CONSORTIUM for BUILDING ENERGY INNOVATION

PennState

# Fiscal Year 2010
# Energy Efficiency Building Systems
# Regional Innovation Cluster Initiative

**July 29, 2016**

*This document is available for unlimited release.*

**DOE Award Number:** DE – EE0004261

**Name of Recipient:** The Pennsylvania State University Consortium for Building Energy Innovation

**Project Director:** Dr. Martha Krebs

**Consortium Members:**

- Balfour Beatty
- Ben Franklin Technology Partners
- Carnegie Mellon University
- Collegiate Consortium
- Covestro (formerly Bayer Material Sciences)
- Drexel University
- Delaware Valley Industrial Resource Center (DVIRC)
- IBM
- Lawrence Livermore National Laboratory
- Massachusetts Institute of Technology
- Morgan State University
- New Jersey Institute of Technology
- Pennsylvania College of Technology
- Philadelphia Industrial Development Corporation
- PPG
- Project Based Learning, Inc.
- Princeton University
- Purdue University
- Rutgers University
- United Technologies Research Center (UTRC)
- University City Science Center
- University of Pennsylvania
- University of Pittsburgh
- Virginia Tech

# Contents

# Executive Summary

The Consortium for Building Energy Innovation (CBEI) was established through a Funding Opportunity Announcement led by the U.S. Department of Energy, under a cooperative agreement managed by the National Energy Technology Laboratory. CBEI is led by The Pennsylvania State University and is composed of partners from academia, the private sector, and economic development agencies. The Consortium has included as many as 24 different partners over the five years, but 14 have been core to the work over the five year cooperative agreement.

CBEI primarily focused on developing 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 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 five categories: tools to make integrated design and delivery easier and more complete, packages of components, sub-systems, controls and diagnostics that in combination result in greater energy reduction, solutions that can be applied through public policy or on a portfolio-wide basis, tools and training materials to enhance the energy efficiency competencies of the workforce, and demonstrations and deployment. A sampling of solutions and their impacts is provided in Figure 1.

**Figure 1: Examples of CBEI Solutions and Impacts**

| Examples of Solutions and Impacts | | | |
|---|---|---|---|
| **Integrated Design** | **Technology Packages** | **Portfolio Solutions** | **Workforce Development** |
| 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. | 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. | 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. | 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. |

When CBEI was established five years ago, little was known about the needs of the existing small and 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 and medium building retrofits are necessary to achieve greater impact in this market segment.

# I. Introduction

In February 2010, a Funding Opportunity Announcement was 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, Department of Labor, Department of Education, Small Business Administration, and National Science Foundation. The focus of the FOA was to create 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 distribution.

In response to this FOA, the Pennsylvania State University (PSU) built a consortium of academic institutions, private sector companies, and economic development agencies to focus on the challenges of the market. The PSU-led consortium had several names over the five-year cooperative agreement, including the Greater Philadelphia Innovation Cluster (GPIC), the Energy Efficiency Buildings Hub (EEB Hub), and finally the Consortium for Building Energy Innovation (referred to subsequently in this report as CBEI). The Consortium partners varied over the five years as CBEI direction evolved; however, fourteen core partners participated throughout the five years (Figure 2). Throughout the five years of the agreement, the core partners contributed members of the governing Executive Board as well as senior researchers, who served as Task Leads. An additional eleven participated in the Consortium, but primarily in the first three years of the cooperative agreement (Figure 3).

**Figure 2: Core CBEI Partners**

**Figure 3: Former CBEI 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

CBEI is headquartered at The Navy Yard (TNY) in Philadelphia. CBEI is one of three Penn State energy research facilities at TNY. 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, distributed energy generation and storage, and microgrid controls.

The FOA called for the development of a consortium for developing, expanding, and commercializing innovative energy efficient building systems technologies, designs, and best practices. CBEI proposed a focus on developing energy efficiency retrofit solutions for existing "average" size commercial and multifamily residential buildings, taking advantage of the diversity of buildings in the Philadelphia region. This was consistent with the original intent of the FOA, which also was to implement a regional approach to solution development and demonstration. The Consortium focused primarily on commercial buildings throughout the five years, with little focus on multifamily buildings. In the third budget period (BP), in collaboration with DOE, CBEI clarified the building size focus as small and medium commercial buildings, defined by DOE as buildings less than 250,000 square feet. The majority of CBEI demonstrations throughout the five years were in buildings of 50,000 square feet or less.

During BP3, DOE also reduced the annual funding to CBEI from approximately $25M per year to $10M per year and provided project-level guidance on DOE's preferred areas of focus. DOE requested CBEI to support enhancement and deployment of existing DOE tools and requested that CBEI discontinue any further development of new tools. The change in funding and direction contributed to the reduction in the number of partners engaged in CBEI and the breadth of solutions that were being developed; however, it did not substantially change the building types and sizes to which CBEI solutions would be applicable.

Solutions for small and medium buildings are important because this market segment is large and underserved by existing research. This market accounts for 99% of all existing commercial buildings and approximately half of all commercial building energy use. This 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 served by providers that are smaller and less likely to provide integrated, full-service solutions.

To address major challenges in this market sector, CBEI proposed five research focus areas (referred to here as activity areas) in response to the FOA, and these activity areas persisted as themes across the five years of the Consortium's federal funding, even with changes in funding levels and revised direction from DOE. For each activity area, CBEI conducted further characterization of gaps in BP1, and this characterization drove the research agenda for the subsequent four years. The five areas include:

- **Tools for Integrated Design, Verification, and Modeling**: Because service providers supporting the small and medium building market do not often have the expertise or time to perform an integrated design for smaller retrofits, tools that are easier to use provide an incentive for smaller retrofits to be designed for greater system integration. CBEI pursued the development of simplified solutions to support integrated design, with a focus on reducing the level of expertise and time needed to better integrate systems in a retrofit design and implementation.
- **Components, Sub-Systems, Controls, and Diagnostics**: 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. Therefore, CBEI focused on the development and demonstration of technology packages as part of its Components, Sub-Systems, Controls, and Diagnostics research activity area. 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, so CBEI included development and demonstration of sensors and controls in this activity area.
- **Public Policy, Behavior, Economics, and Business**: While building-level solutions are needed for this market sector, there are stakeholders in the market — primarily cities, states, and utilities — that have strong influence on energy use in buildings this size, and they need solutions that can help them achieve scale by improving many buildings in single initiatives. They typically influence or drive retrofits through carrots such as financial incentives for retrofits or sticks such as regulatory actions (e.g., building codes). Therefore, CBEI established this activity area to develop solutions for cities, states, and utilities. Recognizing that solutions affecting a large number of buildings can also be useful to large portfolio owners, including municipalities that own and operate large portfolios of small and medium buildings, CBEI included portfolio solutions as part of this activity area.
- **Education and Workforce Development**: Adding to the challenge for retrofits 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. CBEI established this activity area to develop tools to support professional development of workers and to develop, demonstrate and deliver courses and certifications to enhance energy efficiency capabilities.
- **Demonstration, Deployment, and Intellectual Property Management**: 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; therefore, CBEI established an activity area that focuses on demonstration and deployment of solutions. Recognizing that CBEI researchers and external partners may develop IP for commercialization, CBEI included approaches for commercialization and IP management in this activity area.

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. CBEI established an approach to its research that engaged the broadest, relevant set of stakeholders in each project. CBEI structured its research to ensure continuous market engagement from problem identification through solution deployment and commercialization. Researchers drew on the extensive market networks of the Consortium partners to identify and engage before, during, and after each project. This allowed 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.

These impacts are showcased in the summaries that follow in this report. The report was structured to provide a high level overview of the progress that CBEI made against the original expectations set out in CBEI's proposal to the FOA. It also further describes the challenges identified above and the approaches that CBEI researchers took to develop solutions to these challenges. As a result of all this work, CBEI created a substantial number of interim and final products, provided to DOE. The entire list of materials delivered to DOE is provided in Appendix A. Documents useful by all stakeholders in the small and medium commercial building market are listed in Appendix B of this report and are available at www.cbei.psu.edu.

# II. Comparison of Accomplishments to Goals and Objectives

CBEI goals and objectives were established annually in collaboration with DOE. These goals and objectives were refined each year based on the results of the previous year's research and to be consistent with any changes in DOE's Commercial Buildings Integration (CBI) program goals and priorities. However, one overarching goal has been to demonstrate retrofit solutions that result in a 50% reduction in building energy use. The end date for achieving the 50% reduction was ultimately set at 2030, to be in line with DOE's 2030 goal. Two other thematic goals articulated in the proposal, but not officially described as goals until BP4 were to identify and overcome market barriers in implementing energy efficiency in existing buildings, and to accelerate adoption of energy efficient retrofit solutions at local and national scales.

Objectives changed from year to year as well, and were focused on the research projects for that year. However, in the proposal for the FOA, CBEI identified metrics by activity area for measuring research progress across the five years. Because these metrics were meant to be used to assess overall performance over the five years, CBEI is using these metrics to represent research objectives for the full five years. A summary of the CBEI accomplishments to the proposed research objectives by activity area is provided in Figure 4.

**Figure 4: Comparison of Accomplishments to CBEI Objectives**

| Objectives | Progress Against Objectives |
|---|---|
| **Tools for Integrated Design, Verification, and Modeling** | |
| **Integrated lifecycle project delivery process models demonstrated and deployed** | • Developed Integrated Design Advanced Energy Retrofit Roadmap for Lite, Partial, Substantial, and Comprehensive retrofits and deployed through CBEI website. These concepts were demonstrated in CBEI's HQ building (Building 661) retrofit.<br>• Developed a BIM Planning Guide for Retrofit Projects that enables teams to quickly plan the model adoption process early in a project. The guide has been deployed through the CBEI website. |
| **Hierarchical modeling for building design representations demonstrated and deployed** | • Developed the BIM Datahub which allows design teams to store, retrieve and share information generated by building design and construction software. It also transforms the data into outputs compatible with simulation software (e.g., OpenStudio, EnergyPlus, and Radiance).<br>• Developed 7 OpenStudio measures for HVAC retrofit package solutions for 3 climate zones that provide 50% HVAC energy savings with a payback of less than 4 years.<br>• Developed a prototype VOLTTRON utility to automatically infer the semantic meaning of building points for cost-effective deployment of intelligent building apps.<br>• Developed 3 new modules for OpenStudio, EnergyPlus, and Radiance modeling suite to support modeling the air-flow network; energy savings of various lighting designs, taking into account daylighting; and impacts of occupant behavior.<br>• Developed the Immersive Construction Lab (ICon Lab) to provide a three-dimensional visualization environment in which groups of up to 40 people can simultaneously participate in integrated design, demonstrated the system for the design of Building 661 and deployed a guide to interactive workspaces through the CBEI website. |
| **Performance computational tools and applications demonstrated and deployed** | • Developed and demonstrated a prototype Retrofit Manager Tool, which allows owners/operators to perform reduced order energy simulations using a library of building classes prior to engaging a design team. The tool uses OpenStudio and EnergyPlus as its engine. This work did not proceed to deployment at DOE's request. |

| Objectives | Progress Against Objectives |
|---|---|
| | • Developed and demonstrated a prototype Design Advisor Tool, which allows a design team to conduct reduced order modeling of the energy performance of key design decisions. This work did not proceed to deployment at DOE's request.<br>• Developed and demonstrated a prototype Energy Audit Tool, which allows facility managers or commissioners to easily conduct a Level I, walk-through audit. This work did not proceed to deployment at DOE's request. |
| **Integrated delivery process infrastructure design packages demonstrated and deployed** | • Developed and prototyped an energy simulation platform that merged three different energy simulation tools – Design Advisor Tool (DAT), Energy Auditing Tool (EAT), and Retrofit Manager Tool (RMT) – into a single platform to perform building benchmarking, reduced order energy simulations, advanced retrofitting planning, and detailed energy simulations. The platform was a cloud-based deployment. This work did not proceed to deployment at DOE's request. |
| **Components, Sub-Systems, Controls, and Diagnostics** | |
| **Integrated lifecycle project delivery process models demonstrated and deployed** | • Used the retrofit of the CBEI Headquarters building (661) as a test bed for demonstrating integrated project delivery and developed X case studies to describe lessons learned and deployed the lessons learned through the CBEI website, DOE workshops, and conferences. |
| **Façades, integrated HVAC, and lighting technologies demonstrated and deployed** | • Developed a technology roadmap in the first year that drove research on packages of systems for smaller/medium commercial buildings.<br>• Evaluated the impact of increased insulation, reflective membranes, and sky lighting and developed solutions that demonstrate that that insulation between R20 – R30 can save 26% on heating loads in low rise buildings; 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. Work on roof systems was stopped after the third year, as industry began adopting these approaches.<br>• Developed 20+ HVAC retrofit package solutions for 6 climate zones that provide 50% HVAC energy savings with a payback of less than 4 years.<br>• Developed and demonstrated an integrated, energy-efficient and cost-effective wall retrofit solution for interior of existing masonry walls that provide 18% building energy savings with a payback of less than 15 years.<br>• Executed nine projects to evaluate and test glazing, shading, lighting, and control technologies and their integration; confirmed through modeling 30% savings in building lighting energy usage for selected solutions. Work on the integration of windows, lighting, and controls was stopped at DOE's request. |
| **Robust control systems demonstrated and deployed** | • Developed robust software implementations of a Plug and Play (PnP) RTU coordinator that provides 15% operation cost savings<br>• Developed a scalable low-cost optimal chiller plant control algorithm that can provide an average energy savings of 15% with less than 3 years payback |
| **Performance monitoring and diagnostic systems** | • Developed an embedded fault detection and diagnostics (FDD) capabilities with a demonstrated performance of less than 1% false alarms, more than 90% diagnosis rate for faults, and less than 2% additional installed cost.<br>• Developed cost-effective & VOLTTRON compatible AHU fault diagnosis solutions which save at least 10-30% HVAC energy with 2-3 years payback.<br>• Developed, demonstrated, and evaluated hardware and software implementations of virtual sensors for RTUs for RTU refrigerant charge, capacity, and power. |
| **Public Policy, Behavior, Economics, and Business** | |
| **Expertise deployed in GPIC Commercialization and Creativity Institute (CCI) projects** | • Engaged through the CCI and commercialization center. See impacts in CCI task in Demonstration, Deployment, and IP Management. |

| Objectives | Progress Against Objectives |
|---|---|
| **Build, demonstrate, and deploy practice/ performance knowledge repository** | • Developed a repository of polices in the greater Philadelphia region, which was used to help inform CBEI on gaps in the market to assist in policy implementation. This information helped shape CBEI support for benchmarking and code compliance. |
| **Demonstrate and deploy energy management strategies for buildings** | • Demonstrated approaches for achieving energy use data transparency between utilities, building owners and the City of Philadelphia and deployed these strategies in collaboration with DOE's Energy Data Accelerator to enable 22 city-utility pairs to develop similar data accessibility programs.<br>• Developed solutions for regions to make use of benchmarking data and included these solutions in a Benchmarking Data Analytics Guide to help municipalities and other entities that may need to analyze large sets of building data.<br>• 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.<br>• Developed enhancements to DOE's Standard Energy Efficiency Data (SEED) platform allowing SEED to retrieve, store, and analyze 15-minute building energy use data, which provides actionable intelligence for cities and other large portfolio owners to support operational optimization and investment.<br>• Created an easy-to-use interactive guide and video demonstration to introduce users to DOE's Asset Score Tool (AST) and gained commitment from 19 portfolio owners (collectively addressing a 6.5 million square foot portfolio of buildings) to apply AST. Introduced AST to 65 new organizations including AIA PA, who is working to disseminate the benefits of AST to their large membership and shared CBEI online AST educational opportunities during the national AIA convention. |
| **Policy simulator for codes, incentives, and adoption demonstrated and deployed** | • Developed an alternative compliance approach for change of occupancy, worked with three municipalities to develop and test the approach and submitted a code change proposal to the International Code Council for incorporating the change into the 2018 International Energy Conservation Code. |
| **Behavior in technology and policy deployment integrated in demonstrations & deployments** | • Developed approaches and tools for post retrofit evaluation and measurement of Indoor Environmental Quality (IEQ), which included assessment of spatial, occupant satisfaction, and environmental conditions in 21 buildings including seven CBEI test beds, which were actively used by CBEI investigators in the course of the program.<br>• Developed and demonstrated prototype of an interactive occupant dashboard to influence occupant behavior and plug loads, with preliminary results of 20% plug load energy reduction. This work did not proceed to deployment at DOE's request. |
| **New business models for unlocking value in building energy efficiency developed and deployed** | • Designed and piloted an on- bill financing program at The Navy Yard to incentivize deep energy retrofits, taking advantage of a wide variety of energy savings measures, including renewables and combined heat and power and shared results with 10 microgrid and utility partners across the U.S.<br>• Created an easy-to-use interactive guide and video demonstration to introduce users to DOE's Asset Score Tool and gained commitment from 19 portfolio owners (collectively addressing a 6.5 million square foot portfolio of buildings) to apply AST.<br>• By increasing adoption of AST, CBEI increased adoption of DOEs BuildingSync as the industry standard for cataloging data collected during building energy audits. CBEI secured commitment from three market partners for BuildingSync use testing: Connecticut Department of Energy and Environmental Protection, Washington State Department of Enterprise Services- Energy Program, and the City of Newark Department of Engineering. |
| **Education and Workforce Development** | |
| **Education/training board created and operating** | • Created an Education and Workforce Development Advisory Board in BP1; however, CBEI determined that input could be solicited from CBEI's education and workforce development network without the need for the administration associated with managing a Board solely for education and workforce development. |

