energy efficiency solutions among all stakeholders — from the technicians performing the work to the building owners paying for services, to city or utility staff developing incentives, to those involved in real estate transactions. Education and training tailored to the roles of the individual stakeholders is essential to improving the number and quality of retrofits.

The CBEI partnership was established to create solutions to address these critical gaps in the market and to develop solutions at a building and regional level, which can be pushed out nationally with the support of market partners.

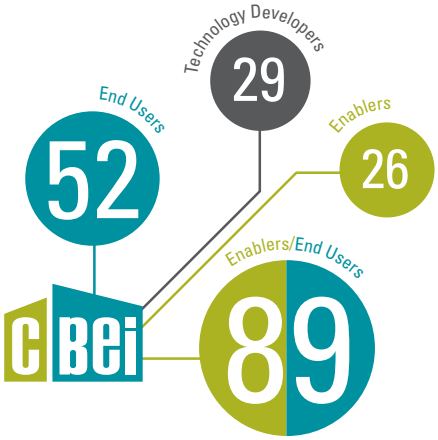
Market-oriented Approach

Taking a new energy efficiency solution from a concept to a common practice in the market is challenging. Too often the concept is formed — and developed — without input from the market on how the solution can best meet individual stakeholder needs. New solutions also often lack proof that they will work in a real world setting and not just a laboratory or controlled pilot setting, which adds risk — or perceived risk — for solution implementation.

CBEI's membership and approach to solution development, deployment, and commercialization was designed specifically to overcome these challenges. The partnership of world-class university research institutions, technology developers, and economic development agencies brings a diverse set of capabilities and perspectives that CBEI integrates into innovative systems solutions for the commercial buildings market. CBEI's research approach is based on overcoming the fragmentation in the market by continuously engaging with a diverse set of stakeholders to develop easily implemented solutions.

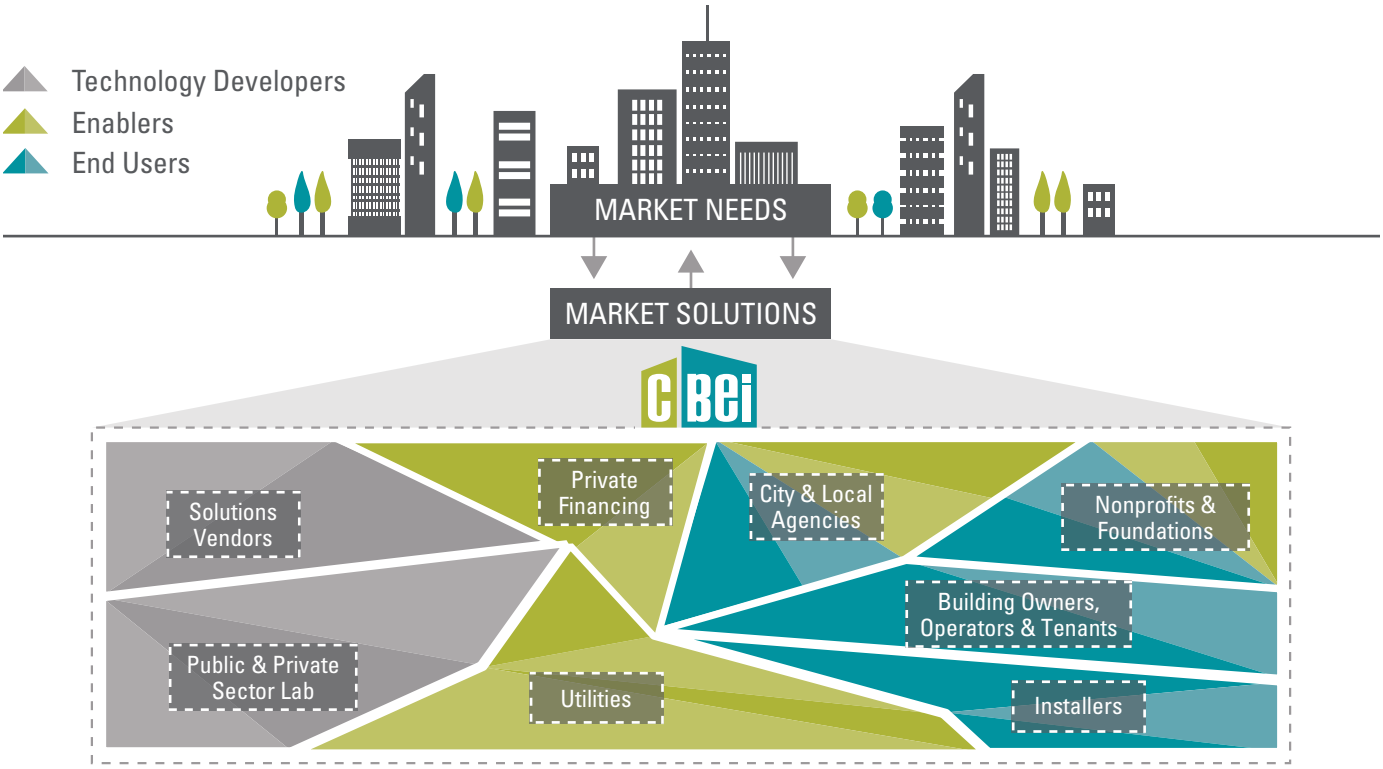
STAKEHOLDER INVOLVEMENT

In the last two years, CBEI projects engaged with 196 stakeholder groups.



MARKET ENGAGEMENT

CBEI structures its research to ensure continuous market engagement from problem identification through solution deployment and commercialization. Researchers draw on the extensive market networks of the Consortium partners to identify and engage before, during, and after each project. This allows solutions to be shaped by input from critical users of the solutions, including building owners and operators, tenants, retrofit service providers, state and local governments, and utilities. Close involvement of these end users ensures that solutions have greater potential for deployment in the market, since the users have helped shape the solution in a way that makes it easier for them to implement. CBEI has had substantial success with market uptake of solutions as a result of this market-oriented approach.



SYSTEMS INTEGRATION

There is no lack of commercially available solutions that can reduce building energy use. What is lacking are the approaches and tools necessary to combine technologies and provide the training and market incentives in a way that maximizes their potential — making the whole stronger than the sum of the parts. CBEI's approach to solutions in the market is to take a systems integration approach, where teams of multidisciplinary researchers — engineers, architects, economists, human factors scientists — work together to identify and test solutions to create combinations that improve building energy performance, indoor environmental quality, and return on investment.

The renovated CBEI headquarters serves as a living laboratory, featuring numerous energy efficient features and systems and built-in monitoring designed to facilitate research in energy efficiency and building-to-grid connectivity.

REAL-WORLD DEMONSTRATIONS

Owners/operators tend to be risk averse. They like using approaches that have been proven to be cost effective in an existing building, where the operating environment is more realistic and not controlled like in a laboratory. Without knowledge about how reliably a solution will perform in a real building, retrofit service providers also are unlikely to recommend a solution. Demonstrations in operating buildings reduce deployment risk. However, real-world demonstrations are difficult to set up and manage, and therefore are not often used to prove performance of newer solutions. Even when real-world demonstrations are utilized, the information is often not readily shared. As a result, newer solutions are harder to get into the market.

CBEI has developed a robust capability for performing real-world demonstrations. The Consortium has performed demonstration activities in 28 commercial buildings, covering a wide range of end uses and sizes. These include testbeds with multi-measure testing capabilities and sites identified for testing specific technology types. All of these buildings are operating for their primary purpose (e.g., restaurant, office, retail), and CBEI has established strong working relationships with the owners/operators to allow for technology demonstrations during business-as-usual for the building owner.

These demonstration sites have been used over the last five years to refine and prove multiple technologies, technology packages, and processes such as advanced controls and diagnostics, building energy systems, and integrative design processes. CBEI develops case studies from the demonstrations and pushes these out through its partner network and industry journals and conferences.

COMMERCIALIZING TECHNOLOGIES

Recognizing the gap in the market for helping new technologies achieve commercial scale, CBEI established a commercialization center, in collaboration with the Department of Energy, Small Business Administration, and National Institute for Science and Technology, Economic Development Administration of the Department of Commerce, and the Commonwealth of Pennsylvania. The CBEI Commercialization Center focuses on supporting commercialization and deployment of advanced energy retrofit-related products and services. The Center provides an integrated suite of programs and services to entrepreneurs and established companies. Services include helping with business plan development, market assessment, connections to design engineering and prototyping firms, marketing, and support to non-local and foreign-based companies to expand into the Philadelphia market.

Developing tools that make it easier to integrate solutions during the retrofit design that cost-effectively reduce energy use and improve occupant health and comfort.