| Objectives | Progress Against Objectives |
|---|---|
| **Educational pathway/pipeline development demonstrated and deployed** | • Developed career and development pathways and competencies required in each role for energy auditor, commissioning professional, operations professional, and energy manager in the Advanced Career Commercial Buildings Workforce Competency Model and Career Map, available to users since May 2015 on the Competency Model Clearinghouse website, and the Career Map has been publicly available since February 2016 on www.facilitiescareermap.feapc.com. |
| **Educator professional development (RETs) programs demonstrated and deployed** | • Within the first year, CBEI deviated from an emphasis on educator professional development to providing educational training to the broader workforce, including:<br>• Enhanced DOE's Building Re-Tuning (BRT) course with additional content and designed it to be a train-the-trainer program and piloted the course, which helped set the stage for BOMA and APPA to begin national deployment.<br>• Developed and established continuing education credits for a Broker Training course; conducted the training in multiple states; and the program is being expanded to a national audience through partnerships with national players.<br>• Offered the Building Operator Certification program, which continues to be offered by Pennsylvania College of Technology, which is part of the Penn State system. |
| **Associate through graduate degree programs demonstrated and deployed** | • Within the first year, CBEI deviated from an emphasis on degree programs to providing certificates in new areas and supporting the development of a new college-level course:<br>• Collaborated with the Pennsylvania Department of Environmental Protection to provide content for a college course: Leadership in Building Energy Efficiency, which includes BRT, Asset Score Tool, and Benchmarking training. It is offered at Penn State and is being expanded to other higher education institutions in Pennsylvania.<br>• Created a National Benchmarking Proficiency Certificate in collaboration with the U.S. Environmental Protection Agency and the Natural Resources Defense Council. The certificate program has been included in New York City's benchmarking program and is being offered by Salt Lake City Community College.<br>• Created a certificate of proficiency course in the use of DOEs AST, which is being deployed by the New Jersey Institute of Technology (NJIT). |
| **Diverse student recruitment/marketing programs fully underway** | • In the first year, CBEI convened all of the Philadelphia region (nine counties) Workforce Investment Boards to discuss energy efficiency. CBEI ended this work stream after the first year because fewer job opportunities in the region made this less relevant than originally conceived.<br>• CBEI supported the development of a new program between Drexel University's Goodwin College of Professional Studies and the School District of Philadelphia to assist incumbent workers into the energy efficiency field. |
| **Outreach programs to underserved/underrepresented people fully underway** | • Collaborated with labor organizations in the Philadelphia region, including the AFL-CIO, Philadelphia Area Labor Management Committee, and the Sheet Metal Workers to identify a productive method of engagement.<br>• Collaborated with The Franklin Institute to develop content for their workshops with K-12 teachers in the region to highlight the need to diversity the workforce.<br>• Collaborated with middle-school teachers from 9 schools to link building science and Science, Technology, Engineering and Math (STEM) education.<br>• At the conclusion of BP1, CBEI determined that the best path to engage with underrepresented and displaced workers was through the K-12 education focus area and the Building Energy Assessment Center. When these two efforts were discontinued in BP3, this focus was also terminated. |
| **Human capital development across HUB members fully underway** | • Held over 400 events in groups up to 100 that had as the principal or secondary focus the capital development of CBEI members. These events included conferences, workshops, webinars, and meetings, predominantly held with external stakeholders (e.g., manufacturers, utilities, government, service providers, and owners/operators). |
| **Demonstration, Deployment, and IP Management** | |

| Objectives | Progress Against Objectives |
|---|---|
| **Demonstration and deployment via operating test beds** | • Performed demonstration activities in 36 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. 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. |
| **Commercialization and Creativity Institute operating** | • 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, the Commonwealth of Pennsylvania, and Ben Franklin Technology Partners. 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 mentoring, business plan review, 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. The center also developed and operated the Opportunity Research Fund (ORF) grant program to enable collaboration among CBEI members and non-members to commercialize CBEI products; however, the ORF was stopped in the third year at DOE's request. |
| **Outreach and communication to partners and IP commercialization underway** | • Developed and maintained CBEI website to share CBEI findings and topics of interest. CBEI also produced more than 50 newsletters, distributed nationally.<br>• Local sponsor of the U.S. Green Building Council's Greenbuild 2013 conference in Philadelphia and organized a campaign around the conference to reach a national audience of approximately 25,000 attendees.<br>• Developed an IP management approach and a multi-institution IP agreement. The approach was followed for all commercialized content including the RTU coordinator and Air Handling Unit Fault Detection and Diagnostics solutions that are in the process of being commercialized. |
| **Leverage DOE Centers, Small Business Development Centers and NIST Manufacturing Extension Partnerships** | • Worked collaboratively with multiple DOE National Laboratories throughout the five years, including ORNL with the development and use of their Flexible Research Platform; NREL to collaborate on support for DOE's AST, SEED, and Buildings Performance Database (BPD); PNNL on sensors, controls, and building re-tuning; and NETL on contract management.<br>• Wharton Small Business Development Center (SBDC) was active in establishing a presence at CBEI and provided advice to 21 small businesses in the industry about strategies to grow in the industry.<br>• Engaged with over 50 regional manufacturers to expose them to CBEI through on-site visits by CBEI and the New Jersey Manufacturing Extension Partnership (NJMEP) and with support of NIST MEP E-RIC. |
| **Develop new partnerships and RDD&D projects** | • Developed partnerships with 200 organizations. This includes engagement with at least 50 building owners/tenants, 20 utilities, 30 technology developers, 35 municipalities, 40 non-governmental organizations, 15 service providers, and 10 public/private sector labs.<br>• Collaborations of CBEI partners allowed for easy partnering on other FOAs from DOE and DOD. |
| **Outreach to underrepresented partners** | • CBEI followed multiple paths to develop partnerships with entities not solely engaged in commercial building retrofits. Efforts were wrapped into the work around underrepresented workers, particularly engaging with labor organizations, schools and other educational institutions (e.g., The Franklin Institute) |

As shown in the figure above, CBEI made substantial progress in achieving the objectives set out in the original proposal, particularly taking into account the reduction in funding for BP4 and BP5. CBEI not only developed many new solutions but demonstrated them in operating buildings, in collaboration with many market stakeholders, which has also resulted in strong deployment pathways for the solutions. More detail is provided in the next section on select accomplishments to further describe the impact of these accomplishments in supporting the transformation of the market for small and medium commercial retrofits.

# III. Project Activities

CBEI grouped research into five activity areas to address five challenges in the market, as described in the Introduction. The titles of these activity areas changed slightly each year, but they remained consistent in theme over the course of the five years. Each year, research projects were aligned to a primary activity area; however, CBEI did not create silos for the research because in many cases the research addressed multiple challenges. For example, the development of the Benchmarking Certification program is primarily aligned with Education and Workforce Development, but also supports the Public Policy activity area, because it benefits the workforce addressing the growth of city benchmarking ordinances. CBEI partners worked collaboratively and in an integrated manner for the research. The majority of research projects had multiple partners participating in the research, to apply the most relevant technical expertise within the Consortium to the research.

For each activity area summary below, the report provides a description of the challenge being addressed and the research objectives (Hypothesis), how CBEI approached the research and how the approach may have changed over the five years (Approaches Used and Departures from Planned Methodology), and a more detailed description of the impacts of multiple highlighted research projects, including how the solutions were deployed.

## A. Tools for Integrated Design, Verification, and Modeling

### Hypothesis

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. Additionally, it is cost prohibitive to support the design of smaller projects with existing modeling tools. The retrofit teams typically do not 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. Reduced order modeling and integrated systems would be useful to reduce the time and expertise required to achieve integrated designs in small/medium buildings.

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, and 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.

## Approaches Used and Departures from Planned Methodology

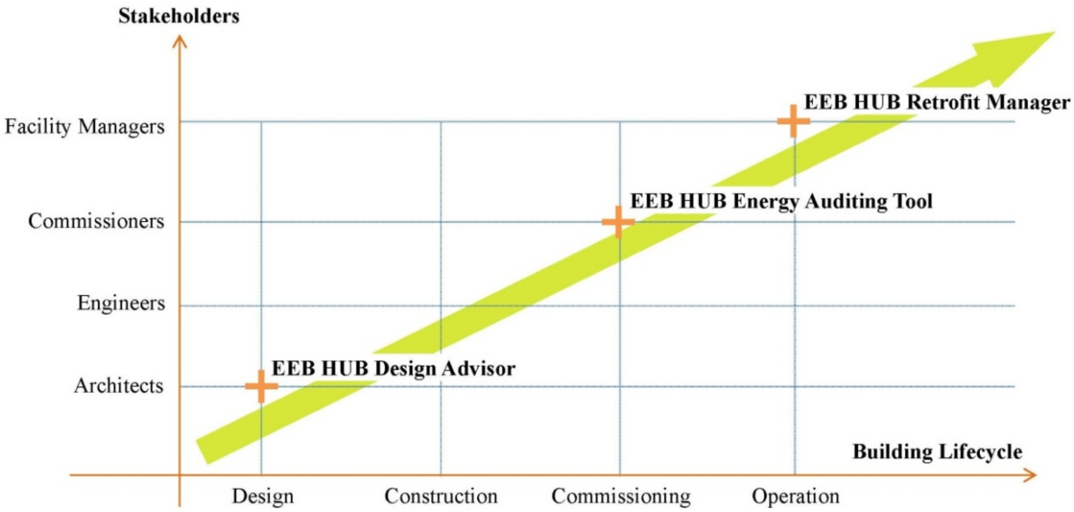
### APPROACH

CBEI researchers conducted a gap analysis of processes and tools currently applied to integrated design to identify specific research focus areas. Four 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 develop simple tools that can be accessed through a cloud-based platform to support evaluation of design options, conduct energy audits, and continuously evaluate operational and equipment improvements. The fourth 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. Each of these paths were pursued across CBEI's five years with the exception of the cloud-based platform and integrated tool development, which is further described below. Highlights from the other three paths are provided in the Impacts section.

### DEPARTURES FROM PLANNED METHODOLOGY

In BP1 CBEI set out to develop and deliver a new cloud-based methodology for integrated retrofit design project delivery. The system would include computational tools and performance simulation methods to substantially enhance the speed with which design studies can be conducted and improve the extent to which energy performance guarantees can be made during retrofit design. By BP3 CBEI successfully delivered and demonstrated a prototype simulation tool platform, accompanied by three computation tools for integrated design and performance. These tools included: a Design Advisor Tool to allow designers to rapidly assess the energy impact of key design decisions; an Energy Audit Tool to standardize data collection and analysis and reduce audit time by 20 percent; and a Retrofit Manager Tool to help facility managers evaluate performance for better continuous building management (Figure 5). These tools were integrated into a cloud-based platform to allow easy sharing of data across tools and successfully demonstrated; however, in BP3 DOE requested CBEI to pivot from further demonstrating these tools to focus on supporting enhancement and deployment of existing DOE tools. The Retrofit Manager Tool development helped support CBEI's efforts to enhance DOE's OpenStudio.

**Figure 5: Proposed CBEI Energy Simulation Platform**




## Impact Highlights

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.

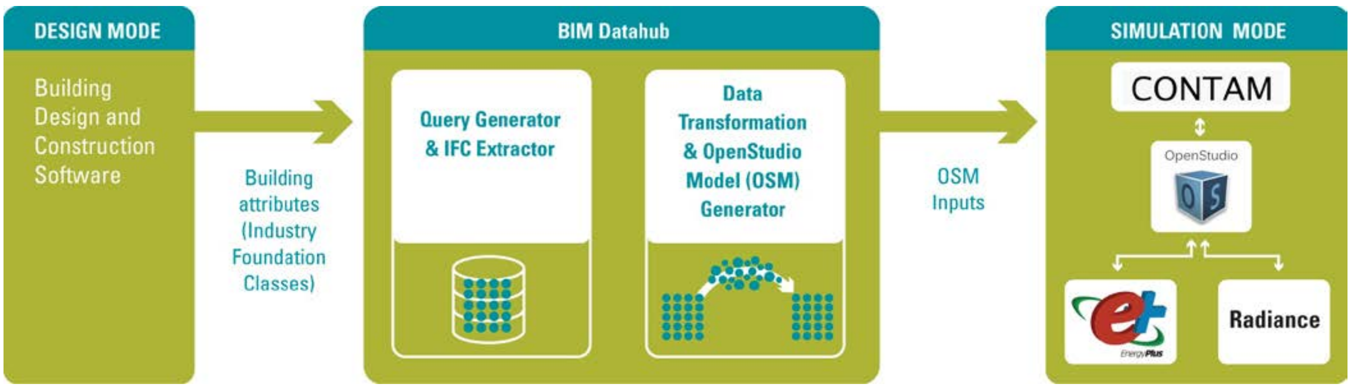
**Advanced Energy Retrofit Roadmap**: CBEI researchers recognized that the market lacks process-based products which offer the architecture, engineering and construction industry a comprehensive action plan for applying Integrated Design principles to advanced energy retrofits in small/medium buildings.

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, illustrated in Figure 6, makes it possible for design teams to more easily apply BIM in retrofits.

**Figure 6: BIM Datahub**




**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

**Immersive Construction Laboratories (ICon Lab)** — CBEI developed the 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.

# B. Components, Sub-Systems, Controls, and Diagnostics

## Hypothesis

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 and the building envelope (windows, walls, doors) have a long product life or require invasive and disruptive action. Equipment making up these systems also tend to be addressed singularly, without thought to integrated solutions and the potential for greater energy reduction when they are addressed in an integrated manner. The ability of service providers or utilities to offer integrated solutions as packages 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.

## Approaches Used and Departures from Planned Methodology

### 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 integrated packages of technologies (HVAC packages, roof systems, wall systems, and window packages) and building operations solutions utilizing sensors and controls.

For the HVAC packages and wall 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 packages were developed, tools and best practice guides were developed to accelerate adoption. Research on roof systems and window packages were approached in the same manner but research was discontinued on each of these for different reasons, as noted in the Departures from Planned Methodology section below.

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. Work performed on sensors and controls proceeded from initial conception through development throughout the five years. No sensors and controls work streams were discontinued.

### DEPARTURES FROM PLANNED METHODOLOGY

Based on the analysis conducted in the research roadmap in BP1, CBEI determined that research on roof systems and windows packages would be useful for the small/medium commercial building market. Research at the time indicated that there was little information available on effective roof systems, preventing owners from taking advantage of periodic roof replacements to improve the energy performance of the building. Also, CBEI determined that there was a growing set of improved window options but few solutions that integrated windows with building systems to improve building efficiency and occupant comfort.

CBEI conducted research on roof retrofits in the first three budget periods in collaboration with a national roofing association and two leading manufacturers. 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 was determined to reduce cooling loads by 12%, and incorporating skylights with lighting controls could 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. By the end of BP3, many of these solutions were beginning to achieve market traction; therefore, CBEI redirected their envelope work to focus on wall retrofit solutions, which are further described in the Impact Highlights below.

CBEI conducted research on window packages in BP2 and in the early part of BP3. In BP2 work centered on developing an intelligent glazing package, which would use a sensor to measure real time energy flux through a window. The sensor would communicate wirelessly with the building energy management system for more efficient thermal control. The research proceeded through a laboratory demonstration of the technology; however, in BP3 DOE requested that work which included the development of hardware solutions be discontinued. CBEI also pursued the development of window and lighting packages. This work included evaluating different combinations of three advanced glazing products, two framing options, three shading types, and two direct/indirect control options. CBEI conducted preliminary modeling to develop window/lighting packages; however, this work was discontinued by DOE because it did not fit within DOE’s priorities at the time.

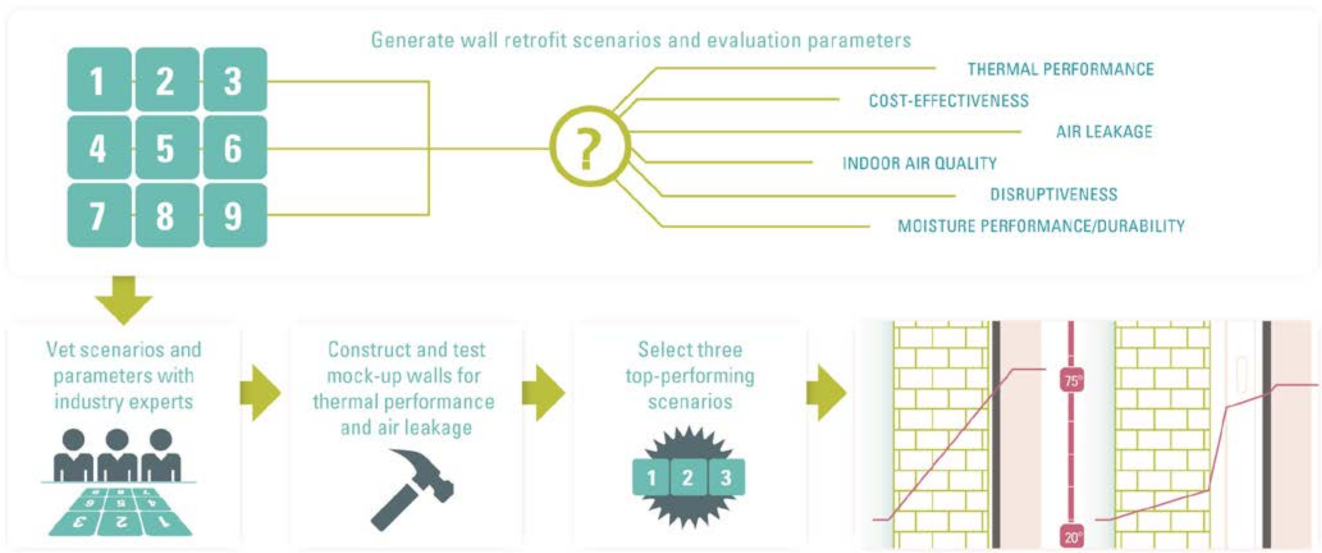
## Impact Highlights

### 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 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 the Oak Ridge National Laboratory’s Flexible Research Platform and underwent extensive evaluation in a controlled environment.

The packaged solutions, illustrated in Figure 7, 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.

**Figure 7: Wall Retrofit Package**



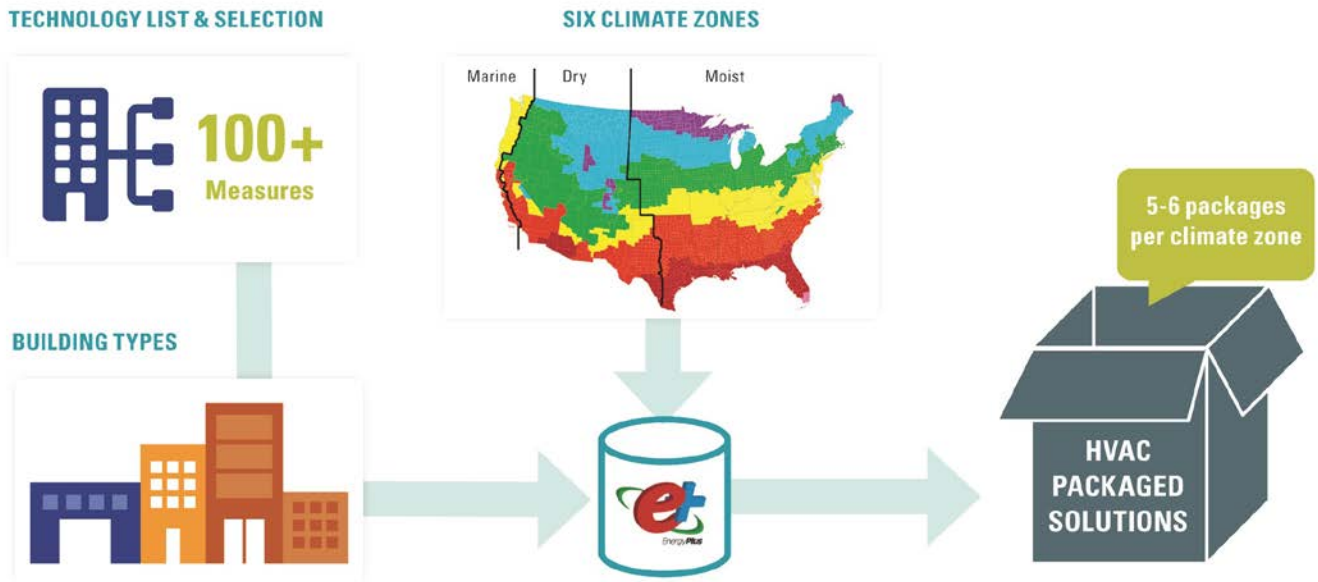

## HVAC PACKAGES

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 them 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. The approach is illustrated in Figure 8.

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.

**Figure 8: HVAC Packages**




## 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

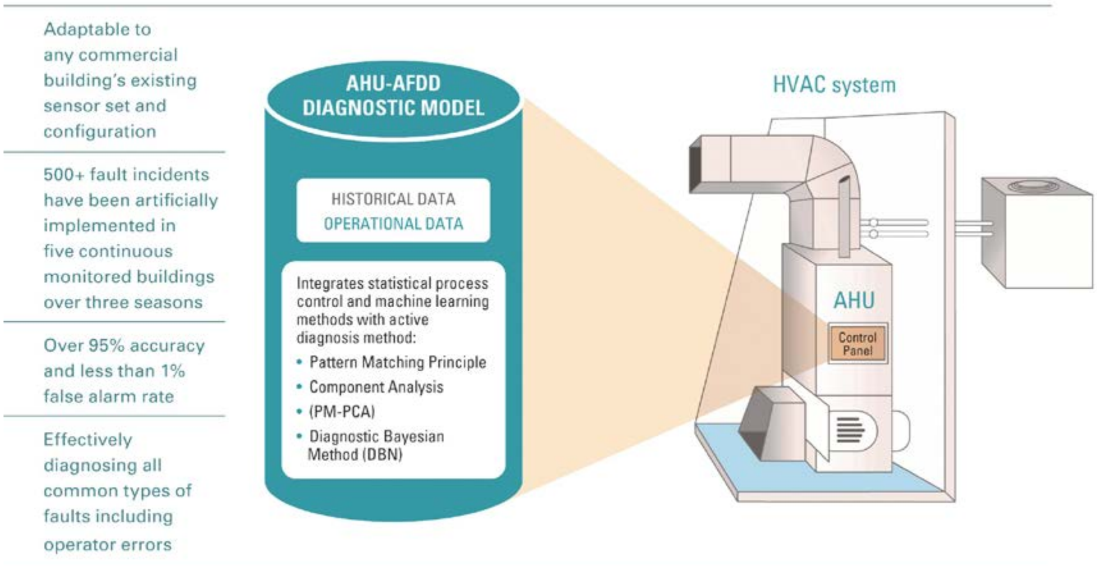
CBEI developed site-specific, control-oriented models that are needed for practical application of model-predictive controls. The models can be trained using data collected over a relatively short time period (e.g., one to two weeks) with better than 10% prediction accuracy. In addition, different approaches 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 (Figure 9) 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.

**Figure 9: RTU Coordinator**


## 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 (Figure 10). 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.

**Figure 10: AHU AFDD**




## 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.

# C. Public Policy, Behavior, Economics, and Business

## Hypothesis

The diverse nature of small/medium commercial building 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.

## Approaches Used and Departures from Planned Methodology

### APPROACH

Recognizing that major shifts in retrofits in small/medium buildings are dependent on actions taken at scale, CBEI conducted a review in BP1 of current and trending policies, regulatory strategies, and incentive programs that have the most significant bearing on the implementation of retrofits in large numbers of commercial buildings. This research set the agenda for the CBEI public policy, behavior, economics, and business work across the five years. The BP1 analysis led to a focus on researching challenges and opportunities in energy benchmarking and disclosure, historic preservation, code compliance, and municipal portfolios in BP2. Major effort in the subsequent years was focused on developing best practices in building performance transparency and benchmarking and supporting other regions in their implementation of transparency and benchmarking programs. CBEI also maintained focus on developing and testing guidance on change of occupancy code compliance.

Several focus areas were halted in BP3, as described below, and in BP4, CBEI was subsequently requested by DOE to support the development and deployment of multiple DOE-developed solutions, including the Asset Score Tool (AST) and Standard Energy Efficiency Data (SEED) platform. This work involved reaching through CBEI's network to identify use cases and build training materials on the use of AST and an app for analyzing and visualizing portfolios in SEED and new computer code that retrieved and stored utility 15-minute interval Green Button data and paralleled with the existing PostgreSQL relational database. In BP4 and BP5, CBEI also tested approaches useful for utilities to reach more customers by engaging utilities in the technology package development work to support improved incentive programs and testing a new on-bill financing model to spur deep energy retrofits.

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 and whole building data access 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.

## DEPARTURES FROM PLANNED METHODOLOGY

In BP2, CBEI researched and wrote white papers on eight policy issues affecting the retrofit market, including:

- Energy benchmarking and disclosure
- Conflicts between historic preservation and energy efficiency
- Code compliance challenges
- The Pennsylvania Separations Act
- Standup of the Philadelphia Energy Authority and associated challenges facing municipal portfolios
- Property tax incentives
- Opportunities to collaborate with peer organizations
- Opportunities to support developing a chapter on systems integration for a book by the Alliance Commission on Energy Efficient Policy (ACEEP).

(These were produced in BP2 Subtask 6.1 No25 and No26 deliverables and can be found in appendix A)

Based on the analysis, CBEI determined that they could not have sufficient impact in historic preservation, the Pennsylvania Separations Act, and property tax incentives, so there was no additional work performed in those areas in subsequent BPs. The results of the analysis for the Philadelphia Energy Authority on existing practices in other jurisdictions for managing operating and capital budgets to promote building energy efficiency, and the chapter for the ACEEP book were considered complete at the end of BP2. CBEI continued informal collaboration with peer organizations beyond BP2, but these were no additional projects as a result of this white paper.

In BP4, CBEI initiated an effort to identify opportunities to align building owners and service providers in the small/medium commercial market. Often this market is served by service-specific providers (e.g., HVAC service providers, window providers, roofing providers). Because these service providers do not often collaborate, building owners do not reap the benefit of integrated retrofits. CBEI researchers began an analysis of options, primarily at a policy level (e.g., for a state or utility program) to develop approaches that would incentivize collaboration. However, CBEI leadership determined that this work was not achieving sufficient impact at its go/no-go point and discontinued the research.

In BP5, CBEI initiated a project to support one or more municipalities with approaches for developing a benchmarking help desk. This project was discontinued at the first go/no-go point, since the partner municipalities had not yet made sufficient progress in their programs such that the team could assist them in developing a help desk.

## Impact Highlights

### TRANSPARENCY AND BENCHMARKING

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. Additionally, CBEI met with leaders from other cities to share these materials so that these cities could take advantage of the lessons learned in the EDA cities. For example, the Pittsburgh, PA Mayor's office included the material in the early draft for their benchmarking policy.

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, as well as past instructional webinars, 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. Through CBEI's work, AIA PA has taken a role to continue disseminating the value of AST to their members.

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 — 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 and the increased use of Green Button data. 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.

### 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.

# D. Education and Workforce Development

## Hypothesis

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.

## Approaches Used and Departures from Planned Methodology

### 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 partnered 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 was based on the collective input from the full spectrum of employers and educational institutions focused on this market segment. In BP1, CBEI conducted an analysis of educational gaps. This analysis set the stage for the remaining four years and focused CBEI on developing a structured approach to professional development for workers in the field and a set of targeted training programs that fill some critical gaps. In BP1 and BP2, CBEI also identified opportunities to connect underrepresented and displaced workers as well as veterans with the growing market. It also partnered with education providers for K-12 and college students to increase interest in pursuing jobs in the energy efficiency field.

### DEPARTURES FROM PLANNED METHODOLOGY

In BP2 and BP3, CBEI initiated a program to develop content for, and engage middle school and high school teachers to enhance science, technology, engineering, and mathematics (STEM) programming with content about building science. This included a focus on leveraging school energy use data in the STEM programming. In

BP2 CBEI established working relationships with the American Association for the Advancement of Science (AAAS), the Alliance to Save Energy (ASE) and US Green Building Council (USGBC), to leverage their network to promote curriculum partnerships. CBEI developed a ten member teacher cadre experienced in teaching building energy efficiency; they were to develop and test activities that linked building science and STEM education. In BP3 CBEI supported two project-based educational modules at The Workshop School in which 1) students convert a shipping container into a fully monitored high energy efficiency living space, and 2) students conduct a study to replace existing light bulbs in commercial and residential properties with highly efficient LEDs. The program was a success; however, The Workshop School was relocated and CBEI funding reductions in BP4 and BP5 resulted in CBEI discontinuing K-12 educational development.

In BP2, CBEI researched and began preparation to develop an approach to using CBEI research projects as additional external training opportunities. The proposed result would be the Building Energy Assessment Center, which would integrate practical experience for emerging professionals with CBEI demonstration projects and deployment activities. The Center would also pilot and test new tools and technologies as it delivered education, training, and teaching programs to the market. The intent was to demonstrate how to set up and run the Center as a model for other regions to replicate. In BP2, the CBEI team developed the concept and in BP3, the team began development of the long term-business plan for the Center. However, upon review, CBEI's executive board decided to terminate the project due to lack of long-term financial feasibility of the Center.

CBEI had a focus on improving opportunities for underrepresented and displaced workers. In BP1, CBEI conducted research on best practices for recruiting, educating, and training these workers in the building trades. At the conclusion of BP1, CBEI determined that the best path to engage with underrepresented and displaced workers was through the K-12 education focus area and the Building Energy Assessment Center. When these two efforts were discontinued in BP3, this focus was also terminated.

From work conducted in BP1 – BP4, CBEI developed a robust energy efficiency worker career map. In the first quarter of BP5, DOE required CBEI to identify a process and funding model for the long-term maintenance and use of the career map as part of a go/no-go decision point. To fulfill this requirement, CBEI proposed hosting the career map website for two years; however, DOE determined that this was not sufficiently long term and discontinued further work on the career map in BP5. Subsequently, CBEI was able to obtain commitment from its research collaborator, Facility Engineering Associates, to host and update the career map.

## Impact Highlights

### 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.

## 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.

## 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.

## 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.

# E. Demonstration, Deployment, and IP Management

## Hypothesis

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, which inhibits deployment. As a result, newer solutions are harder to get into the market.