Integrated Design

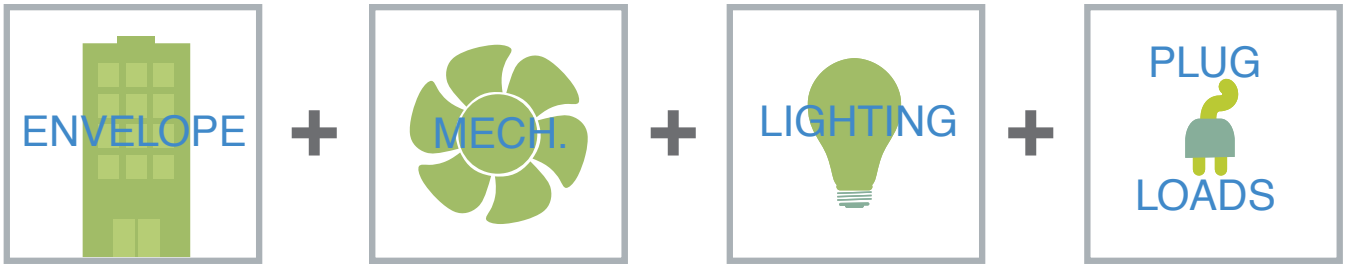
MARKET CHALLENGE

Integrated retrofit design has been shown to provide better value for building owners when they align construction and design impacts across multiple systems. However, the process for achieving an integrated design is not well understood in the commercial building market and currently requires specialized skills to leverage models, many of which do not share information seamlessly. One of the greatest challenges when using building information modeling (BIM), is dealing with multiple file-exchange formats and platforms that lack interoperability. Retrofit teams for smaller projects do not typically have a staff of knowledgeable modelers and design professionals capable of supporting an integrated retrofit project, nor do they have the time or resources to support the use of multiple modeling tools required for implementation.

Regardless of building size, there is also a need to make existing models more robust to handle integrated design and to improve the visualization of modeling data for design teams. While the Department of Energy has developed sophisticated modeling tools (e.g., Energy Plus, OpenStudio, Radiance) that have made integrated design easier, additional functionality is necessary. For example, it is difficult to model lighting design energy performance in a building, taking into account daylighting. Information from the models can be more effectively used by designers if the information is visualized, but few simple visualization tools are available that allow teams to optimize the design and collaborate around shared information.

APPROACH

CBEI researchers conducted a gap analysis of processes and tools currently applied to integrated design to identify specific research focus areas. Three interconnected paths were developed. The first path involved mapping steps across the design process, taking into account multiple system processes and needs. This path identified the need for guidance on how to approach integrated design as well as the need for specific tools that are critical for integrated design. The second path focused on challenges related to the lack of interoperability among BIM tools and a growing demand for additional modules in existing tools. An important part of this path was to support the use of open standards among existing design and analysis tools to better integrate and connect design information. Additionally, CBEI improved the Department of Energy's Airflow Network, EnergyPlus and OpenStudio with additions that better model airflow, daylighting and lighting design, and occupancy. The third path was to improve the ability of design teams to visualize modeling results. The growing availability of three-dimensional modeling tools allows a virtual reality approach to integrated design, which helps identify potential issues before they impact project cost and schedule.



IMPACTS

INTEGRATED PROCESS

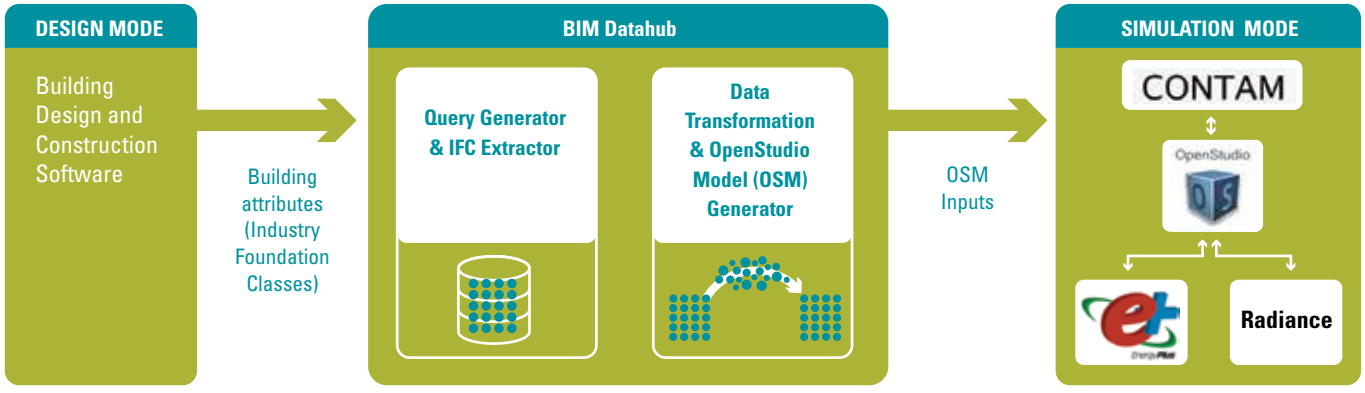
BIM Planning Guide: CBEI researchers delivered a concrete stepping stone for real estate development teams implementing BIM strategy and planning through the life-cycle of a project. The BIM Planning Guide provides a structured procedure for creating and implementing a BIM Project Execution Plan for Energy Retrofits. The BIM Planning Guide provides a five-step structured procedure to facilitate planning and communication among project team members during the early phases of a project. Since the best method for BIM implementation is unique for every project, each team must effectively design a tailored execution plan by understanding the project goals, the project characteristics, and the capabilities of the team. The BIM Planning guide supports the entire life-cycle of a project, including post-construction follow-ups considering measurement, verification, and performance monitoring, enabling maximum long-term benefits. The BIM Planning Guide is available for download at www.cbei.psu.edu.

The Advanced Energy Retrofit Roadmap: CBEI researchers recognized that the market lacks process-based products which offer the architecture, engineering and construction industry a comprehensive action plan for applying Integrated Design principles to advanced energy retrofits in small/medium buildings. The investigators developed a set of step-by-step guidelines and protocols that organizes the design and construction process needed during a retrofit project, geared to building owners, their staff, and the retrofit project team members. The Roadmap consists of a three-tiered suite of guides: The Integrated Design Advanced Energy Retrofit Roadmap Overview; a detailed Retrofit Roadmap Reference Manual; and a set of four Project Team Guides outlining the activities involved in projects at four levels of effort — Lite, Partial, Substantial and Comprehensive. These documents are available at www.cbei.psu.edu.

SIMULATION MODELING & INTEROPERABILITY

BIM Datahub: CBEI researchers developed a database for building information modeling (BIM Datahub) for storage, retrieval, and exchange of standards-based building data to support design tool integration. It serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its lifecycle from inception onward.

BIM removes issues common to both new construction and facility improvement projects, such as questionable communication between team members, difficult visualization of end results, unrealistic user expectations, and post-construction complications. The BIM Datahub makes it possible for design teams to more easily apply BIM in retrofits.



High Performance Computing Tools & Applications: CBEI researchers delivered substantial value to the Department of Energy's suite of tools for building energy modeling (BEM). CBEI developers demonstrated an advanced computational method for simulating the air-flow network and associated energy use in a building. CBEI successfully implemented new structural variables and atmospheric conditions to existing tools, and delivered a capability for accurately assessing design impacts on air-flow based on this implementation of Fast Fluid Dynamic (FFD) modeling. CBEI delivered an optimized module solution for implementation in the Radiance simulation tool. Enhancements to the model enable more informed lighting design and energy savings estimates, when taking into account key design elements such as lighting layouts and daylighting configuration, combined with installed sensing and controls technologies.

This allows the user to maximize energy savings potential based on building design inputs. Enhancements to OpenStudio include the exporting of lighting system and control data to a new Radiance daylighting and electric lighting simulation module and a Building Component Library measure.

CBEI developed a calibrated occupant behavior module for incorporation into EnergyPlus, which delivered an informed feature to simulated occupants' influence on building performance. The inclusion of occupant related data assumptions is important to enhance BEM tool capabilities, as research has proven occupants influence building performance through temperature set-points, schedules, and adaptive behaviors.

ENERGY INFORMATICS & VISUALIZATION

CBEI developed the Immersive Construction Laboratories (ICon Lab) — at TNY with a sister facility at Penn State's main campus in University Park PA — to provide a three-dimensional visualization environment in which groups of up to 40 people can simultaneously participate in integrated design. The ICon Labs serve as a resource for integrated design and can be synced, so that the two systems interact with one another, allowing participants at both sites to be immersed in the same content. The ICon Lab was used to support the design process for CBEI's headquarters design (Building 661 at The Navy Yard). It was used during design review meetings to display the design model of Building 661, review energy modeling results, discuss alternative system options, and use gaming tools to live navigate the building early in the design process. During the design of Building 661's renovation, the highly interactive workspace of the immersive display system allowed the project and research teams to navigate the design and analyze the model at a 1:1 scale. CBEI has developed a guide to interactive workspaces, which can be found at http://interactiveworkspaces.weebly.com.

The ICon Lab spaces were leveraged by more than a dozen project teams, ranging from end-user walk-throughs, to facility management reviews, energy modeling discussions, and simply typical project meetings in which the model was used to facilitate discussions.

Making retrofits easier by identifying combinations of technologies that maximize efficiency and minimize cost and by creating automated sensors and controls to simplify operation.