Similar challenges also exist in the market for commercializing new technologies. In addition to needing real-world demonstrations, entities that are trying to commercialize a technology often struggle with developing their business plan and making connections that will allow them to successfully sell their technology or services. This is true whether the new approaches are developed by a startup, an established business, or through a CBEI research project. Additionally, agreements must be reached about how intellectual property (IP) will be protected in the process of technology development and commercialization. To address these challenges, CBEI had a significant focus on conducting real-world demonstrations of existing and new technologies and service models. To ensure better market uptake of demonstrated solutions, CBEI worked with industry on deployment of all solutions, and developed approaches to support commercialization and protect IP.

## Approaches Used and Departures from Planned Methodology

### APPROACH

CBEI developed a robust capability for performing real-world demonstrations. The Consortium identified and developed test beds of buildings at TNY, including Buildings 1, 100, 101 (used as the CBEI HQ for multiple BPs), and 661 (current CBEI HQ). CBEI established baselines for these buildings and installed monitoring and verification (M&V) equipment to prepare them as test beds. Additionally, CBEI developed and issued a request for proposal to solicit building owners interested in using their buildings as test platforms, resulting in a suite of available buildings with different use types to allow a variety of test conditions. CBEI also identified buildings on partner campuses, which were also used as test platforms. CBEI developed the necessary infrastructure to gather, store, and analyze data from the buildings. CBEI used these monitored platforms to conduct real-world demonstrations of technology packages identified or developed by CBEI researchers.

Recognizing the gap in the market for helping new technologies achieve commercial scale, CBEI established the CBEI 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, the Commonwealth of Pennsylvania, and Ben Franklin Technology Partners. 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 mentoring, business plan review, 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.

To support the proper protection of IP, CBEI developed an MOU to codify the process for disclosing and prosecuting any new IP generated as a result of CBEI funding. This included disclosure requirements to DOE, Penn State, and the CBEI Principal Investigator's Member organization. The MOU addressed IP developed solely or jointly among CBEI partners. It further codified the licensing and commercialization process. Equally important, the MOU codified the agreement to negotiate in good faith for existing background IP that may be required to practice newly developed IP at CBEI. The MOU was instrumental in ensuring CBEI IP was identified, secured, and actively offered to the marketplace.

### DEPARTURES FROM PLANNED METHODOLOGY

In the CBEI FOA proposal, the team proposed a commercialization center (referred to as the Commercialization and Creativity Institute (C2I)), which would operate an Opportunity Research Fund (ORF) in addition to providing incubation services for new advanced energy retrofit companies. The ORF would add to the culture of innovation CBEI was fostering by providing a means to develop new ideas. In BP1, CBEI set up the infrastructure to operate the ORF, including developing the process to solicit and evaluate proposals and fund research projects. Proposals were required to have an existing CBEI partner and a co-applicant from the commercial sector. CBEI successfully solicited 83 external reviews, who reviewed 42 proposals. CBEI selected seven proposals for funding, and those seven were approved by DOE. One of these projects presumed the development of the Flexible Research Laboratory at ORNL, which was used for testing wall retrofit systems in subsequent BPs. During the development of the BP2 SOPO, Congress and DOE requested that CBEI discontinue the ORF program as a result of concerns over CBEI conducting solicitations outside standard federal processes. As a result the C2I was renamed the Hub Commercialization Center and then CBEI Commercialization Center, which remained focused on supporting the incubation of new business ventures focused on the advanced energy retrofit market.

## Impact Highlights

### DEMONSTRATIONS

CBEI has developed a robust capability for performing real-world demonstrations. The Consortium has performed demonstration activities in 36 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.

### DEPLOYMENT, COMMERCIALIZATION, AND IP

CBEI's membership and approach to solution development, deployment, and commercialization was designed specifically to drive greater uptake of solutions in the market. CBEI structured its research to ensure continuous market engagement from problem identification through solution deployment and commercialization. Researchers drew on the extensive market networks of the Consortium partners to identify and engage relevant stakeholders before, during, and after each project. For example, in just BP4 and BP5 projects, CBEI researchers engaged directly with 35 owners/operators/tenants, 17 retrofit providers, 23 utilities, 24 solution vendors, 37 city/state/federal agencies, and 27 Technical Advisors recruited for their industry expertise. This allowed solutions to be shaped by input from critical users of the solutions. Additionally, two technologies are on path to be commercialized with industry partners, using IP guidance developed in BP1. Other technology package solutions have been introduced to the market through partner associations and through their inclusion in standard modeling tools. All best practice solutions were distributed to interested partners, including cities, states, utilities, and microgrid managers. Lastly, all final products are available publicly on the CBEI website.

The CBEI Commercialization Center was jointly funded by CBEI and the U.S. Department of Commerce's Economic Development Administration. The Center focuses on supporting commercialization and deployment of advanced energy retrofit-related products and services. It also offers a marketing, technology assessment, and commercialization resource provided by the CBEI's commercialization technology assessment experts through the Center. An integrated suite of programs and services are available to entrepreneurs and established companies. Services include mentoring, business plan review, 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. Over the course of the five years, this joint funding resulted in support to ~500 companies, with 10 receiving seed investment of $1.4M. These 10 companies provided a combined $1.9M in matching investment and raised an additional $54M of external investment over the last five years.

# IV. APPENDIX A: Products Developed

## A) Contract deliverables submitted to DOE

Listed by budget period. Task structures and naming conventions changed over the lifetime of the consortium.

**BUDGET PERIOD 1 – Feb. 1 2011- Jan. 31, 2012**

Q1 - 1.1.1 Financial and Programatic reporting - Quarterly 1 Report.pdf
Q1 - 1.1.2 Budget and Adm Mangt system - PMP.pdf
Q1 - 1.1.3a Initial Spherical integration program plan - GPIC Overview.pptx
Q1 - 1.1.3b Initial Spherical integration program plan - GPIC 22 min video.wmv
Q1 - 1.1.7a Quarterly Executive Board and Advisory Board meetings - ExB roster.pdf
Q1 - 1.1.7b Quarterly Executive Board and Advisory Committee meetings - April 18 Executive Board Meeting Agenda.doc
Q1 - 1.1.8 Subaward agreements (CONFIDENTIAL)
Q1 - 1.2.1a Bldg 661 design charrette.ppt
Q1 - 1.2.1b Bldg 661 design charrette - GPIC PSU Program Package.pdf
Q1 - 1.2.2 Plan for Bldg 661 integrated design process - EDA Activities and Budget.doc
Q1 - 1.3.1a PSU I-CON Lab specification.pdf
Q1 - 1.3.1b CISCO telepresence order (CONFIDENTIAL).pdf
Q1 - 1.3.1c Navy Yard I-CON Lab specification and RFP.pdf
Q1 - 1.3.1d Navy Yard I-CON lab equipment order (CONFIDENTIAL).pdf
Q1 - 1.3.3 Information and Communication tech training - SharePoint Training.pdf
Q1 - 1.4.2a Publication of regular periodic update - GPICHUB_ORG.pdf
Q1 - 1.4.2b Publication of regular periodic update - GPIC FaceBook.pdf
Q1 - 1.4.2c Publication of regular periodic update - GPIC Twitter.pdf
Q1 - 1.4.4a HUB marketing materials - GPIC one-pager.docx
Q1 - 1.4.4b HUB marketing materials - GPIC Brochure-v5.pdf
Q1 - 1.4.4c HUB marketing materials - GPIC logo options.pdf
Q1 - 1.4.4d HUB marketing materials - GPIC logo options Set2.pdf
Q1 - 1.5.3 HUB historical reporting and program assesment team.pdf
Q1 - 1.5.5a HUB historical reporting and assesment plan.docx
Q1 - 1.5.5b Plan for HUB historical reporting and assessment data collection.docx
Q1 - 2.1.1 Y1-Q1 Deliverable- Methodology_selection.pdf
Q1 - 2.2.1 GPIC Report_Y1Q1_Revit Model of Building 661.pdf
Q1 - 2.2.2 GPIC report Immersive Lab - y1q1.pdf
Q1 - 2.4.1 GPIC Cloud Infrastructure Report.pdf
Q1 - 2.5.1 Historical Reporting Team.pdf
Q1 - 2.5.2 Task 2 Metrics.pdf
Q1 - 2.5.3 Y1Q1 Data Collection Plan.pdf
Q1 - 3.1.1 Building 661 Technological Spec - Progress Report.docx
Q1 - 3.2.1 Technology Roadmap - Progress Report.docx
Q1 - 3.3.1 Database Report - Progress Report.docx
Q1 - 3.4.1 Preliminary Task 3 assessment metrics established.docx
Q1 - 3.4.2 Focus Groups Established.docx
Q1 - 3.4.3 Historical reporting and assessment data collection.docx
Q1 - 4.1.1a Final_Contact_List.docx
Q1 - 4.1.1b Contact_List.docx
Q1 - 4.1.2 SOPO_Distilled_Fishbowl_Copy.pdf
Q1 - 4.1.3 Project_Fishbowl_one_page_5.pdf
Q1 - 4.3.1 Repository_Report.pdf
Q1 - 4.4.1 Regional_Advisory_Committee.pdf
Q1 - 4.4.2 CBB_DRAFT_Agenda_-_4.19.11.docx
Q1 - 4.5.1 Assesment and Continuous Improvement.pdf
Q1 - 4.5.1.pdf
Q1 - 5.2.1 Gap Analysis_WorkPlan.doc

Q1 - 5.3.1 GPIC-Power and EnergyRelatedJobs-IHSGlobalInsight.xlsx
Q1 - 5.4.1 Green Jobs May 2011--PartialListing.doc
Q1 - 5.5.1 WORKFORCE INVESTMENT BOARDS PILOT PROGRAM.docx
Q1 - 5.7.1 GPIC-DRAFT WorkforcePerformanceTables_May2011.xlsx
Q1 - 6.1.1a Intra-HUB structure - HUBlog.jpg
Q1 - 6.1.1b Intra-HUB structure - Add HUBblog.jpg
Q1 - 6.1.1c Intra-HUB structure - Add a blog.jpg
Q1 - 6.1.1d Intra HUB structure - images1-HUBlog.jpg
Q1 - 6.1.1e Intra-HUB structure - Web Registration Form.jpg
Q1 - 6.1.1f Intra-HUB structure - Web Registration Form 2.jpg
Q1 - 6.2.1a Uniform documents - Survey for Manufacturers.pdf
Q1 - 6.2.1b Uniform documents - Surveys.docx
Q1 - 6.3.1 Multi-institution IP agreement.pdf
Q1 - 6.4.1a Framework, structure and data policies - GPIC Memorandum Template.docx
Q1 - 6.4.1b Framework, structure and data policies - GPIC Project Reporting.docx
Q1 - 6.5.1a Guidelines for C2IF - ORF RFP.doc
Q1 - 6.5.1b Guidelines for C2IF - RFQ-Draft.docx
Q1 - 6.6.1a Building 661 baseline info.ppt
Q1 - 6.6.1b Building 661 baseline info - Task 6 Deploy_and_Comm__Services_DRAFT.ppt
Q1 - 8.1 Templates for actual result tracking - GPIC Deliverables Tracking.pdf
Q1 - 8.3 Templates to facilitate development and submission of reports
Q2 - 1.1.4a Intellectual Propoerty MOU.pdf
Q2 - 1.1.4b NDA.pdf
Q2 - 1.1.5 GPIC stage gate process Year 1.docx
Q2 - 1.1.6 - Initial spherical integration assessment report -Advisory Board Draft Charter.docx
Q2 - 1.1.7a Second Quaterly Executive Board meeting - Advisory Board Charter.doc
Q2 - 1.1.7b Second Quaterly Executive Board meeting - Agenda.docx
Q2 - 1.1.7c Second Quaterly Executive Board meeting - Proposal on Planning Marketing and Governance.docx
Q2 - 1.1.7d Second Quaterly Advisory Board meeting - Roster 8-8-11.docx
Q2 - 1.1.7e Second Quaterly Advisory Board meeting - Notes.docx
Q2 - 1.2.3 Bldg 661 programming package.pdf
Q2 - 1.3.4 GPIC Project Management Plan.pdf
Q2 - 1.5.1 and 1.5.4 Preliminary Task 1-HUB Continuous improvement plan.docx
Q2 - 2.1.2 - Design Management Techniques - Bldg 661_Final.pdf
Q2 - 2.2.3 - Tool_Use_Survey_Energy.pdf
Q2 - 2.2.4 - Building661_EnergySimulation.pdf
Q2 - 2.2.4 2011 Winter Simulation Conf Paper on Daysim.pdf
Q2 - 2.2.4 Daylighting-661_Report.docx
Q2 - 2.3.1 MZ Security Metric Demonstration - MZ.pdf
Q2 - 2.4.2 Cloud DB and Infrastructure.pdf
Q2 - 3.1.2 Building 661 Technological Spec - Progress Report.docx
Q2 - 3.2.2 Technology Roadmap - Progress Report.docx
Q2 - 3.3.2 Database Progress Report.docx
Q2 - 3.4.4 Stagegate Process Established.docx
Q2 - 3.4.5 Operations Assessed and Documented.docx
Q2 - 4.1.2 Interim Report on Integrated Design-Martin.pdf
Q2 - 4.1.2 PF_Interim Report_1.pdf
Q2 - 4.1.2a Interim report on survey of local and national design teams.pdf
Q2 - 4.1.2b Project Fishbowl Quarter 2 Report.pdf
Q2 - 4.3.2 Knowledge Platform One Pager.docx
Q2 - 4.3.2 Q2 Repository report.pdf
Q2 - 4.3.2 Report on GPIC-wide desired outputs for repository.pdf
Q2 - 4.5.2.pdf
Q2 - 4.5.3 and 4.5.4 and 4.5.5.pdf
Q2 - 4.5.3.pdf
Q2 - 4.8.1 Arch and Energy Workshop Poster.pdf
Q2 - 4.8.2a_Workshop Participants.pdf