Technology Packages

MARKET CHALLENGE

Owners and operators of existing commercial buildings are typically capital constrained, risk averse, and have little experience with energy management. They want cost-effective proven solutions when considering an energy upgrade. In many cases, simple upgrades such as lighting replacements have been completed. Other systems such as HVAC systems and the building envelope (windows, walls, doors) have a long product life or require invasive and disruptive action. The ability of service providers or utilities to offer packaged solutions with a reasonable payback period, reliable long-term savings estimates, and an implementation plan would help building owners decide to implement new energy efficient solutions.

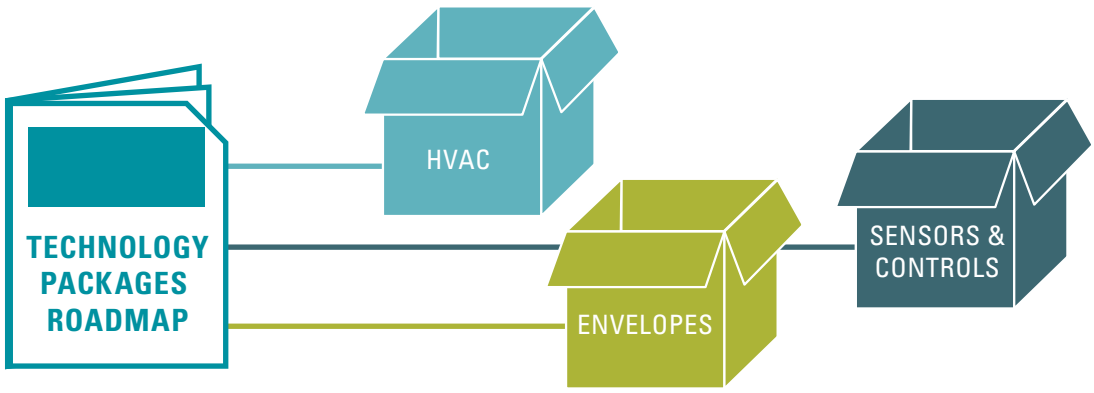
Improved operations in existing buildings through advanced monitoring, controls, and automated diagnostics has the potential to significantly reduce energy use and operational costs with limited investment in hardware. However, this generally requires significant labor costs to engineer and implement site-specific approaches, and the overall economics have not been favorable for many commercial buildings. In order to penetrate this underserved market, automated software solutions are needed that require minimum configuration and can adapt over time to changing equipment performance. Proven packages of technologies and no-touch sensors and controls can be simple and inexpensive solutions for this market, even though developing them can be complicated.

APPROACH

Given the scope and scale of small/medium buildings and the diversity of existing technologies and operational challenges, CBEI started by developing a market characterization and technology roadmap to prioritize opportunities. As a result of these efforts, CBEI determined that the greatest opportunities existed for packages of HVAC technologies, envelope (windows, walls, doors) retrofits, and building operations solutions utilizing sensors and controls.

For the HVAC packages and envelope retrofits, CBEI identified solutions by specific building type and climate zone. To do this, numerous configurations were considered and evaluated using computational modeling as well as input from industry experts. Once solutions were developed, tools and best practice guides were developed to accelerate adoption.

For building operations, CBEI identified the need to increase automation, while minimizing the need for new equipment. Adding automation also generally requires site-specific training of the solution, and CBEI has worked to develop computational approaches that reduce the time and training needed for tailoring the solution to the building. CBEI has focused on developing virtual sensors to reduce the need for physical sensors, controls-oriented models that can be automatically trained using low cost measurements, and embedded approaches for automated fault detection and diagnostics (AFDD). To accomplish this, CBEI also needed to develop virtual testbeds, laboratory test setups, and field demonstration sites to assess solution performance.

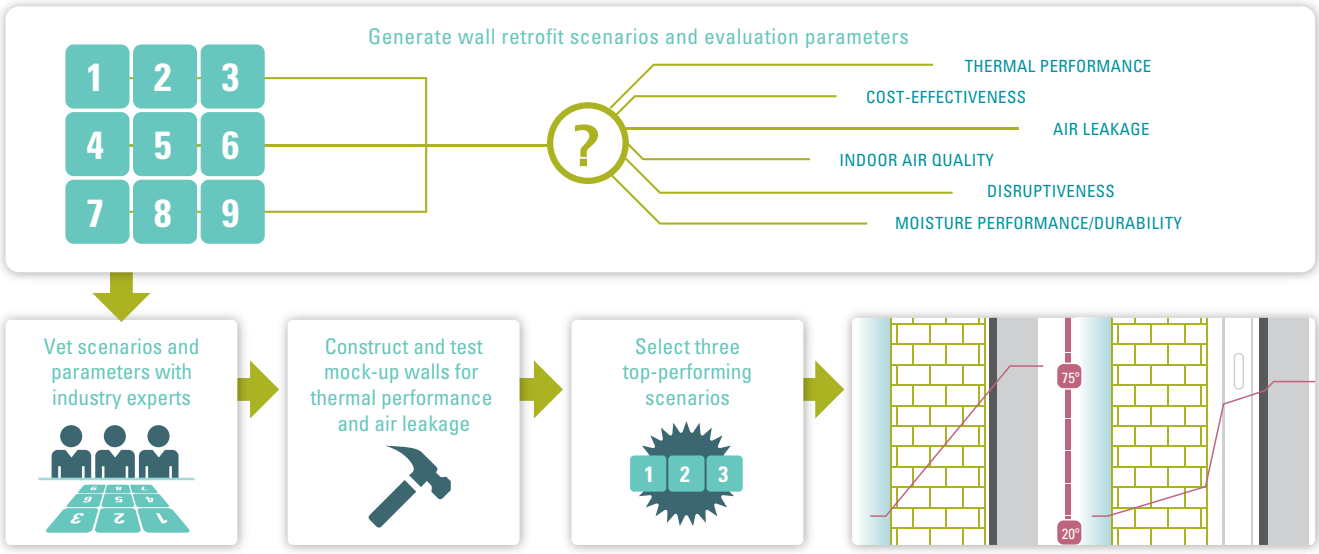


ENVELOPE PACKAGES

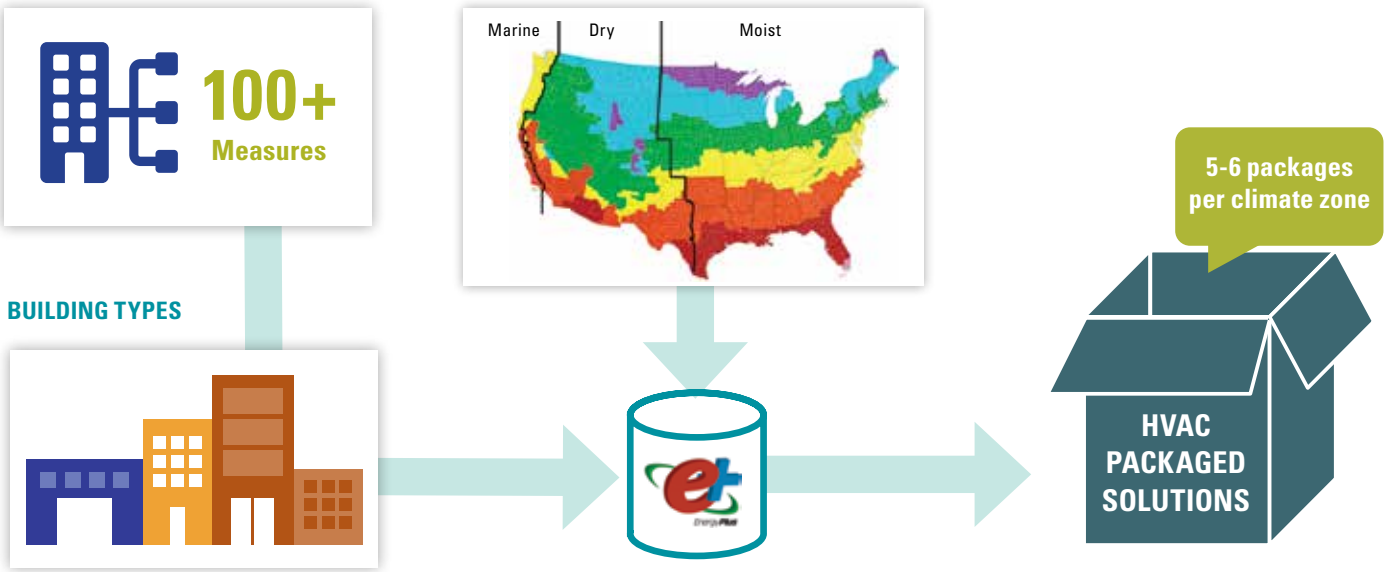
The envelope has a substantial impact on building energy use, but envelope retrofits are rarely undertaken due to higher upfront costs and lengthier payback compared to lighting or HVAC retrofits. CBEI has focused on both roof and wall retrofits. For roof retrofits, CBEI evaluated the impact of increased insulation, reflective membranes, and sky lighting. Modeling confirmed that insulation between R20 – R30 can save 26% on heating loads in low rise buildings. Additionally, a reflective roof can reduce cooling loads by 12%, and incorporating skylights with lighting controls can save 19% on lighting loads when both are integrated with effective insulation. Furthermore, dynamic skylights were shown to keep room temperatures more consistent providing a better occupant experience.