Q2 - 4.8.2b_Workshop Proposal.pdf
Q2 - 6.3.2 An intellectual property team Charter.pdf
Q2 - 6.5.2 The Creativity and Commercialization Institute Fund.pdf
Q2 - 6.5.3 First C2IF Request for Proposals.pdf
Q2 - 6.7.1a Preliminary Task 6 assessment metrics, Task 6.2 Activity and Process Evaluation and ImprovementQ2.xlsx
Q2 - 6.7.1b Preliminary Task 6 assessment metrics, Task 6 4 Activity and Process Evaluation and ImprovementQ2.xlsx
Q2 - 6.7.1c Preliminary Task 6 assessment metrics, Task 6 5 Activity and Process Evaluation and Improvement 7 20 11.xlsx
Q2 - 6.7.1d Preliminary Task 6 assessment metrics, Task 6.1 Activity and Process Evaluation and Improvement Q2 7 20 11.xlsx
Q2 - 6.7.1e Preliminary Task 6 assessment metrics, Task 6.3 Activity and Process Evaluation and Improvement 7 19 11.xlsx
Q2 - 6.7.1f Preliminary Task 6 assessment metrics, Task 6.6_Evaluation_Improvement_Analysis_Task6 6Q2.xls
Q2 - 6.7.2 Assess all activities in 2nd Quarter_.pdf
Q2 - 8.4 First Quarterly Report.pdf
Q3 - 1.1.08 Sub-award agreements with HUB members (CONFIDENTIAL).pdf
Q3 - 1.1.09 Operational metrics_- GPIC Deliverables Summary Sheet v2.xlsx
Q3 - 1.1.10 Modified spherical integration program report.pdf
Q3 - 1.1.11 Third Quarterly Executive Board Meeting.pdf
Q3 - 1.1.12 GPIC EEB Hub 5 Year Plan.docx
Q3 - 1.2.5 Architectural design and engineering (AE) firm selected.pdf
Q3 - 1.3.5 Integrated construction (I-CON) Lab installed .pdf
Q3 - 1.3.6 Cisco Telepresence_directory.pdf
Q3 - 1.4.7 Partners and stakeholders engaged in HUB activities.docx
Q3 - 2.1.3 Defining the Integrated Process.pdf
Q3 - 2.2.5 Progress-ControlsTeam.zip
Q3 - 2.2.5 PSU Weather Processing Report.pdf
Q3 - 2.2.6 Report on Technical Gaps-CMU.zip
Q3 - 2.3.2 Report on Assessing FFD-LES-DES.pdf
Q3 - 2.3.3 Rapid Multizone Modeling Report - MZ.pdf
Q3 - 2.3.4 Demonstration of Modeling Methodology UVGI.pdf
Q3 - 2.4.3 Cloud Framework Architecture.pdf
Q3 - 2.5.5 and 2.5.6 Task 2 Historical Report and Assessment Year 1 1H_final.pdf
Q3 - 2.5.7 Historical Report Year 1 1H_final.pdf
Q3 - 3.1.3 Progress Report - Building 661 Technological Spec.pdf
Q3 - 3.2.3 Progress Report - Technology Roadmap.pdf
Q3 - 3.3.3 Progress Report - Database.pdf
Q3 - 3.4.6 Task 3 Operations Assessed and Documented.pdf
Q3 - 4.1.3 Preliminary Planning for Workshop.pdf
Q3 - 4.1.3 Summary Report of Local and National Design Teams.pdf
Q3 - 4.1.3-Fishbowl Interim Report-Interim Report.pdf
Q3 - 4.1.3-Interim IPD Roadmap-Interim Report.pdf
Q3 - 4.2.2 Policy and Market Macro Modeling-Mid-sized Offices.docx
Q3 - 4.2.3 PSU OB NY Database Characterization.pdf
Q3 - 4.2.3 PSU OB Survey- Database of Building Owners and Occupants.pdf
Q3 - 4.2.3 Rutgers Survey Instrument- Expert Technology Assessments.pdf
Q3 - 4.2.3 TC CHAN BPAT Model Report-Draft 10-20-11.pdf
Q3 - 4.2.3 UPenn TCChan Yr1 Deliverable Report.pdf
Q3 - 4.2.4 Drexel Occupant Behavior-Lit Review.pdf
Q3 - 4.2.4 GPIC Survey Report-RachaelShwom.pdf
Q3 - 4.2.4 PSU EM Demand Response Survey-Paper.pdf
Q3 - 4.2.4 PSU OB Experimental Intervention Design Supporting Occupant Behavior Studies.pdf
Q3 - 4.2.4 PSU OB Occupant Behavior Website Screen Shots.pdf
Q3 - 4.2.4 PSU-OB Study Overview- Experimental Intervention Design Supporting Occupant Behavior Studies.pdf
Q3 - 4.2.4 Rutgers Survey Instrument-10 18 2011.pdf
Q3 - 4.2.4 Va Tech Consumer Behavior Literature Review.pdf
Q3 - 4.2.5 - Capacity vs. Demand Report.pdf
Q3 - 4.2.5 PSU SG Serious Games Website-Screen Shots.pdf
Q3 - 4.2.5 PSU-EM Capacity vs demand report.pdf
Q3 - 4.2.5 PSU-OB Ecological Momentary Assessments (Daily Smart Phone Surveys).pdf

Q3 - 4.2.5 VT Electricity Price Response-Report.pdf
Q3 - 4.2.5-PSU EM Database of NY Tenants, Meters, and Electricity Tariffs-List.pdf
Q3 - 4.2.5-PSU-OB Daily Survey Data Collection Tools.pdf
Q3 - 4.3.3 - Knowledge Platform Prototype.pdf
Q3 - 4.4.3- Cozen O'Connor Report-Policy Study.docx
Q3 - 4.4.3-Econsult Report-Baseline Study.docx
Q3 - 4.5.6-Historial Report.pdf
Q3 - 4.6.1; 4.7.1; 4.7.2- CMU Report.docx
Q3 - 4.7.1 Classification of laboratory, simulation, and field case studies.pdf
Q3 - 4.7.2 Preliminary Schematic for cost analysis.pdf
Q3 - 4.8.2 Arch and Energy Workshop Proposal.pdf
Q3 - 4.8.2 Arch and Energy Worksop Participants.pdf
Q3 - 4.8.2-PSU Sample Email Invitation.pdf
Q3 - 4.8.2-PSU Schedule and List of Contributors.pdf
Q3 - 4.8.3- Book Proposal.pdf
Q3 - 4.8.3-PSU Abstract Samples.pdf
Q3 - 4.8.3-PSU Workshop Proposal.pdf
Q3 - 5.2.2. and 5.6.1. Data collection and analysis - Education and Workforce Report 1-4-12 gh DRAFT.docx
Q3 - 5.3.4 Specific Professional development needs - GPIC-HUB 10-20 attendance list[2] copy.pdf
Q3 - 5.6.2 and 5.6.3. New K-12 education and outreach programs developed - Sustainability Workshop.pdf
Q3 - 6.1.3 GPIC Workshops for Manufacturers and Technology Developers - Agenda.docx
Q3 - 6.1.3 GPIC Workshops for Manufacturers and Technology Developers - narrative.docx
Q3 - 6.1.3 GPIC Workshops for Manufacturers and Technology Developers - Presentation slides.pdf
Q3 - 6.4.3 Preliminary database system design for  ORF Fund.pdf
Q3 - 6.5.3 GPIC ORF RFP.pdf
Q3 - 6.6.1 Baseline information - Visio diagram.pdf
Q3 - 6.6.1 Baseline information from other Tasks and through secondary and primary market research - presentation.pptx
Q3 - 6.7.3 + 6.7.4 Assessment and Continuous Improvement - Narrative.docx
Q3 - 6.7.3 + 6.7.4 Assessment and Continuous Improvement - Subtask 6.1 .xlsx
Q3 - 6.7.3 + 6.7.4 Assessment and Continuous Improvement - Subtask 6.2.xlsx
Q3 - 6.7.3 + 6.7.4 Assessment and Continuous Improvement - Subtask 6.3.xlsx
Q3 - 6.7.3 + 6.7.4 Assessment and Continuous Improvement - Subtask 6.4.xlsx
Q3 - 6.7.3 + 6.7.4 Assessment and Continuous Improvement - Subtask 6.5 .xlsx
Q3 - 6.7.3 + 6.7.4 Assessment and Continuous Improvement - Subtask 6.6 .xls
Q3 - 7.3.1 Working group to guide demonstration site planning effort.docx
Q3 - 7.3.2  Inventory of technology demonstration opportunities at Navy Yard.pptx
Q3 - 8.5 Second Quarterly Report  Apr-Jun 2011.pdf
Q3 - 8.6 Third Quarterly report - GPIC Jul - Sep 11 QuarterlyReport.pdf
Q3 - 8.6 Third Quarterly report - Task 4 Part 1.pdf
Q3 - 8.6 Third Quarterly report - Task 4 Part 2.pdf
Q3 - 8.6 Third Quarterly report - Task 4 Part 3.pdf
Q3 - 8.6 Third Quarterly report - Task 6 Part 1.pdf
Q3 - 8.6 Third Quarterly report - Task 6 Part 2.pdf
Q3 - 8.6 Third Quarterly report - Tasks 1 and 2.pdf
Q4 - 3.x.x Miscellaneous Reports
Task 6 Year One Deliverables (By Subtask)
Q4 - 1.1.12 GPIC EEB Hub 5 Year Plan 09 01 11.docx
Q4 - 1.1.13 GPIC EEB Hub Year Two SOPO 01 18 12.docx
Q4 - 1.1.14 Advisory Board Meeting 2012-01-31 participant list.docx
Q4 - 1.1.14 Executive Board Meeting 2012-01-30 participant list.docx
Q4 - 1.1.14 January 30 Executive Board Agenda FINAL.doc
Q4 - 1.1.14 January 30-31 GPIC Advisory Board Meeting Agenda 01 25 12.doc
Q4 - 1.2.4  Bldg 661 IDP - GPIC 661+ Update.pptx
Q4 - 1.2.4 Bldg 661 IDP - 120111 Programming IDG.pptx
Q4 - 1.2.4 Bldg 661 IDP - 120118 GPIC Sustainability Workshop with workshop notes.pdf
Q4 - 1.2.4 Bldg 661 IDP - Bldg 120125 Programming IDG.pptx
Q4 - 1.2.6 GPIC AE agreement pg 1-2 .pdf

Q4 - 1.2.7 Integrated construction management firm selected.pdf
Q4 - 1.2.8 CM-Agreement.pdf
Q4 - 1.3.10 GPIC TelePresence User Guide.docx
Q4 - 1.3.11 User Manual for NavyYard ICON Lab.pdf
Q4 - 1.3.7, 1.3.8, 1.3.9 I-CON Lab Deliverables.docx
Q4 - 1.4.8 Reports on HUB activities in regional and national media.xlsx
Q4 - 1.4.9 HUB Marketing and Communication Strategy - GPIC vision document 1-25 DRAFT.docx
Q4 - 1.5.2 Task 1 historical reporting and assessment data collection plan.docx
Q4 - 1.5.8 GPIC HUB SOPO REVISED November2011 (2).docx
Q4 - 1.5.9 GPIC Development and Impact Year 1 Report.docx
Q4 - 2.1.4 Integrated Building Process Model.pdf
Q4 - 2.1.4 Integrated Building Lifecycle Process.pdf
Q4 - 2.2.11 CMU R01 Baseline Modeling.pdf
Q4 - 2.2.11 CMU R02 Envelope Parametric 01.pdf
Q4 - 2.2.11 CMU R03 Envelope Parametrics 02.pdf
Q4 - 2.2.11 CMU R04 Daylight Simulations.pdf
Q4 - 2.2.11 CMU R05 Modeling Building Envelope E+.pdf
Q4 - 2.2.11 CMU R06 Design Analysis Support Tools.pdf
Q4 - 2.2.11 CMU R07 Energy CFD Tools Evaluation.pdf
Q4 - 2.2.12 CMU R01 Development of a Web-Based Survey Platform.pdf
Q4 - 2.2.12 CMU R02 Identification and Analysis of Interoperability Gaps.pdf
Q4 - 2.2.13 CMU R01 Envelope Optimization.pdf
Q4 - 2.2.4 Lighting-Daylighting Software Report.docx
Q4 - 2.2.5 PSU Weather Processing Report.pdf
Q4 - 2.2.5-2.2.7-2.2.9-3.3-DynamicModelingAndControlsCrossTaskReport.pdf
Q4 - 2.2.8-AutomatedUQAnalysisAndCalibrationTool-FinalReport.pdf
Q4 - 2.3.2 Purdue Paper for NHT.pdf
Q4 - 2.3.2 Purdue Paper Roomvent.pdf
Q4 - 2.3.5 - 2011 NHT (Purdue).pdf
Q4 - 2.3.6 - Simulation Workflow.pdf
Q4 - 2.3.7 Frameworks.zip
Q4 - 2.4 BIMserverProsCons.pdf
Q4 - 2.4 PSU Paper for ASCE 2012.pdf
Q4 - 2.5.8 Modification Plan to Task 2 Evaluation Metrics and 2H Historical Report Year 1.pdf
Q4 - 3.1.4 BP-1 Building 661 SOA Progress Report v4a.pdf
Q4 - 3.1 Year1Report UTRC.pdf
Q4 - 3.2.4 Roadmap for Integrated Building Technologies.pdf
Q4 - 3.3.4 Database for Integrated Technologies.pdf
Q4 - 3.3 UTRC HubReport Controls.pdf
Q4 - 3.4.6 Modification Plan of Task 3 operations resulting from first assessment.pdf
Q4 - 3.4.7 Modification Plan of Task 3 evaluation metrics based on first assessment.pdf
Q4 - 4.0--PMB Y1 Deliverables Overview FINAL.pdf
Q4 - 4.1.3 Final Project Fishbowl Report.docx
Q4 - 4.1.4 Final Integrated Design Roadmap Report.pdf
Q4 - 4.1.4 NJIT Multimedia Education Platform Report.pdf
Q4 - 4.1.4 PMB Y2-5.zip
Q4 - 4.2.1 Annual Report BP1 Task 4.2 (2-14-12).docx
Q4 - 4.2.1 Subtask 4.2 (4.5 in GPIC Year 2) Occupancy Behavior Group Year 2 Planning Meeting.pdf
Q4 - 4.2.4 PSU-OB Experimental Intervention Design Participant Study Guide.pdf
Q4 - 4.2.5 PSU EM Database of NY Tenants, Meters, and Electricity Tariffs.pdf
Q4 - 4.2.6 Drexel University Year 1- Policy, Markets, and Behavior Research.pdf
Q4 - 4.2.6 Navy Yard NOC Proposal.docx
Q4 - 4.2.6 PSU EM Electricity Pricing and Demand Response-one pager.pdf
Q4 - 4.2.6 PSU SG Serious Games Prototype- Energy Chickens.pdf
Q4 - 4.2.6 PSU SG Serious Games Website Content Screen Shots.pdf
Q4 - 4.2.6 PSU-OB-SG Occupant Behavior and Energy Efficiency Year 2 Project Description.pdf
Q4 - 4.2.6 PSU-SG - Energy Chickens Game Evaluation Survey.pdf

Q4 - 4.2.6 PSU-SG Serious Games - Energy Chickens Testbed - Pilot Study and Initial Report.pdf
Q4 - 4.3.4 - Rutgers RepositoryCaseStudy.pdf
Q4 - 4.3.4 Task 4 3 Roadmap for GPIC-KP Development.doc
Q4 - 4.4.1 - ARCH756 Policy and Design Syllabus.pdf
Q4 - 4.4.1 - Policy Brief--Code.pdf
Q4 - 4.4.1 - Policy Brief--Influence.pdf
Q4 - 4.4.1 PMB Advisory Committee.zip
Q4 - 4.4.2 - Garrison Institute.zip
Q4 - 4.4.2 GPIC RD Scan Summary Report.pdf
Q4 - 4.4.4 - Rutgers Yr 1 Subtask 4.1 Report.pdf
Q4 - 4.4.4 GPIC_Informing_Policies_NJ_2011_12_01.pdf
Q4 - 4.4.4 Idea Exchange Report.pdf
Q4 - 4.5.6 Modification Plan_2.docx
Q4 - 4.5.7 Modification Plan.docx
Q4 - 4.6.2 Dashbaord Information.pdf
Q4 - 4.6.3 Annual Report Overview.pdf
Q4 - 4.6.3 Appendix.pdf
Q4 - 4.7.3 Annual Report Overview.docx
Q4 - 4.7.3 Appendix.pdf
Q4 - 4.8.3 Annual Report BP1 Task 4.8 (2-14-12).docx
Q4 - 4.8.3 Arch and Energy Book Proposal.pdf
Q4 - 4.8.3 Arch and Energy Workshop Papers.pdf
Q4 - 4.8.3 Email from Routledge - agreement to publish.pdf
Q4 - 4.8.3 Workshop Papers.pdf
Q4 - 5.2.5 Complete_Education-WorkforcePrograms_Rpt.pdf
Q4 - 7.1.1-7.1.8 Collaboration with National Laboratories.docx
Q4 - 7.1.3 Preliminary identification of technology development projects to be jointly pursued.docx
Q4 - 7.1.4 Preliminary identification of demonstration opportunities at the Navy Yard.docx
Q4 - 7.2.1-7.2.8 Collaboration with Professional and Technical Societies.docx
Q4 - 7.2.3 ASHRAE MOU.docx
Q4 - 7.3.1-7.3.5 Navy Yard EEB demonstration Site Development.docx
Q4 - 7.4.1-7.4.6 Assessment and Continuous Improvement.docx
Q4 - 8.7 GPIC Year 1 Annual Report - Attachments-Reduced.pdf
Q4 - 8.7 GPIC Year 1 Annual Report-Reduced.pdf
Q4 - 8.7 Q4 report - Attachments 13-14.pdf
Q4 - 8.7 Q4 report - Attachments 15-24.pdf
Q4 - 8.7 Q4 report - Attachments 25-43.pdf
Q4 - 8.7 Q4 report - Report and Attachments 1-12.pdf