CBEI developed integrated solutions for interior masonry wall retrofits. Modeling and stakeholder input was used to develop two promising designs. Both designs, a most cost effective and a most energy efficient, were implemented in a test bed and underwent extensive evaluation in a controlled environment.

The packaged solutions exceed ASHRAE 90.1 2010 requirements and have a payback period of 10–15 years, and are now ready for real-world demonstration and deployment. Guides and best practice materials have been distributed through multiple industry channels including: Carlisle Construction Materials, Air Barrier Association of America (ABAA), Construction Specification Institute (CSI), American Institute of Architects (AIA), and RCI Inc. CBEI anticipates the final materials will be approved for insertion into industry best-practice guides and professional credentialing programs.



Vetted and tested Wall Retrofit System

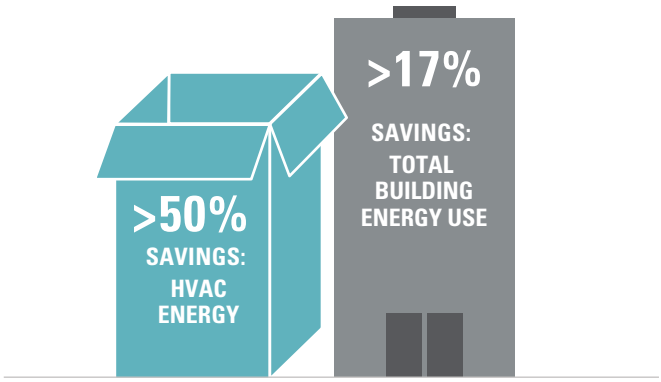


HVAC PACKAGES

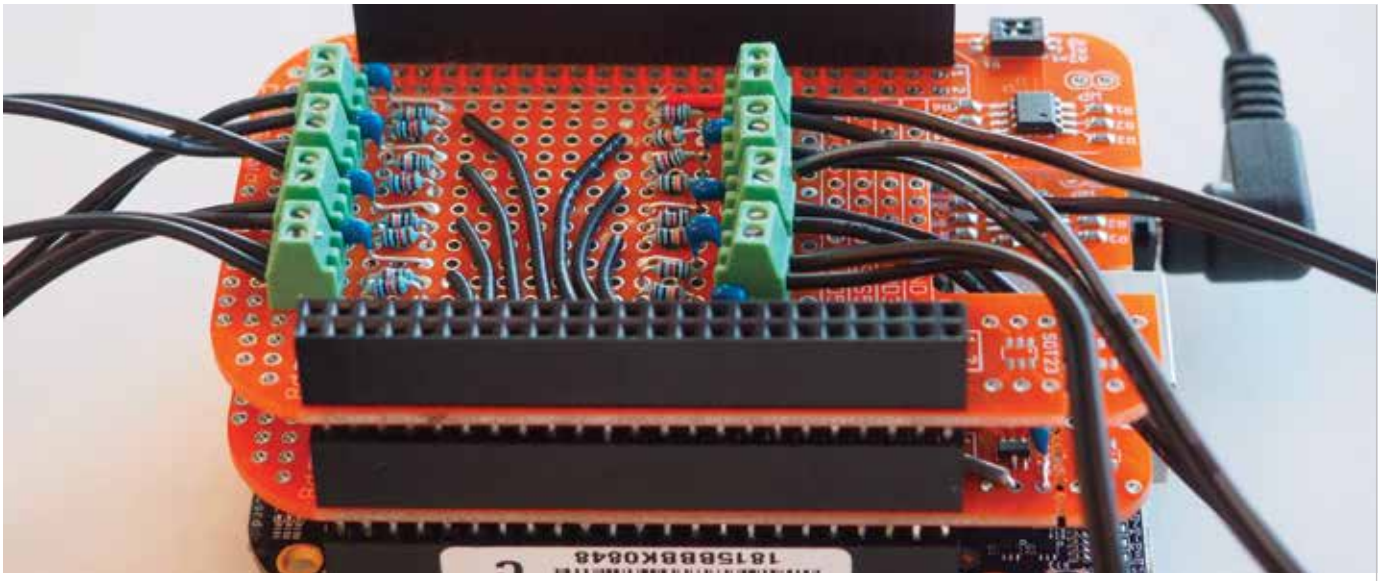
HVAC accounts for, on average, 30% of energy use in small/medium buildings. There are multiple pathways to reduce HVAC energy use that range from the very simple (e.g., duct cleaning) to the very sophisticated (e.g., variable refrigerant flow system); however, it is extremely challenging for retrofit providers to consider all the possibilities.

CBEI developed multiple HVAC retrofit packages, applicable in any continental U.S. climate zone, and modeled for optimization across 11 building types, representing the highest energy consumers. CBEI assembled a list of over 100 potential HVAC energy savings technologies, based on the Department of Energy's standard technology prioritization process. These individual technology options were combined through modeling and evaluated over six U.S. climate zones. Five to six packaged solutions capable of 50% energy reduction were identified for each building type in each climate zone, with a payback of less than four years, assuming an end-of-life HVAC retrofit.

CBEI integrated this work into the OpenStudio measure library so that users will be able to apply them quickly and easily to their building models. This will increase the tool's capability in performance comparisons, modeled against existing baseline energy and financial performance of other typical retrofit solutions using EnergyPlus through OpenStudio.



IMPACTS

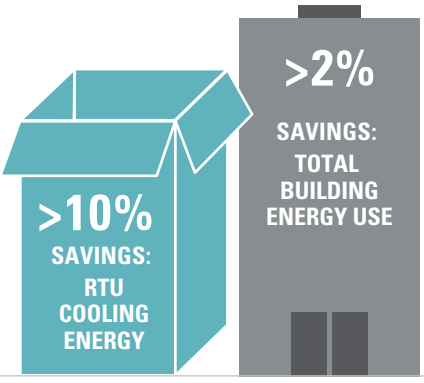


CBEI researchers successfully implemented virtual sensing using low-cost microprocessors embedded into HVAC units. The technology allows for fault detection and diagnostics to improve both sensitivity and accuracy of measurements without significant increases in instrumentation cost. These advances make it easier to identify equipment faults that typically lead to significant energy waste, such as fouling and low refrigerant charge.

LOW COST SENSING

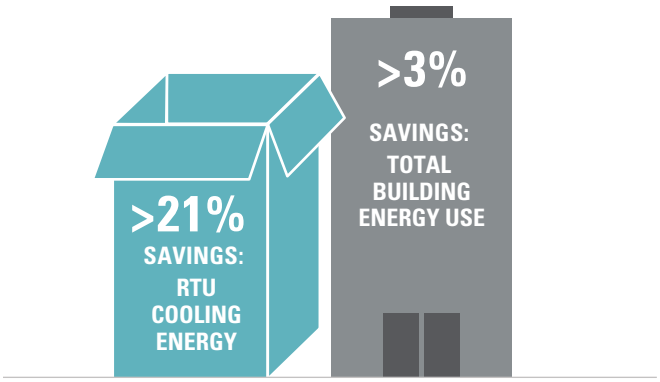
Advanced performance monitoring, control and diagnostic algorithms inevitably require additional sensors, which can be an obstacle to their widespread deployment. A major early focus of CBEI was to develop virtual sensors for indirectly inferring expensive but required measurements from models and physical sensors. CBEI developed and/or demonstrated multiple virtual sensors, including for refrigerant charge, refrigerant mass flow rate, air mass flow rates, compressor power, and cooling capacity.

In general, the accuracy of the virtual sensors was demonstrated to be within 10% of direct measurements at a fraction of the cost. As part of this effort, methods were developed for automatically calibrating virtual cooling capacity and power sensors in the field, and a method and hardware were developed for automatically calibrating virtual refrigerant charge sensors for new rooftop units (RTUs) from the factory.

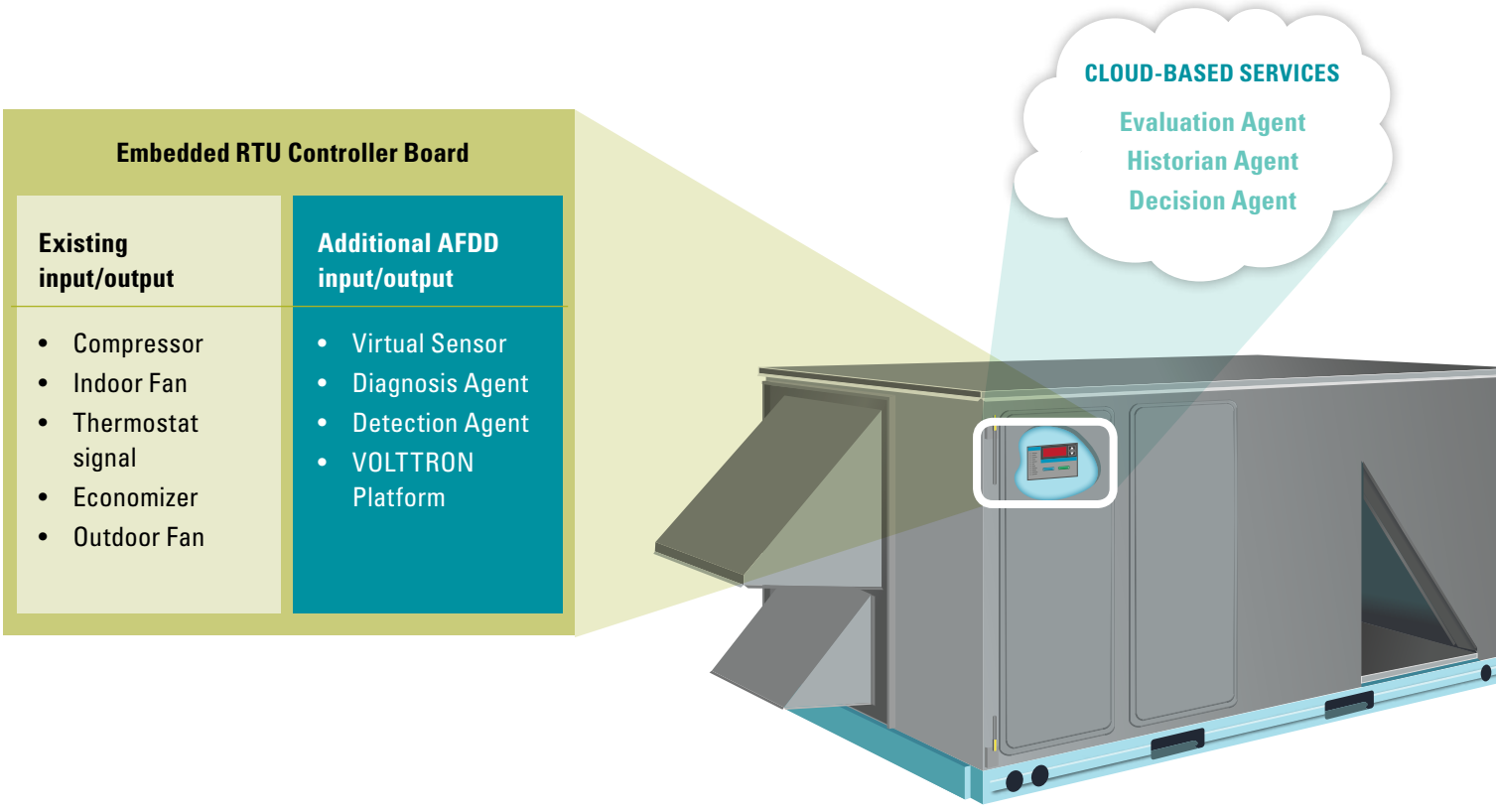


ADVANCED CONTROLS

CBEI developed site-specific, control-oriented models that are needed for practical application of model-predictive controls. The models can be trained using data collected over a relatively short time period (e.g., one to two weeks) with better than 10% prediction accuracy. In addition, different approaches for implementation of optimal controls were developed and demonstrated, including distributed approaches for optimal control of multiple zones and air handling units (AHU), a tool-chain for automatically generating model-predictive control solutions for typical commercial buildings, an automated approach for optimal coordination of multiple RTUs that serve open spaces (e.g., large retail stores), optimal control of chiller plants, and integrated optimal control of retail spaces with air conditioning and refrigeration.



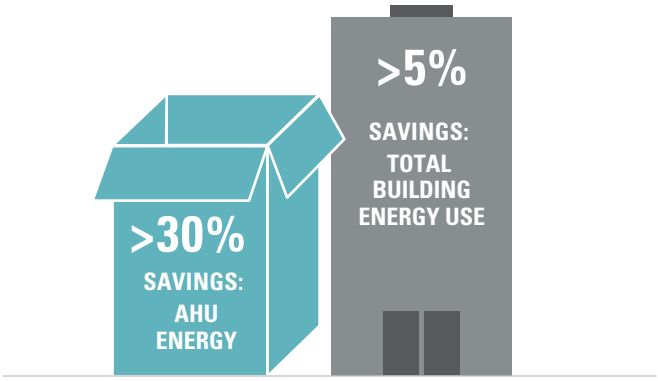
Cost savings for cooling in the range of 10-25% were demonstrated using a variety of real and virtual testbeds developed by CBEI. Payback periods of better than three years were demonstrated.



IMPACTS

AUTOMATED DIAGNOSTICS

To ensure ongoing high performance in buildings, CBEI developed AFDD approaches for RTUs, built-up AHU, sensors, and whole building diagnostics. The RTU diagnostic methods were specifically developed for factory integration and are based on the use a variety of virtual sensors. Besides being lower cost, virtual sensors facilitate the handling of multiple simultaneous faults. Demonstrations were carried out using laboratory and field testbeds, and the methods were shown to correctly detect and diagnose faults before there was a 10% impact on capacity and efficiency. In order to facilitate wider application, the algorithms have been developed for implementation within the public-domain VOLTTRON platform. For built-up AHU AFDD, the technology is applied as a retrofit and automatically learns behavior under normal operation prior to initiating AFDD functions.



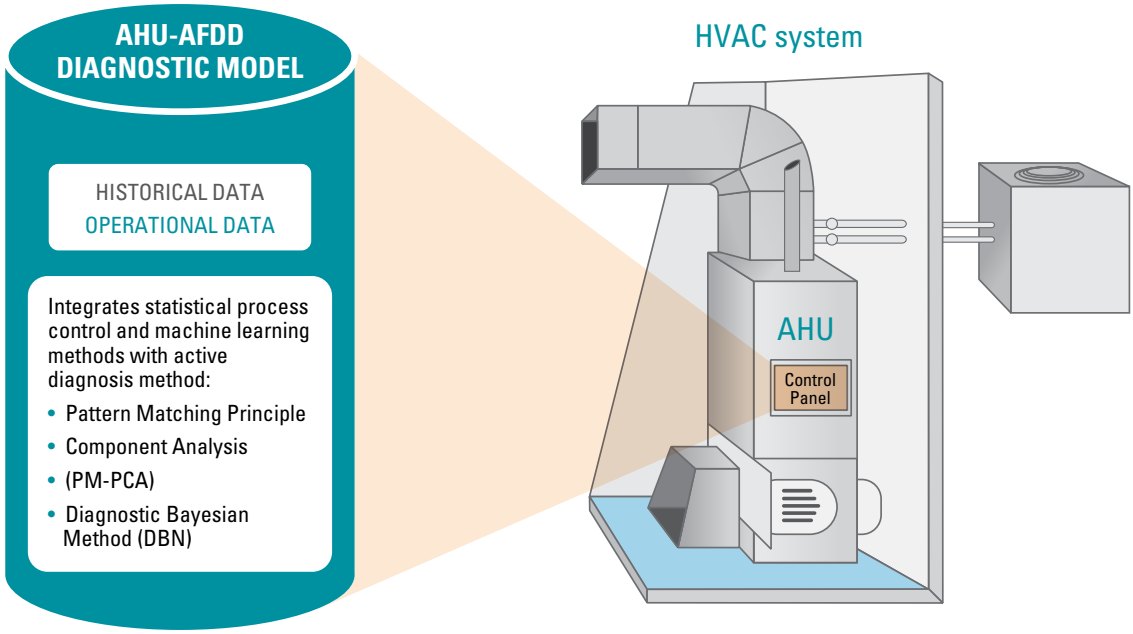
The method has been successfully demonstrated and is projected to have savings of 10-30% depending on current state of equipment and baseline energy consumption, with an estimated payback of less than three years. The technology requires minimum engineering hours and no additional measurements beyond what is normally installed in an AHU. The technology is moving towards commercialization.

Adaptable to any commercial building's existing sensor set and configuration

500+ fault incidents have been artificially implemented in five continuous monitored buildings over three seasons

Over 95% accuracy and less than 1% false alarm rate

Effectively diagnosing all common types of faults including operator errors



Demonstrated cost-effective, VOLTTRON-compatible AFDD strategies for AHU Variable Air Volume/Constant Air Volume (VAV/CAV) systems. These four buildings were continuously monitored, with 500+ fault incidents artificially implemented, over three seasons.

OPERATIONS TECHNOLOGY INTEGRATION AND TESTBEDS

To thoroughly evaluate operations technologies, CBEI developed laboratory setups, field test sites, virtual testbeds with detailed simulation models, and hardware-in-the-loop testbeds that combine simulation and hardware implementations. In particular, the virtual testbeds are an important contribution that can be utilized by future researchers and developers to evaluate the performance of advanced controllers. These included development of modeling approaches that couple dynamic models of building envelopes with reduced-order indoor air models and models of air conditioning and refrigeration equipment. These tools were validated with measurements, and their utility in performing controller assessments was demonstrated through case studies.