**BUDGET PERIOD 2 – Feb. 1 2012- Jan. 31, 2013**

BP2 Deliverables Completion Schedule and Format 12 18 12.pdf
ORNL-BMS ORF - Building Deliverable Report.pdf
PBL ORF Project Report-Sustainability Workshop.pdf
PSU - Viridity ORF award.pdf
PSU-Pace ORF Final Report.pdf
Purdue-LLNL ORF FinalReport.pdf
SubTask 1.1_2_4 - No1_2_6 - Report.pdf
Subtask 2.1 - No07 - Building Classes.pdf
Subtask 2.2 - No08 - Rapid Models_JAN30.pdf
Subtask 2.2 - No09 - Optimization Toolboxes.pdf
Subtask 2.3 - No10 - Software Platform.pdf
Subtask 2.4 - No11 - Energy Audit Tool R1.pdf
Subtask 2.4 - No11 - Energy Audit Tool.pdf
Subtask 3 3 - No14 - Three Use-Cases of Interactive Worskpaces.pdf
Subtask 3.1 - No12 - BIM Datahub deliverable.pdf
Subtask 3.2 - No13 - Enterprise Architecture.pdf
Subtask 3.3 - No14 - Three Use-Cases of Interactive Workspaces.pdf

Subtask 3.4 - No15 - A CASE STUDY_2013AEIConference_KX_1121.pdf
Subtask 3.4 - No15 - Deliverable Report.pdf
Subtask 3.4 - No15 - HOURLY PLUG LOAD MEASUREMENTS AND PROFILES FOR A MEDIUM SIZED OFFICE BUILDING.pdf
Subtask 3.5 - No16 - EEBHub B101 Sankey Diagram.pdf
Subtask 3.5 - No16 - EEBHub Navy Yard Sankey Diagram.pdf
Subtask 4.1 - No17 - BP2 Final Report.pdf
Subtask 4.2 - No18 - BP2 Final Report.pdf
Subtask 4.3 - No19 - BP2 Final Report.pdf
Subtask 4.4 - No20 -  BP2 Final Report.pdf
Subtask 5.1 - No21 - Deliverable Report.pdf
Subtask 5.2 - No22 - Deliverable Report.pdf
Subtask 5.3 - No23 - Deliverable (NEAT Manual current version).pdf
Subtask 5.3 - No23 - Deliverable Report.pdf
Subtask 5.4 - No24 - Deliverable Report.pdf
Subtask 6.1 - No25 - Characterizing Energy Use in New York City Commercial and Multifamily Buildings (Hsu).pdf
Subtask 6.1 - No25 - Disclosure Implementation.pdf
Subtask 6.1 - No25 - Disclosure Website Implementation.pdf
Subtask 6.1 - No25 - Energy Commission Buildings Report.pdf
Subtask 6.1 - No25 - Historic Preservation Policy Brief 1.31.13.pdf
Subtask 6.1 - No25 - Maintenance and capital expenditure.pdf
Subtask 6.1 - No25 - Peer Organization Review.pdf
Subtask 6.1 - No25 - Property tax incentives.pdf
Subtask 6.1 - No25 - Separations Act Bibliography.pdf
Subtask 6.1 - No25 - Systems Integration 112712.pdf
Subtask 6.1 - No26 - Philadelphia Energy Authority White Paper.pdf
Subtask 6.2 - No27 - Attachment - Combining Community Resiliency and EE Retrofits.pdf
Subtask 6.2 - No27 - Attachment - Deep Energy Retrofit Modeling and Cost Effectiveness Study.pdf
Subtask 6.2 - No27 - Attachment - Municipal Guidance for Promoting EE in the Private Sector.pdf
Subtask 6.2 - No27 - Attachment - WWT Bldg Inventory and EE Targeted Marketing Approach.pdf
Subtask 6.2 - No27 - Deliverables report_2013_01_28.pdf
Subtask 6.3 - NO28 - Expanded AER Market Model_1.pdf
Subtask 6.3 - NO29 - Marketing Message Effectiveness.pdf
Subtask 6.4 - No30 - Attachment_ - Modeling Report.pdf
Subtask 6.4 - No30 - Attachment - Occupant Behavior and AERs.pdf
Subtask 6.4 - No30 - Attachment -Post-Retrofit Assessment.pdf
Subtask 6.4 - No30 - Attachment_Post Retrofit Assessment.pdf
Subtask 6.4 - No30 - PSU Attachments.pdf
Subtask 6.4 - No30 - Report 2013-01-28 submitted.pdf
Subtask 6.4 - No31 - CMU Attachments.pdf
Subtask 6.4 - No31 - Report 2013-01-28 submitted.pdf
Subtask 6.4 - No32 - Attachments.pdf
Subtask 6.4 - No32 - Report 2013-01-28 submitted.pdf
Subtask 6.5 - No33 - Architect and energy manuscript proof.pdf
Subtask 6.5 - No33 - Executive Summary.pdf
Subtask 7.1 - No34 - Competency-based_career_map.pdf
Subtask 7.1 - No35 - Building Operator Training.pdf
Subtask 7.1 - No36 - Entry-level energy auditing.pdf
Subtask 7.1 - No37 - ID Leadership.1.pdf
Subtask 7.1 - No37 - ID Leadership.2.pdf
Subtask 7.1 - No37 - ID Leadership.3.pdf
Subtask 7.1 - No37 - ID Leadership.4.pdf
Subtask 7.2 - No38 - Future Workforce Engagement.pdf
Subtask 7.3 - No39 - BuildinEnergyEducationCenterReport-January2013.pdf
Subtask 7.4 - No40 - BP2 Meetings and Events.pdf
Subtask 7.4 - No40 - Educational Workshops.pdf
Subtask 8.1 - No41 - Attachments.pdf
Subtask 8.1 - No41 - Final Report.pdf

- Subtask 8.1 - No42 - Final Report.pdf
- Subtask 8.2 - No43 - 3 Cooper Plaza preliminary assessment.pdf
- Subtask 8.2 - No43 - Attachments.pdf
- Subtask 8.2 - No43 - Final Report.pdf
- Subtask 8.3 - No44 - Report final 012413.pdf
- Subtask 9.1 - No45 - Hub Knowledge Platform - CORRECTED.pdf
- Subtask 9.1 - No45 - Hub Knowledge Platform.pdf
- Subtask 9.2 - No46 - Platforms.pdf
- Subtask 9.2 - No47 - 661IntegratedDesignReport.pdf
- Subtask 9.2 - No48 - AER Retrofit Surveys and Analysis - No Watermark.pdf
- Subtask 9.2 - No48 - AER Retrofit Surveys and Analysis.pdf
- Subtask 9.2 - No48 - Integrated Design Interviews - No Watermark.pdf
- Subtask 9.2 - No48 - Integrated Design Interviews.pdf
- Subtask 9.2 - No48 - Retrofit Roadmaps - No Watermark.pdf
- Subtask 9.2 - No48 - Retrofit Roadmaps.pdf
- Subtask 9.2 - No49 - Small and Minority Engagement.pdf
- Subtask 9.2 - No50 - Valuing Energy Efficient Buildings BP2Deliverables.pdf
- Subtask 9.3 - No51 - Manufacturing SMEs and OEMs.pdf
- Subtask 9.4 - No52 - Entrepreneurial Ecosystem Plan.pdf
- Subtask 9.4 - No52 - Entrepreneurial Ecosystem Plan Appendices.pdf
- Subtask10.2 - No54 - EEB HUB Metrics Session 24Jul2012 FINAL Report V1.pdf
- Subtask10.2 - No54 - EEB Hub Metrics LLNL 10.2 BP2 v2.pdf
- Subtask10.2 - No54 - EEBHub synthesis metrics ncg Jan122013.pdf

**BUDGET PERIOD 3 – Feb. 1 2013- Apr. 30, 2014**

- 2-Deliverable2Reports.pdf
- 2-VTreport OnaReduced-OrderModel.pdf
- 3-Demonstrations.pdf
- 4-6.2 RU APA 2013 Saving Jobs and Energy in a Changing Region.pdf
- 4-6.2 RU GreenBuildingStudio PP Planning Standards to EncourageEE.pdf
- 4-6.2 RU GreenBuildingStudio UsingPlanningTools.pdf
- 4-6.4 RU Experimental Evaluations of OccupantBehaviorDuringLoadShedding.pdf
- 4-6.4 RU Incorporating Information on Occupant Behavior Modeling Report.pdf
- 4-6.4 RU ScalingUpAdvanced Energy RetrofitsReport20140131.pdf
- 4-6.4 RU User Needs Assessment HMI Report.pdf
- 4-6.4 RU USGBC Investigating Opportunities for Improving Building Performance.pdf
- 4-Drexel BP3 Report.pdf
- 4-On-Bill Repayment Program.pdf
- 6-AERDesign and ConstructionPractices.pdf
- 7-Research Digest Quarterly Reporting Summary.pdf
- 7-ValueChainMappingActionItems.pdf
- BP3 Deliverable Report (1-7).pdf

**BUDGET PERIOD 4 – May. 1 2014- Apr. 30, 2015**

- BP4 D1 1 1.pdf
- BP4 D1 3 1.pdf
- BP4 D2 1 1.pdf
- BP4 D2 2 1.pdf
- BP4 D2 2 2.pdf
- BP4 D2 3 1 V2.pdf
- BP4 D2 3 2 controls deployment case study V2.pdf
- BP4 D2 4 1.pdf
- BP4 D2 5 1.pdf
- BP4 D3 1 1.pdf
- BP4 D3 1 2.pdf
- BP4 D3 2 1.pdf
- BP4 D3 2 2.pdf

- BP4 D3 3 c Transitioning Technology to Market final report.pdf
- BP4 D4 1 1 and D4 1 2.pdf
- BP4 D4 1 3 Guides Collection.pdf
- BP4 D4 3 1 V2.pdf
- BP4 D4 5 1.pdf
- BP4 D4 5 1 v2.pdf
- BP4 D4 5 2.pdf
- BP4 D4 6 1 1 OBFTenantBriefingMaterials V2.pdf
- BP4 D4 6 1 2 OBF Implementation Plan.pdf
- BP4 D4 6 1 3 OBFFinalCaseStudy V2.pdf
- BP4 D4 7 1.pdf
- BP4 D5 1 1.pdf
- BP4 D5 2 1 1 1.pdf
- BP4 D5 2 1 1 2 IDRRWorkingGroupReview V3.pdf
- BP4 D5 2 2 1.pdf
- BP4 D5 2 2 2.pdf
- BP4 D5 2 5 1ProjectTeamGuideforLiteRetrofit.pdf
- BP4 D5 2 5 2 ProjectTeamGuideforPartialRetrofit.pdf
- BP4 D5 2 5 3 ReferenceManual.pdf
- BP4 D5 2 5 4 ProjectTeamGuideforComprehensiveRetrofits.pdf
- BP4 D5 2 5 4 ProjectTeamGuideforSubstantialRetrofits.pdf
- BP4 D5 2 5 5 MarketDeploymentPlan.pdf
- BP4 D5 3 1.pdf
- BP4 D5 3 2.pdf
- BP4 D6 1 1.pdf
- BP4 D6 1 f Final Deliverable.pdf
- BP4 D6 2 1.pdf
- BP4 D6 2 1 a.pdf
- BP4 D6 2 2 NJIT.pdf
- BP4 D6 2 3 Case Study.pdf
- BP4 D6 3 1(v2).pdf
- BP4 D7 2 1 Summary Report of Performance April 30 2015.pdf

**BUDGET PERIOD 5 – May. 1 2015- Apr. 30, 2016**

- BP5 D1 1 1.pdf
- BP5 D1 2 1.pdf
- BP5 D1 3 1.pdf
- BP5 D2 1 1.pdf
- BP5 D2 2 1.pdf
- BP5 D2 2 2.pdf
- BP5 D2 3 1.pdf
- BP5 D2 4 1.pdf
- BP5 D2 5 1.pdf
- BP5 D2 6 1.pdf
- BP5 D2 6 2.pdf
- BP5 D2 7 1.pdf
- BP5 D2 7 2.pdf
- BP5 D3 1 1.pdf
- BP5 D3 2 1.pdf
- BP5 D3 3 1.pdf
- BP5 D3 4 1.pdf
- BP5 D4 1 1.pdf
- BP5 D4 2 1.pdf
- BP5 D4 3 1.pdf
- BP5 D4 4 1.pdf
- BP5 D4 5 1.pdf
- BP5 D5 1 1.pdf

BP5_D5_1_2.pdf
BP5_D5_1_2-BPD Data Template - Bldg 101 - 2015.xlsx
BP5_D5_1_2-BPD Data Template - Bldg 489 - 2015.xlsx
BP5_D5_1_3.pdf
BP5_D5_2_1 - Copy.pdf
BP5_D5_2_1.pdf
BP5_D5_3_1.pdf
BP5_D5_4_1.pdf
BP5_D5_4_2.pdf
BP5_D5_4_2-BPD Data Template - Bldg 661 - 2015.xlsx
BP5_D5_5_1.pdf
BP5_D5_6_.pdf
BP5_D5_6_1.pdf
BP5_D5_6_2.pdf
BP5_D5_7_1.pdf
BP5_D5_7_2.pdf
BP5_D5_7_3.pdf
BP5_D6_2_1.pdf
BP5_D6_2_2.pdf
BP5_D6_3_1.pdf
BP5_D6_4_1.pdf
BP5_D6_4_2.pdf
BP5_D6_4_3_Intermediate and Advanced Level.pdf
BP5_D6_4_3_Introductory Level.pdf
BP5_D6_4_4.pdf
BP5_D7_1_1.pdf
BP5_D7_2_1.pdf
BP5_D7_4_1.pdf

## B) Publications

This list of publications includes peer-reviewed articles, professional and trade materials, as well as internal Hub and Consortium publications.

01_2011 An inverse method_jiip_Burns_Childers.pdf
01_2015 Full Flux Models for Control of Heat Exchangers_ACC 15 1061.pdf
01_akhtar2012ncs.pdf
02_2012 An example of thermal regulation of a two dimensional_CDC12.pdf
02_2013 Control of PDE Systems with Delays IFAC PARIS.pdf
02_2015 SOLUTIONS AND APPROXIMATIONS TO THE RICCATI EQUATION SICON15 94851.pdf
02_borggaard2012mri.pdf
02_giere2015supg.pdf
03_2012 Control of the Boussinesq Equations with Implications for Sensor_ACC_2012.pdf
03_2015 The Effect of Viscosity in a Tracking Regulation Problem for a Counter flow HX_cdc15.pdf
03_hay2012usa.pdf
03_Proper_Orthogonal_Decomposition.pdf
032615-BxEventLunch_Krebs_Final.pdf
04_2012 An Optimal Control Approach to Sensor- Actuator Placement_HPBUILDINGS_12_3466.pdf
04_2013 Infinite dimensional delay differential equations.pdf
04_2015 Using functional gains for effective sensor location_J. Fluid Mech.pdf
04_borggaard2012obe.pdf
05_2013 NUMERICAL APPROXIMATIONS OF THE DYNAMICAL_13_ABG_M2NA_S0764583X13000848a.pdf
05_Optimal Sensor Location.pdf
05_wang2012pod.pdf
052115_Better Buildings Summit presentation.pdf

06 2013 On Optimal Thermal Control of an Idealized Room including Hard  CDC 13.pdf
06 borggaard2012tld.pdf
06 borggaard2016gor.pdf
07 2016 Control of a Thermal Fluid Heat Exchanger with Actuator Dynamics  CDC16 .pdf
07 akhtar2012udm.pdf
07 Revised Numerical Methods.pdf
08 2016 Control of composite distributed parameter systems with actuator Dynamics MESA Vol 7 No 2, 2016.pdf
08 Coupled CFD Building Model.pdf
08 Senitivity and Uncertainty Quantification.pdf
09 2016 Feedback stabilization of a thermal fluid system  2016.pdf
1 13 16 OSBA V1.pdf
140618 BRT CBEI benchmarking session.pdf
140926 Greenbuild Presentation G06 FINAL.pdf
150107-EJ-regularization-R1-1.pdf
150120-AE-submission.pdf
1Vivian Bruegge Kolloquim.pdf
2014.05.05 PUC CBEI Krebs.pdf
2015-06-02 MAK Alstom Grid Event.pdf
2015-06-25 DEP Briefing.pdf
2015-07-23 Drexel Volttron wkshp[1].pdf
20150911AEE NCC.pdf
2015-Winter-Conference-RTU PnP.pdf
2016 TriStateSS-CBEI presentation.pdf
2310 hjortland.pdf
2584-Cheung Paper v05.pdf
3254-2014 High Perf Bldgs Conf JanghyunK.pdf
3263 2014 FullPaper V3.pdf
3339-2.pdf
3385 Informed Building Retrofit based on Simulation and Data Analysis rev2.pdf
3385 Informed Building Retrofit Wagner - PRESENTATION.pdf
3571Heuristic DX control Purdue 2nd draft submitted.pdf
3575-Experimental paper final version 4.pdf
3611 PurdueConf2014-Paper3611.pdf
3616-FDD and MPC HighPerfBldg 2014 submitted.pdf
3635.pdf
3636 Submission.pdf
3638-Stochastic model predictive control of mixed-mode buildings based on probabilistic interactions of o.pdf
3641.pdf
3646 final.pdf
45 Heidarinejad.pdf
5 5 CornerGrocery   slides OctoberMtg V1.pdf
6 3 EDA BOMA-20150630 (V6).pdf
6 4Rebate Master Builder Presentation2015.pdf
76 Rackes.pdf
9 park.pdf
A Framework for Integrating Change Management with Building Information Modeling.pdf
A Taxonomy for Building Energy Dashboards.pdf
A Distributed Approach to Efficient Model.pdf
A general approach for generating.pdf
A general method for calculating.pdf
A generalized control heuristic.pdf
A hybrid ray-tracing and radiosity method.pdf
A practical and scalable inverse modeling.pdf
A Semi-Empirical Model for Studying.pdf
A simulation and experimental study.pdf
A state-space modeling approach.pdf
A switched dynamic programming approach.pdf

ABAA Desjarlais and Wylie Final 3-24-16.pdf
Accelerating Fast Fluid Dynamics.pdf
ACEEE - Program C4-Stutman-BP4.pdf
Advanced turbulence models.pdf
AESP 7 14 15.pdf
AGENDA.pdf
An EnergyPlus whole building energy model calibration method for.pdf
An Integrative Process for Advanced Energy Retrofit Projects.pdf
An Approach 4-Capturing Frazier 2013.pdf
An experimental and simulation study.pdf
Analysis and Comparison of Absorbed Solar Radiation Distribution.pdf
ANALYSIS OF BALANCE BETWEEN MODELING ACCURACY.pdf
Andrews ASHRAE 20150613.pdf
ASHRAE IEQ draft v6.pdf
Asset Score Introduction 20150714.pdf
Asset Score Introduction MBA 20151015.pdf
Aziz - Airport Going Green.pdf
Aziz Lasternas - DC Building Data Analytics.pdf
B2-Stutman Framework v7.pdf
benayed2014rom.pdf
BIM-ITCon-2015.pdf
BOMA 2015 BRT final.pdf
BOMA 529.15 LS.pdf
BOMA INTL conference-Building ReTuning 062114 final.pdf
BOMA-CMU.pdf
BOOS meeting images.pdf
borggaard2014cvh.pdf
borggaard2014pro.pdf
BP2 4.4 HPB Deep Green Metrics.pdf
BP3 5.4 CMU Triple Bottom Line Benefits of Investing in Lighting and Daylighting No Copyright.pdf
BP3 5.4 Let There Be Light CMU IFMA 2013.pdf
BP3 5.4 Integrated Indoor Environmental Quality.pdf
BP3 5.4 Investing in Building Energy Retrofits.pdf
BP4 5.1 Comparison of the result.pdf
BP4 Pub IMT Rutgers White Paper FINAL.pdf
BP4 Pub Occupant Behavior in Buildings Andrews ASHRAE2014.pdf
BP4 Pub Results of Testing Energy Marketing IMTWebinar 041615.pdf
BP5 Pub Modeling, Simulation and Application Occupant Behavior in Buildings ASHRAE 20150613.pdf
BTO Peer Review 3 3 T2M CBEI Wagner 3.30.15.pdf
BTO Peer Review 4 6 OBF CBEI Terry 3.30.15.pdf
Building 661 HVAC Design Intent to Occupancy Meeting v4.pdf
Building 661 Lighting Design Intent to Occupancy Meeting v4.pdf
Building Data Analytics - CBEI Informatics Summit V2.1.pdf
Building Energy Models Quantifying uncertainties due to stochastic processes.pdf
Building Monitoring System and Preliminary Results.pdf
burns cliff 2014 acc.pdf
Burns Cliff Farlow ifac 2014.pdf
CAPITAL COSTS AND ENERGY SAVINGS.pdf
CASE2013.pdf
CBEI 4 3 DOE March23-2016-final.pdf
CBEI 4.3 IECC Change of Occupancy April 2016.pdf
CBEI 4.3 NEEP 28Oct2015.pdf
CBEI CC-MVM Presentation Webinar 1015 (002).pdf
CBEI Presentation for CT AEE V2 3-3-15.pdf
CBEI SFWA Preliminary Conclusions 12 18 2015 final.pdf
CBEI Value of BRT 20160126.pdf
CBEI 011515 final.pdf

Change of Occupancy_Senick,Hattis.pdf
Characterizing_the_In-Situ_Performance.pdf
CISBAT2013_Zhao Jie.pdf
ClimateChangeHitHome.pdf
CMU_40 V2.pdf
CMU_BCA June 2014.pdf
CMU_City of Cambridge August 2014.pdf
Cochran CISBAT 2013 paper.pdf
Cochran_ASHRAE_HPB_2014 Clear.pdf
Cochran_President_Innug.pdf
Comparative_control_strategies_for_roller_shades.pdf
Comparative_evaluation_of_model_predictive_control.pdf
COMPARISON_OF_SHADING_CONTROL_MODES.pdf
Comparisons_of_Building_System_Modeling_Approaches.pdf
Comparisons_of_model_structure.pdf
CONSTRUCT 2015_Desjar-Wylie Final 9-28-15.pdf
Context and Prediction of Building Efficiency_EDRA_2012.pdf
CornerGrocery_Dusquesne_slides_V1.pdf
CornerGrocery_PECO_slides_SeptemberMtg_5.pdf
Coupled_Simulation_of_Indoor_Environment.pdf
CPB AST CEP Presentation.pdf
D6.2 Aziz.pdf
Daylighting_and_energy_analysis.pdf
DE DVGBC Nov 2015 v2.pdf
Deep Retrofit System Solution Assessment for Phila Navy Yard Office Bldgs.pdf
DEMO_CBEI-PSU_Stutman.pdf
Development of Control Benefit Evaluation Tool.pdf
Development of Control-Oriented Models for Model Predictive Control in Buildings.pdf
Development_and_evaluation.pdf
Development_and_experimental_demonstration.pdf
Development_of_a_plug-and-play.pdf
Development_validation_and_application.pdf
Disaggregated Retrofit Savings using a Calibrated Whole BEM for MSOB.pdf
Dynamic_Programming_based_approaches.pdf
EE2015 CPB Presentation.pdf
EEB_HUB_Presentation_v2_GUI_Aug_2012.pdf
Efficient and robust training methodology for inverse building modeling.pdf
Efficient_and_robust_training_methodology.pdf
Efficient_Venetian_Blind_Control_Strategies.pdf
Ener_CBEICMU_Cochran.pdf
Engineering Sustainability 2015 V5.pdf
Erica Cochran_Greenbuild.pdf
EUEC_D2.6_Whole building Data Access_Utilities Perspective.pdf
EVALUATION OF SHADING RETROFIT STRATEGIES FOR ENERGY SAVINGS IN OFFICES.pdf
Evaluation of virtual refrigerant mass flow sensors.pdf
Evaluation_of_the_impacts_of_refrigerant_charge.pdf
Extension_of_a_virtual_refrigerant_charge_sensor.pdf
Eyboosh_Taxonomy.pdf
FDD for advanced RTUs.pdf
Full-scale_experimental_study_of_lighting_performance.pdf
General_Outdoor_Air_Economizer_Fault_Detection.pdf
Gray-Box_Modeling_of_Multistage.pdf
greenbuild presentation.pdf
GreenBuild Spengler_Loftness nov 10-3.pdf
Greenbuild_E04_whitepaper_2013.pdf
Gurian De Lagev2.pdf
Gurian Wharton Energy Efficiency.pdf

H09.pdf
How_to_Make_Green_Your_Competitive_Advantage.pdf
HowToMakeGreenYourCompetitiveAdvantage.pdf
Hsu - 2014 - How much information disclosure of building energy.pdf
HVAC_UTRC_Taylor_V3.pdf
Hybrid Amorphous, Nanocrystalline Silicon Schottky Diodes for High Frequency Rectification.pdf
IE for Multizone Airflow Analysis_Final 2.pdf
IES2014_ImpactOfSnowOnPhotosensorControl.pdf
IMPACT_OF_SHADING_CONTROL_AND_THERMOSTAT.pdf
Improvement_of_Fast_Fluid_Dynamics_2.pdf
Improvements_of_fast_fluid_dynamics_1.pdf
Information Exchanges requirements - Energy retrofit.pdf
Integrated Dynamic Skylight Solutions.pdf
Integrated Dynamic Skylights Solutions to reduce Energy_and Improve indoor Energy Quality.pdf
Integration_of_Plume_Model.pdf
Internet of Things - EnVisioneering Symposium.pdf
Investigating Building Performance_Greenbuild2012.pdf
Investigating Occupant Response_RU EEBHub-workshop_2013.pdf
KREBS, Martha - NEEP Introduction 091714.pdf
Lasternas - EMEA User Conference.pdf
LeanCertificationModule-SmallBuildingRe-tuningTraining_wSpeakerNotes.pdf
Life Cycle Optimization (2).pdf
Lisbon_Lasternas.pdf
Liu - ICCCBE 2014 - Immersive Visualization Case Study_Full paper submission_Feb.20th.pdf
M.Eybpoosh_B.Akinci_M.Berges_CRC2012_Manuscript.pdf
MAK- PSU Service Engineering - FINAL 091614.pdf
MAK_CBEI Overview to PSU PACE_060614 FINAL.pdf
Martha - WEEC Presentation - FINAL.pdf
McKinley_final pres.pdf
Mistrick-STADIC.pdf
Model_predictive_control_strategies.pdf
Model-Based_Predictive_Control_for_Buildings.pdf
Modeling Social Aspects of Occupant Behavior in Commercial Buildings_EDRA_5_28_15.pdf
Modeling_and_Analysis_for_Mixed-Mode.pdf
MPC_OF_MIXED-MODE_BUILDINGS_WITH_MATLAB_GENOPT.pdf
Multi-Agent_Control_for_Centralized.pdf
NineInterventionTEchnique.pdf
Optimization Office.pdf
PA Energy Code Collaborative_2015_02_18_final-Rutgers.pdf
PA-Edu-final pres.pdf
Paper 05.pdf
Paper_13896_Use Calibrated Whole Building Energy Model to Disaggregate Retrofit Energy Savings_revised0525.pdf
Paper3617_Purdue_2014_InitialUpload_HaydenMarked_PengfeiUpdate_v3.pdf
Pareto Efficient Retrofit Package Selection for Multi-Family Buildings.pdf
Performance Benchmark.pdf
Performance_evaluation_of_a_virtual_refirgerant_charge_sensor.pdf
phillips2014ete.pdf
PnP Control ORNL 6-12-14.pdf
poster v8.pdf
Presentation_slides_V2_share.pdf
Prospective Modeling of Occupant Behavior During Design abstract - Energy_Buildings.pdf
Purdue.Albee_FINAL.pdf
Purdue.Trubiano_FINAL.pdf
Purdue_Albee_Presentation1.pdf
Purdue_Albee_Presentation2.pdf
PurdueConference_2014_full_draft_v3_3568.pdf
rackes_waring_2013_vent_offices_BE.pdf

rackes_waring_2014_multiobjective_vent.pdf
RCI_2016_Wylie and Desjarlais_Final.pdf
RCI_Wylie and Desjarlais Final 3-14-16.pdf
Reduced_Order_Building_Modeling.pdf
Regnier_Wen_ASHRAE_Presentation_2015_r1.pdf
RegNo_JRC75412__IEECB_2012_Proceedings_ONLINE.pdf
Retrofitting the Urban League of Greater Pittsburgh.pdf
Review_of_modelling_approaches.pdf
Ruchie_Kothari_Final_ATHENS1.pdf
Rutgers_NEEP_CBEI_4.3_17Sept2014.pdf
S15_BCD_POE_Lecture_Park (1).pdf
san2014bsc.pdf
Sensitivity_analysis_on_daylighting.pdf
Session 1 - Martha Krebs.pdf
Session 3 - Dinghao Wu.pdf
Session 4 - Jason DeGraw.pdf
Session 5 - Ben Cohen.pdf
Session 6 - Jennifer Lather.pdf
Session 6 - Robert Leicht.pdf
Simulating Occupant Behavior_20130117.pdf
Simulating_natural_ventilation.pdf
SIMULATION_AND_ANALYSIS_OF_PREDICTIVE_CONTROL.pdf
SIMULATION_OF_ANTICIPATORY_CONTROL.pdf
STADICUtilities-Radiance Workshop2015.pdf
Stutman - Panel 2-CBEI v3.pdf
Stutman-2016_Globalcon.pdf
Sustainable Jersey 091615.pdf
Sustainable Pittsburgh - abstract.pdf
T7S3 EE2015 Presentation_track 7_session 3.pdf
TH16_Koloskyfinal.pdf
The Current State of Energy Retrofits for Small and Medium Buildings.pdf
The Joint Influence of Albedo and Insulation on Roof Performance An Observational Study.pdf
The Waldorf School Presentation 4.24.12.pdf
TowardDesignDAshboard.pdf
ULI_DC_BP_CMU_presentation.pdf
Uncertainty QUantification in Energy Efficient Building Performance Simulations.pdf
UPennIUR_030515_V2.pdf
Usin_CBEICMU_Cochran.pdf
Validation_of_three_dimensional.pdf
Variation_photovoltaic Nagengast.pdf
Virtual_Refrigerant_Mass_Flow_and_Power__Sensors.pdf
Wessex Presentation.Albee.2014.pdf
WessexPaper.Trubiano.2014.pdf
WSC_2011_Zhang Lam_Conformal paper.pdf
zoo_final_3-23-15.pdf

## C) Websites or Other Internet Sites

CBEI has maintained a website since the inception of the cooperative agreement. The website has been continually updated and currently maintains content generated over the five-year cooperative agreement (link provided below). This material is presented in formats most useful for public use. CBEI partners have posted major products from their research on their organizational websites (not listed here), as well. Additionally, several CBEI products were developed in a web-enabled format to provide an easier means to access the content. Links to these sites are also provided on the main CBEI website and provided below.

- Main CBEI website: http://cbei.psu.edu/
- Advanced Career Commercial Buildings Workforce Competency Model: http://www.careeronestop.org/competencymodel/
- Advanced Career Commercial Buildings Workforce Career Map: http://www.facilitiescareermap.feapc.com/
- Asset Score Tool Certificate of Proficiency: http://ast.njit.edu/login/index.php
- Certificate of Proficiency in Benchmarking: http://online.njit.edu/cbk/
- Guide to Interactive Workspaces: http://interactiveworkspaces.weebly.com
- Saving Energy in Leased Spaces: http://savingenergyinleasedspace.com/

## D) Networks or Collaborations Fostered

CBEI developed a substantial network within the Philadelphia region and nationally as a part of the cooperative agreement. Many of the relationships in the network were brought to CBEI by tapping the extensive relationship network of the researchers and their parent organizations. New relationships were developed for the network as project needs arose. For example, in order to establish the demonstration sites, CBEI created a request for proposal to solicit building owners interested in using their building for research. As a result in, CBEI created relationships with more than 36 building owners and tenants, primarily in the Philadelphia region but expanded to other parts of the country as opportunities became available. These relationships were further helpful to CBEI in projects where buying trends in the region were needed, since these building owners and tenants provided insights to CBEI through their participations in multiple workshops and meetings coordinated by CBEI researchers.