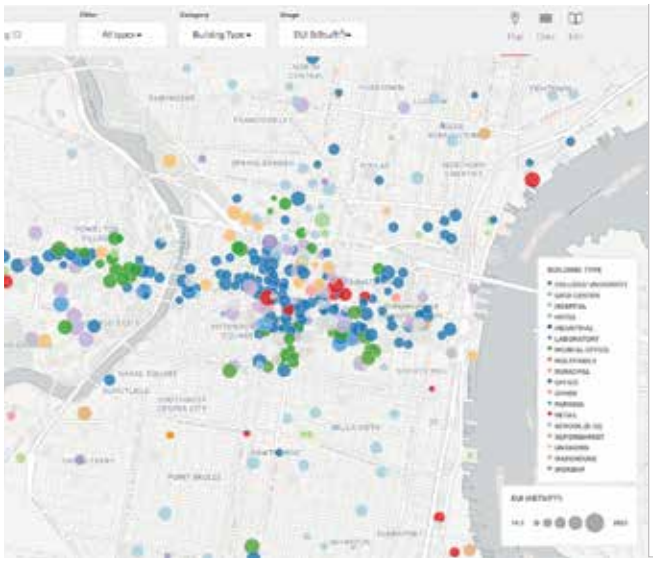
CBEI researchers also worked to simplify the integration of these technologies. This included developing user interfaces that can enhance the ability of operators to understand and take advantage of advanced controls and diagnostics. The work also included development and demonstration of approaches for automatically mapping points to existing energy management and control systems to facilitate cost-effective deployment of advanced control and diagnostic technologies as a retrofit in existing systems.

Creating solutions in collaboration with owners, utilities, and states/cities that can be applied to reduce energy in large numbers of commercial buildings.

Portfolio Solutions

MARKET CHALLENGE

The diverse nature of ownership makes achieving scale in this market sector particularly difficult. Developing solutions that overcome challenges at the building level is critical but only if these solutions are developed in tandem with solutions that make it easier for large numbers of retrofits to be performed. The stakeholders most capable of reaching large volumes of buildings are state and city governments, utilities, and owners of large portfolios. Solutions at this scale require different approaches. For example, there are often large quantities of data that need to be combined and analyzed to prioritize retrofit opportunities, and the data may be in the hands of different stakeholders. Energy consumption data may be available at a fine scale at the utility level but not accessible by a building owner. Or a city or utility may lack access to data about the building stock that would allow them to develop programs that incentivize retrofits. Even portfolio owners may not have a good understanding of the performance of buildings in their portfolio, but completing energy audits of every building in their portfolio may be cost prohibitive, so they require solutions that make the process of prioritizing investments in their portfolio easier.



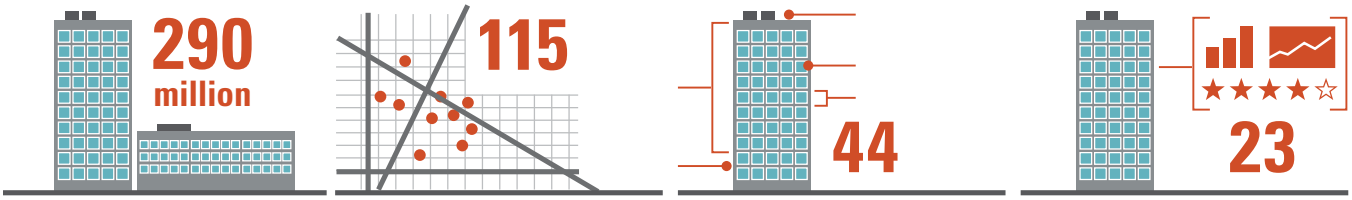
APPROACH

CBEI has played a strong role in developing and promoting solutions on a portfolio scale. To help prioritize efforts in this space, CBEI conducted a review of current and trending policies, regulatory strategies, and incentive programs that have the most significant bearing on the implementation of retrofits in commercial buildings. This research set the agenda for the CBEI portfolio work. CBEI has focused primarily on developing best practices in building performance transparency and benchmarking, testing approaches useful for utilities to reach more customers in their energy efficiency programs, demonstrating the value of solutions that can be applied at a portfolio level to better gauge building performance, and developing guidance that helps regulators and the building owners more effectively meet codes and standards.

A consistent approach that CBEI has applied in portfolio solutions is to engage with and connect the relevant stakeholders throughout the process of developing solutions. Developing a solution that provides value to each of the stakeholders ensures greater uptake of the solution in a region — and nationally. For example, CBEI was instrumental in convening the City of Philadelphia, PECO, and building owners to identify the value of a benchmarking ordinance to each stakeholder. This approach has since been replicated in multiple cities around the country to bring stakeholders together to improve access to energy consumption data and enable a deeper understanding of the performance of buildings in a region, which allows owners to better prioritize retrofits and cities and utilities to better design programs that incentivize energy efficiency.

Philadelphia's Office of Sustainability initiated a benchmarking and disclosure program for the city's commercial building stock. The data captured is making it possible to perform advanced analytics that help target buildings for energy retrofits to improve performance.

TRANSPARENCY AND BENCHMARKING



Sq Ft of Building Area Analyzed

Buildings Analyzed

Unique Building Attributes Studied

Distinct Metrics of Energy Use identified

CBEI developed a highly accurate method to assess the sources of building energy use thanks to the large sets of building energy data available from benchmarking programs across the country. CBEI studied 44 building attributes that could be collected without actually entering the building and found that as few as 23 of them could be used to discern energy use.

CBEI and the Pennsylvania Public Utilities Commission convened the Regional Data Management Working Group to develop best practices to make energy consumption data more transparent for building owners and operators. The Working Group — comprised of local utilities, regulators, building owners and experts from the real estate industry — produced the Utilities' Guide to Data Access for Building Benchmarking. The guide is an introduction to the challenges and opportunities for implementing data accessibility practices, with case studies of successful programs.

CBEI applied the successful strategies developed for the Philadelphia region to enable 22 city-utility pairs develop similar data accessibility programs through the Department of Energy's Energy Data Accelerator (EDA). CBEI published a program inception checklist, a series of instructional case studies, and a list of cities that will continue to act as mentors to their peers looking to replicate their successes. CBEI expertise and guidance materials were instrumental in helping cities in their efforts to achieve the EDA goal of whole building data access for at least twenty percent of commercial and/or multi-family building owners by the end of 2015.

CBEI took an early lead in developing solutions to support benchmarking of building energy performance on a regional scale. CBEI supported the City of Philadelphia as it implemented its ordinance in 2012, acting as a neutral party to convene stakeholder meetings and providing technical expertise on the value of understanding how building energy performance compares regionally. CBEI used this experience to help develop solutions for regions to make use of benchmarking data. CBEI produced the Benchmarking Data Analytics Guide to help municipalities and other entities that may need to analyze large sets of building data. The guide has content tailored to beginner, intermediate, and advanced levels and helps analysts understand how to check data quality, analyze the results across multiple characteristics (e.g., building usage), and identify building segments that may be candidates for retrofits. CBEI has pushed these guides out nationally. CBEI also collaborated with utility incentive program administrators to develop approaches for using benchmarking data to more specifically target buildings for incentives, making it easier for program administrators to reach the best candidates and therefore reduce the overhead cost of an incentive program. These transparency and benchmarking tools are available at www.cbei.psu.edu.

PORTFOLIO TOOLS

CBEI has developed and supported deployment of multiple tools useful for portfolio managers to better understand the performance of their assets as well as improve occupant health and comfort.

The Department of Energy has developed the Asset Score Tool (AST) as an easy way to determine the energy performance of a building's physical characteristics independent of occupant behavior. AST provides upgrade recommendations for each building system. CBEI created an easy-to-use interactive guide and video demonstration to introduce users to the AST. CBEI then took the tool on the road, finding market leaders to test the tool and adopt it to assess their own building stock. This engagement reached more than sixty organizations.

Recognizing the importance of occupant health and comfort in the long-term value of an asset to a portfolio owner, CBEI developed approaches and tools for post retrofit evaluation and measurement of indoor environmental quality (IEQ). The IEQ study was undertaken to assess spatial and environmental conditions as well as user satisfaction in the workplace before and after a retrofit.

The set of measures include: as-built records of the technical attributes of building systems; spot measurements using the National Environmental Assessment Toolkit (NEAT) instrument cart and 24-hour continuous measurements using Aircuity optima unit for the thermal, air quality, acoustic, and visual conditions in the workplace; and short-term user satisfaction questionnaires in the sampled workstations. The study was focused on measuring IEQ on a winter day — thermal, air, lighting and acoustics — capturing the physical attributes of the building systems that may be critical to those measurements as well as user satisfaction on a "right-now" basis for comparison to the measurements. This IEQ study was used by the energy retrofit project team to prioritize energy conservation measures, and where possible to provide further cost-benefit justifications for energy retrofit investments.

CBEI also developed enhancements to the Department of Energy's Standard Energy Efficiency Data (SEED) platform that helps manage energy data of large groups of buildings. Enhancements allow SEED to retrieve, store, and analyze 15-minute data which is increasingly available with the advent of smart meters. The ability of the platform to import data from multiple sources will provide actionable intelligence for cities and other large portfolio owners to support operational optimization and investment.

CBEI helped market leaders test the Asset Score Tool and adopt it to assess their own building stock.

IMPACTS

Corner Grocery Store Energy Project — Philadelphia, PA

Results from these stores, "...are valuable to the Office of the Small Business Advocate, because they offer data supported technical solutions that may increase kW and kWh savings projects achieved through Act 129 small business direct install energy efficiency programs"

— John Evans, PA PUC Office of the Small Business Advocate

UTILITY PROGRAMS

CBEI has collaborated with local utilities and the Pennsylvania Public Utility Commission to demonstrate several solutions useful for utility programs. This collaboration extends across multiple research areas. For example, incentive program administrators were engaged for the HVAC and wall retrofit solutions to help guide the development of those packages such that the packages could more easily be incorporated into an incentive program. CBEI also collaborated with the Food Trust to identify simple retrofit packages for small corner stores to support the development of a direct install incentive program.

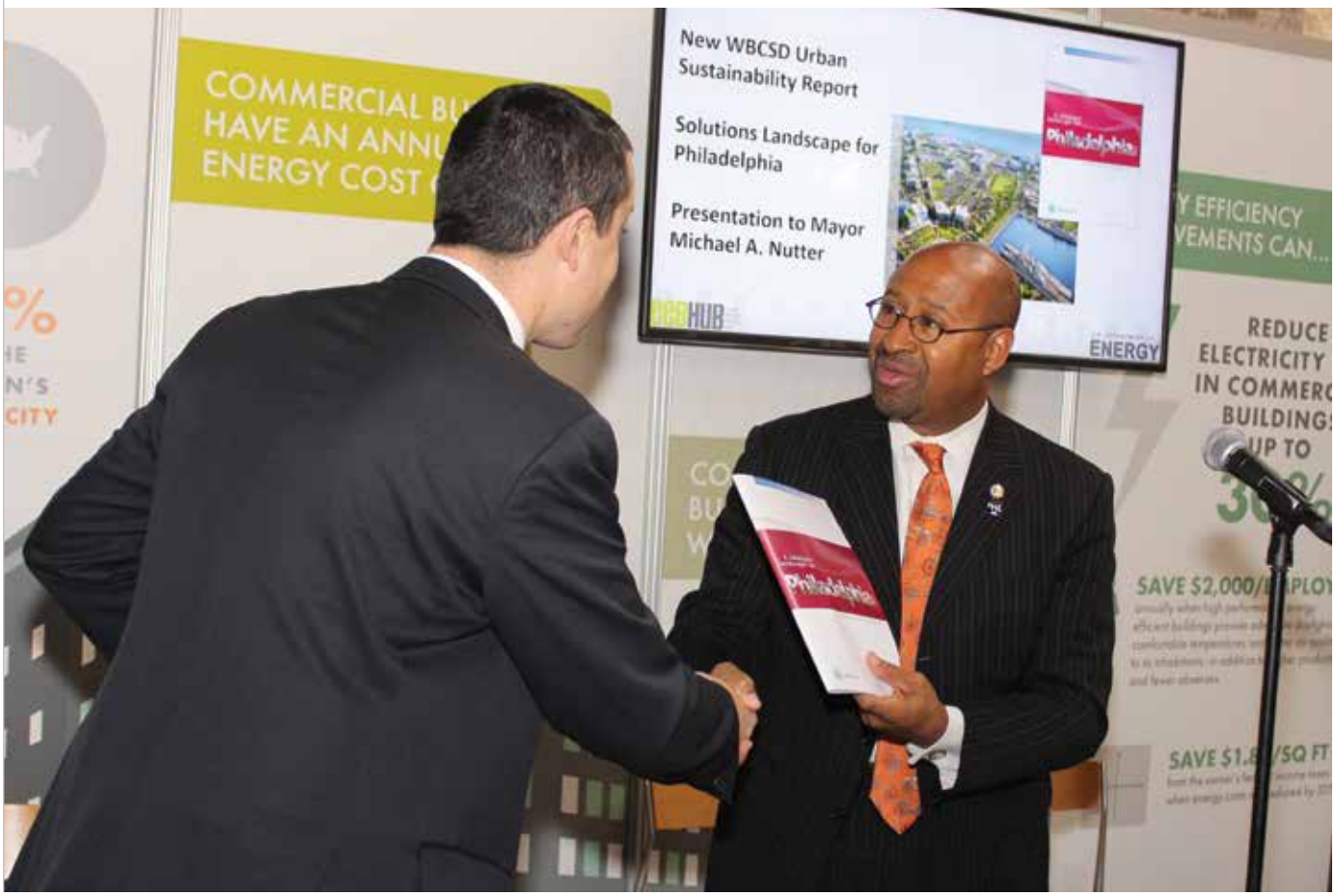
A key challenge for smaller commercial retrofits is access to capital. CBEI worked with the Navy Yard Electric Utility (NYEU) to design and pilot an on-bill financing program. In this program, financing is provided for a building energy retrofit on TNY and the financing is paid back through regular monthly electricity bills. Unlike most on-bill programs, the NYEU program will incentivize deep energy retrofits taking advantage of a wide variety of energy savings measures, including renewables and combined heat and power. CBEI developed a case study usable by municipalities or other microgrid energy managers to incentivize deep energy efficiency retrofits and has distributed the case study to multiple microgrid energy managers and nonprofits with substantial membership reach.

CODES AND STANDARDS

Local building codes regulate new construction and repair, alteration, addition, and change of use in existing buildings. The latter, change of occupancy classification or use, is a common trigger for requiring an existing building to comply with the current building code requirements but it is not widely enforced. CBEI proposed an alternative compliance approach that uses historic energy use intensities of different building types as the metric for the requirement's energy demand provision.

In this approach, a change of one building type to another that increases end use energy intensity would require compliance with the code. CBEI worked with three partner municipalities (Upper Merion Township, West Chester, and Lower Merion) in Pennsylvania, code officials/consultants, energy organizations, code organizations, professional associations, industry, and other associated stakeholders to develop and test this approach. CBEI then submitted a code change proposal to the International Code Council for incorporating the change into the 2018 International Energy Conservation Code.

Philadelphia Mayor Michael Nutter was a major driving force behind CBEI's work.



Building the capability of all workers to improve building energy use across the building lifecycle — from design to occupancy to transfer.

Workforce Development

MARKET CHALLENGE

People own, sell, design, build, operate, work in, supply power to, and regulate commercial buildings. Yet, the level of literacy about energy efficiency among these people is surprisingly low. To make a substantial gain in efficiency in the market, it requires a knowledgeable community. Furthermore, the growth of the building energy efficiency field is limited by the availability of a skilled workforce to carry out the work. Employers — including owners, operators, architecture firms, real estate brokerages, service providers — want standardization to have confidence in the quality of employees. Job-seekers want guidance about entry points and career advancement opportunities. Professional associations and training & education providers need to be able to counsel workers and establish training and other programs to support movement into energy-related jobs. And policymakers want to specify levels of competency in their programs.

Changes within the workforce development and education systems have been accelerating as the traditional lines between occupations, particularly in the trades, have changed in the face of a rising demand for energy efficiency workers. Curricula are being modified, the design and engineering enterprise is changing, operations and maintenance functions are becoming more complex, new energy-related educational programming is emerging, unions and associations are trying to keep pace with standards and certifications, and the energy efficiency services sector is gaining a life of its own. However, the market is challenged with much needed standardization and availability of training and education options.

APPROACH

CBEI recognizes that education and workforce training is foundational to a strong energy efficiency market. In addition to the depth of expertise of the university, private sector, and economic development expertise within the Consortium, CBEI partners with organized labor, workforce investment boards, and certification bodies, to guide workers entering the industry and pursuing additional professional growth within the industry.

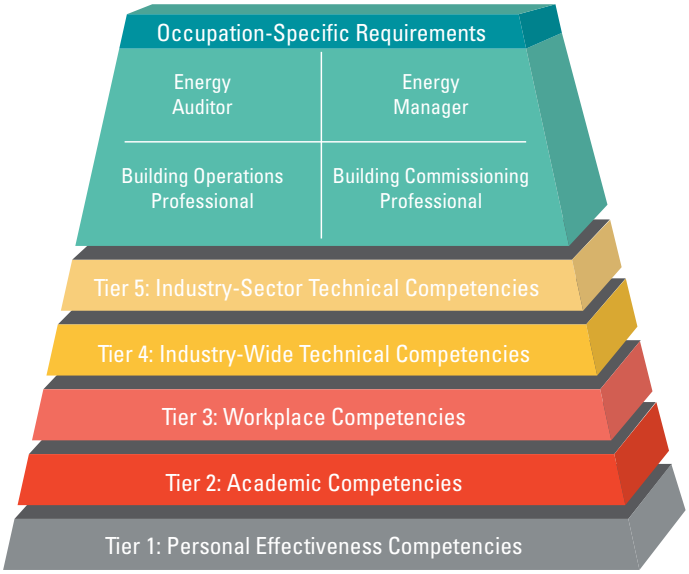
CBEI's approach to developing education and workforce solutions for the market is based on the collective input from the full spectrum of employers and educational institutions focused on this market segment. In addition to looking at the educational gaps, CBEI also identified opportunities to connect underrepresented and displaced workers and veterans with the growing market.

What emerged from CBEI's early scoping efforts was the need to develop both a structured approach to professional development for workers in the field and a set of targeted training programs that fill some critical gaps. CBEI also partnered with education providers for the K-12 and college students. While early education is critical, CBEI ultimately directed its attention to trade, college, and post-graduate studies.

COMPETENCY MODEL AND CAREER MAP

The Department of Energy's Better Buildings Program has developed guidelines to improve the quality and consistency of commercial building workforce credentials for four key energy-related jobs: energy auditor, commissioning professional, operations professional, and energy manager. The industry needed documented career and development pathways and a clear representation of the competencies required in each role in order to accelerate the movement of competent people into these jobs. CBEI developed the Advanced Career Commercial Buildings Workforce Competency Model and Career Map. The competency model documents the technical skills and competencies required for workplace success and provides a resource for the development of curriculum, certifications, and the tests that assess work-related competencies. The competency model has been available to users since May 2015 on the Competency Model Clearinghouse website www.careeronestop.org/competencymodel/, sponsored by the U.S. Department of Labor.

The career map depicts clear workforce development pathways and career progressions into the advanced commercial buildings workforce. The model and map have been pushed out through multiple professional associations. The Career Map is being maintained and updated by the Facility Engineering Associates (FEA), www.facilitiescareermap.feapc.com.



CBEI Competency Model

BROKER TRAINING

Properly evaluating a building's energy performance is regarded as a critical element to a healthy marketplace for driving commercial building energy efficiency. Commercial brokers who handle the sale of these buildings are well positioned to represent these elements for their clients. CBEI's Commercial Broker Training program aims to increase commercial brokers' understanding of energy efficiency measures to enable them to better facilitate transactions for both the owners and tenant.

Where previous education efforts have been hampered by the difficulty in reaching brokers and earning approval from state real estate commissions, CBEI has succeeded in gaining significant traction in providing this energy efficiency education to brokers.

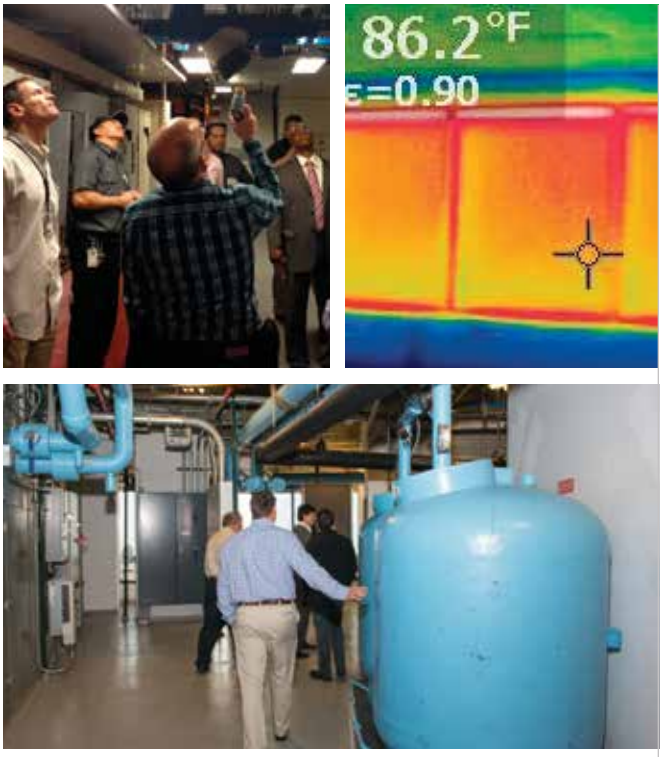
The project team developed the training course, established continuing education credit for that course, and conducted the training in multiple states. CBEI is expanding the Broker Training program to a national audience both through continuing education credit offerings and through partnerships with national players to help further the program's reach. CBEI has offered nine trainings in five states and Washington, D.C. and has trained over 250 brokers. The training program was designed to be sustained through partnerships. Training partners in three to five states have already committed to continue to offer the course.

BUILDING OPERATOR TRAINING

A capable workforce of building operators literate in energy efficiency concepts can identify and help to implement low- or even no-cost energy saving strategies. Further, operators are well-positioned to advise owners about current building systems inefficiencies, which when addressed and resolved through energy retrofits can yield high returns on investment. CBEI enhanced and supported national deployment of two operator-focused training courses.

CBEI offered the Building Operator Certification program in 2012 to train operators on building systems maintenance and equipment troubleshooting. The program continues to be offered by Pennsylvania College of Technology, which is part of the Penn State system. The course is divided into two levels with the first providing a foundational understanding of building energy uses and energy accounting practices, while the second level focuses on preventative measures, electrical system diagnostics, HVAC troubleshooting, and control and optimization of building automation systems.

Working in conjunction with Pacific Northwest National Laboratory, Building Owners and Managers Association (BOMA), and APPA: Leadership in Educational Facilities, CBEI enhanced an existing course aimed at building operators called Building Re-Tuning (BRT). BRT is the process of bringing a building back to its optimal performance. CBEI enhanced the curriculum with additional content and designed it to be a train-the-trainer program. CBEI piloted the BRT train-the-trainer course to several dozen students representing over 100 buildings in three BOMA markets and national gatherings of BOMA and APPA trainers. The piloting of this new approach helped set the stage for BOMA and APPA to begin national deployment of the program in 2016.



Building operators receive hands-on training to better assess building performance and opportunities for energy savings.

ASSET SCORE TOOL TRAINING

CBEI advanced the market penetration of the Department of Energy's Asset Score Tool (AST) by creating a new, certificate of proficiency course that can be readily integrated with other building energy assessment education and training programs. Leveraging prior experience in the development of the Certificate of Proficiency in Benchmarking program, CBEI conducted a needs assessment to build upon and sharpen initially identified education and training needs. Based on this assessment, a modular curriculum plan was created to address critical needs as defined by the experience of AST users.

IMPACTS

BENCHMARKING PROFICIENCY

With the growth of building energy benchmarking and disclosure laws adopted throughout the U.S., concerns have risen about the accuracy of the data that is being collected. Inaccurate data threatens the credibility of benchmarking programs. In response to this need, CBEI worked with the Natural Resource Defense Council and the U.S. Environmental Protection Agency (EPA) to design, test and deploy the National Benchmarking Proficiency Certificate and Training Program. Through CBEI's leadership and support, the certificate program was successfully deployed and is being adopted as a means for ensuring accurate data collection.

New York City incorporated the credential into its training program to help address its data quality control issues. Salt Lake City Community College integrated the training program into its curriculum as of mid-2015, as part of their benchmarking workforce training. CBEI supported its training program's national deployment in cooperation with Natural Resources Defense Council (NRDC) and EPA, while also providing necessary upgrades in conjunction with updates to Portfolio Manager and user feedback. Working to ensure the long-term viability of the training program, CBEI also developed a business plan and revenue model for maintaining and sustaining the certificate program.

Through a collaboration between CBEI and the Pennsylvania Department of Environmental Protection, building energy efficiency training is being provided across the Commonwealth of Pennsylvania. In addition to providing BRT training at the municipal, school district, and state level, the Department of Environmental Protection funded the development of a college course: Leadership in Building Energy Efficiency. This course includes CBEI-developed training in BRT, Asset Score Tool and Benchmarking and is currently offered by Penn State and plans are underway to expand to other higher education institutions in Pennsylvania.

CBEI's Leadership Team:
(back row, left to right) Jim Braun, Amy Wylie, John Messner, Leslie Billhymer, Lisa Shulock, Scott Wagner;
(front row, left to right) Mark Stutman, Tim Wagner, Martha Krebs, Edit Radone, Erica Cochran.

THANK YOU

Penn State would like to thank the many organizations and staff that contributed to CBEI's success over the past five years. In particular, we'd like to thank the sponsoring Federal agencies for funding support, the Department of Energy National Laboratories for technical collaboration, and especially the National Energy Technology Laboratory for contract management. At the State, regional, and local level, we'd like to thank the contributions of the Pennsylvania Department of Environmental Protection, Department of Community and Economic Development, and Public Utility Commission, as well as PECO and the City of Philadelphia, in particular Mayor Nutter and the Office of Sustainability. For providing leadership and technical advice, we'd like to thank the many members of CBEI's Executive Board, Advisory Board, and Technical Advisory Groups. Lastly, we'd like to thank all the CBEI partners, their staff, including graduate and undergraduate students, and consultants for the work performed on behalf of CBEI. A full list of contributors to CBEI's success can be found at www.CBEI.psu.edu.

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CBEI
CONSORTIUM for BUILDING ENERGY INNOVATION

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CBEI is one of three Penn State energy research facilities at The Navy Yard (TNY) in Philadelphia. Penn State also runs GridStar, a smart grid education and research center, and the Mid-Atlantic Combined Heat and Power Technical Assistance Partnership at TNY. These facilities are part of TNY's smart energy campus, which is an ideal setting for demonstrating and deploying energy efficient technologies, energy generation and storage, and microgrid controls and distribution.