CBEI developed networks and collaboration partners at the local and national levels. Local collaborations were valuable to enable CBEI to create a regional network that researchers could draw upon to made integrated solutions. For example, CBEI was able to bring relationships with the City of Philadelphia, PECO, and major Philadelphia-region building owners to develop solutions that allowed the City's benchmarking program to provide value to each of the key stakeholders, which simplified implementation. National collaborations were valuable in moving solutions developed locally to the national marketplace. Several market analysis projects resulted in a substantial collection of relationships with national and regional manufacturers and service providers. CBEI developed a network within the sensors and controls and shading film and window attachment communities. CBEI engaged with 12 companies focused on sensor and control technology to identify potential commercialization partners and interviewed nearly 40 building owners, architect/engineering firms, utilities, and manufacturers to gain a deeper understanding of the challenges in the shading, films and window attachment industry. This provided direct engagement with the research departments in these companies. Additional examples of key collaborations are provided below:

### Local Collaborations

CBEI build many collaborative partnerships in the Philadelphia region. Some of these partnerships were with local chapters of national organizations and others were with distinctly local organizations. These local relationships allowed for networking opportunities to reach deeper into the local stakeholder base, such as with building owners and tenants, but they also provided an avenue to understand regional priorities and interests in the retrofit marketplace. Some key examples of local partnerships include:

- **Greater Philadelphia Chamber of Commerce**: Early on, CBEI established a strategic partnership with the Greater Philadelphia Chamber of Commerce. This relationship was critical to engage relevant stakeholders in CBEI research. CBEI organized a series of events throughout the region which allowed CBEI to build relationships that were used throughout the five years.
- **City of Philadelphia**: CBEI's partnership with the City provided CBEI with an understanding of key challenges to municipalities, particularly as they develop benchmarking programs. Additionally, as the City established the Philadelphia Energy Authority, it provided CBEI with experience with and the opportunity to develop solutions for municipal portfolios.
- **PECO**: CBEI developed a close working relationship with PECO early on, and that relationship expanded over the five years. This relationship was instrumental in the CBEI's ability to support data access for building owners in the region. PECO also offered utility perspectives and collaborations on multiple projects, such as on-bill financing, to identify utility interests in program structure, and the corner store project and multiple technology projects to identify data from the projects necessary to a utility to build a solution into an incentive program.
- **Delaware Valley Green Building Council (DVGBC)**: CBEI established a strategic partnership with the DVGBC. DVGBC and CBEI co-sponsored multiple events in the region to engage DVGBC members. DVGBC and CBEI worked collaboratively on the host committee for GreenBuild in Philadelphia in 2013. This event provided substantial visibility for CBEI research nationally and an opportunity to continue to build CBEI's national network, including with the U.S. Green Building Council.

Additional regional relationships used for networking include the Building Industry Association of Philadelphia, Sustainable Business Network of Greater Philadelphia, and Economy League of Greater Philadelphia.

## National Collaborations

We also engaged national organizations including Rocky Mountain Institute, US BOMA, IMT, NRDC and DOE's Commercial Building Energy Alliance in an expert workshop to discuss green lease models that provide tools for owners and tenants who need to negotiate split incentive issues that are hurdle for energy efficiency projects

- **AIA National and local (Philadelphia and NJ)**: The relationship with AIA at the local and national level was leveraged for collaboration on planning and designing retrofits demonstrations in early BPs and for expanding deployment to local and national members on multiple later projects, including wall retrofit solutions, code compliance, and asset score tool.
- **ASHRAE**: CBEI developed an MOU with ASHRAE to coordinate on relevant research, identify educational gaps in the market, and utilize ASHRAE conferences to organize sessions and present CBEI research results. CBEI used the annual conferences to obtain market feedback to guide projects, including for using benchmarking data to target utility customers for incentives and the occupancy module for OpenStudio.
- **Institute for Market Transformation**. The Hub worked closely with the Institute for Market Transformation on a white paper intended to help utilities and regulators understand how to implement enhanced data access services for building owners in the early years of the Consortium and this led to an

ongoing relationship with IMT for commercial broker education and the National Certification for Proficiency in Benchmarking.

- **National Institute of Building Sciences:** This collaboration was critical for development of the competency model and career map.
- **NRDC:** In the early BPs, CBEI worked closely with NRDC on their new effort to engage ten cities in energy efficient building legislation and program implementation. In later years, CBEI collaborate with NRDC on the National Certificate of Proficiency in Benchmarking

## E) Technologies/Techniques

CBEI developed two new technologies that were in the process of being commercialized as of the completion of the cooperative agreement. These two technologies are building systems controls, which are generally incorporated into a thermostat or building automation system. The two technologies are (1) a Plug-and-Play Roof Top Unit Coordinator, developed by Purdue and potentially being commercialized by Field Diagnostic Services, Inc., and (2) an Air Handling Unit Automated Fault Detection and Diagnostic solution, developed by Drexel University and being licensed by KGS Buildings and Kinetic Buildings. Both of these technologies are described further in the Components, Sub-Systems, Controls, and Diagnostics section of this document.

## F) Inventions/Patent Applications and Licensing Agreements

2012-GPIC001: Pragmatic Energy Performance Rating Method for Building components – Method to evaluate energy performance based on realistic environment, IBM: Zhang, Rui; Yang, Jeaha; Snowdon, Jane, CMU: Lam, Khee Poh

2012-GPIC002: Pragmatic Energy Performance Rating Method for Building Components – Method to make energy rating system available to user in real time, IBM: Zhang, Rui; Yang, Jeaha; Snowdon, Jane, CMU: Lam, Khee Poh

2012-GPIC003: Pragmatic Energy Performance Rating Method for Building Components – Method for decision support system for customer, IBM: Zhang, Rui; Yang, Jeaha; Snowdon, Jane, CMU: Lam, Khee Poh

2012-GPIC004: Method and apparatus of BIM Enablement Platform of BIM data model, data management services / APIs, RESTFul APIs for BIM content and meta data hosing format exchange , and workflow enablement, IBM: Chao, Tian; Younghun, Kim,

2012-GPIC005: Methods and Apparatus of interoperability/format translation and transformation between IFC architectural design file and simulation file formats (EnergyPlus/Radiance), IBM: Chao, Tian; Younghun, Kim,

2012-GPIC006: Humidity control, buildings, microwave, absolute humidity, Penn State: Lanagan, Michael; Agrawal, Dinesh; Hoover, Richard,

2012-GPIC007: PrjBuilder – Software for Streamlined Multizone Model Creation, Penn State: Jason DeGraw, William Bahnfleth,

2012-GPIC008: Glass Edge Light Transmission Sensor: PPG Industries, Inc., N. Duarte, Y. Jiao, J. Finley,

2013-GPIC009: Ultra Low Cost BTU Meter, UTRC: Jinliang Wang, Mikhail Gorbounov, Ashutosh Tewari, None

2013-GPIC012: Low Cost Thermal Metering Method, UTRC: Ashutosh Tewari, Mikhail Gorbounov, Jinliang Wang,

2013-GPIC010: Daysim C-module, Penn State: Richard Mistric and Craig Casey, 2013-GPIC011: DaysimPS GUI, Penn State: Richard Mistrick, Bing-Rong Lin, Raghav Pisolkar, Ahmed Bahjat, Shibamouli Lahiri,

2013-GPIC013: An Automated Computer Query Generation Method and System for Building Information Modeling (BIM), Penn State: Dinghao Wu, Yufei Jiang, Nan Yu, Jiang Ming, Lannon Luo, Sanghoon Lee, Abdou Jallow, John Yen, John Messner, Robert Leicht,

2014-GPIC014: Hybrid sensing and computation networks based on large-area electronics and small scale IC's, Princeton University: Naveen Verma, James Sturm, Sigurd Wagner,

2014-GPIC015: Sensing Sheet for High-Resolution Structional Health Monitoring Over Large Structures, Princeton University: Branko Glisic, Naveen Verma,

2014-GPIC016: Scalable hybrid systems based on large-area and nano-scale electronics, Princeton University: Naveen Verma, James Sturm, Sigurd Wagner,

2014-GPIC017: Stick-On Very-Low-Cost Sensor Node, Princeton University: Naveen Verma, James Sturm, Sigurd Wagner,

2014-GPIC018: HVAC Fault Impact Assessment Using Bayesian Networks, UTRC: Ashutosh Tewari, Ritesh Khire

2014-GPIC019: C++Modules for Annual Daylight Modeling, Penn State: Craig Casey, Richard Mistrick, Sarith Subramaniam

2014-GPIC020: OpenStudio Measures for Annual Daylight Modeling, Penn State: Craig Casey, Richard Mistrick

Drexel License Agreement

## G) Other Products (e.g., data or databases, physical collections, audio or video software or netware, models, educational and curriculum instruments or equipment)

CBEI produced other products, such as data sets, model components, and educational and curriculum instruments. The educational and curriculum instruments, which are web-based, are identified in the Websites or Other Internet Sites section above. The remaining materials, which consisted of datasets and model components, were incorporated by DOE into existing DOE systems. These are described below:

- **Building Datasets** – CBEI generated datasets from multiple buildings as part of the research. The datasets were for Navy Yard Buildings 101, 489, and 661. The datasets contained detailed building characteristics and whole building and sub-metered energy consumption. These datasets were provided directly to Lawrence Berkeley National Lab to be included in DOE's Building Performance Database.
- **Models** – no standalone models were developed by CBEI; however, multiple enhancements were made to DOE models and tools, such as OpenStudio and EnergyPlus. CBEI worked directly with NREL to build these new modules or other enhancements directly into the appropriate DOE tools. These CBEI model enhancements include:

- New contributions for OpenStudio and BIMserver to incorporate an annual daylight simulation measure leveraging the STADIC annual daylight simulation utilities for Radiance, which permits a user to layout and perform a detailed electric lighting control system analysis within individual spaces via a control file editor.
- New Industry Foundation Classes (IFC) import capability within OpenStudio to import the geometry and material properties for building elements using the IFC data schema.
- Enhanced OpenStudio to enable users of OpenStudio SDK-based applications to add the necessary inputs to their models to use AirflowNetwork without having to use non-standard workflows.
- New OpenStudio measures for seven systems/components used in HVAC retrofit packages identified with high energy saving potentials for small office, medium office, stand-alone retail, and primary school buildings in certain climate zones.
- A calibrated occupant behavior module that aids building design & operation by simulating user impacts on energy use and connected to EnergyPlus.

- **SEED Module and App/Widget** – CBEI developed a real-time 15-minute interval Green Button and spreadsheet based data module for SEED and app/widget to support energy conservation for various stakeholders. To support the significantly increased number of granular interval data, CBEI integrated a parallel time-series database into the existing relational database. The implementation of the time-series database improves on the current utility data input, focusing on real-time data collection, storage, analytics and data quality control. The fully integrated data platform supports APIs for utility apps development by third party software developers. CBEI worked directly with NREL to incorporate the enhancements directly into SEED.

# V. APPENDIX B: Publicly-available Documents

Below is a list of the products generated by CBEI and prepared in final form for public distribution. These documents are found on the CBEI website at http://cbei.psu.edu/.

## Technology Packages

- Best Practice Recommendations for Wall Retrofit on the Two-Story Flexible Research Platform (FRP) at Oak Ridge National Laboratory (ORNL)
- Commercial, Institutional, Multifamily, Medium and Small Building Integrated Technology Research Roadmap
- Demonstrating the scalable installation of advanced building controls and diagnostics as overlays on the building automation system
- Demonstration and Commercialization of VOLTTRON Compatible AHU Diagnosis
- Demonstration of Low-Cost Rapid Scalable Deployment of Optimal Controls for Buildings and Chiller Plants in MSCB
- Demonstration of new lighting, HVAC, window, enclosure, control, or other technologies to reduce building energy use while improving indoor air quality
- Detached Eddy Simulation Model for Indoor Airflow Modeling
- Energy Audit Tool Overview
- Energy Retrofit Market Opportunities
- Field testing of diagnostics for state-of-the-art RTUs
- Finding: Integrated Hardware Systems
- Improvements of Fast Fluid Dynamics for Simulating Airflow in Buildings
- Integrated Controls for Retail Stores with Refrigerated Cases
- Model Predictive Control and Fault Detection and Diagnostics of a Building Heating, Ventilation, and Air Conditioning System
- Occupant Behavior Module for EnergyPlus/OpenStudio
- State of the Art in Enclosure Technologies and Integrated Systems for 50% Energy Savings in Existing Commercial Buildings
- Uncertainty Quantification in Energy Efficient Building Performance Simulations
- Virtual RTU Sensing Automation, Demonstration, and Assessment
- Voltron Compatible Virtual Sensor FDD System for Roof Top Units
- Volttron application for assisted discovery of semantic meaning of BAS points.
- Whole Building Diagnostic & Decision Support

## Integrated Design

- A Novel Human Machine Interface for Advanced Building Controls and Diagnostics
- Automation and Demonstration of a Plug -and-Play (PnP) RTU Coordinator
- BIM Planning Guide
- Building 661 Integrated Design Process Report - Early Lessons Learned
- Cost Effective Building Retrofit through Robust Control and Scalable Algorithms
- Coupling of Whole-Building Energy Simulation and Multi-Dimensional Numerical Optimization for Minimizing the Life Cycle Costs of Office Buildings
- Deep Energy Retrofit Modeling and Cost Effectiveness Study
- Demonstration of a rapid and reliable advanced energy retrofit decision support tool

Expand Analysis of HVAC Retrofit Solutions for Other Building Types and Climate Zones
Experimental Demonstration of Model Predictive Control in a Medium-Sized Commercial Buildings
Investigating building performance through simulation of occupant behavior (Greenbuild 2012)
OpenStudio Enhancements: Daylighting Measures
OpenStudio Enhancements: BIMserver Integration
OpenStudio Measure Development for Integrated HVAC Retrofit

## Portfolio Solutions

A Review of Electricity Consumption Behavior
Analysis of Residential & Commercial Buildings: Alliance Commission on National Energy Efficiency Policy
Benefits of public energy benchmarking data
Broadening Use of DOE BTO Tools in the SMSCB Market
Capital Costs and Energy Savings Achieved by Energy Conservation Measures for Office Buildings in the Greater Philadelphia Region
Characterizing Energy Use in New York City Commercial and Multifamily Buildings
Combining Community Resiliency and EE Retrofits
Conformal Adaptive Hexahedral Dominant Mesh Generation for CFD Simulation in Architectural Design Applications
EDA Stakeholder Engagement Continued Effort
Energy Efficiency and Occupant Behavior Case Study
Energy Efficient Tenant/Owner Education Program
Federal Historic Preservation and Energy Efficiency Policies: Exploring Alignments and Conflicts
Finding: Improving Energy Efficiency Code Compliance
Improving Code Compliance Phase 2 – Implementation Tools, Training and Stakeholder Development
Intermediate and Advanced Level – A guide to Community-Wide Benchmarking Analysis
Introductory Level – A Guide to Community-Wide Benchmarking Analysis
Marketing Engagement Plan for Certificate of Proficiency in Benchmarking
Municipal Guidance for Promoting EE in the Private Sector
On-bill Financing Case Study of Projects
Policy and Process Factors Impacting Commercial Building Energy Efficiency in Pennsylvania and New Jersey
Potential for Various Policies to Impact the Retrofit Market
Preliminary Experimental Evaluations of Occupant Behavior During Load Shedding
Quantification of the value of benchmarking to DSM programs
SEED Platform Enhancements to Support Energy Efficiency at the Portfolio Level
Systems Integration Approach
Targeting Rebate Program Customers with Benchmarking Data Analytics Methods
The Market for Commercial Property Energy Retrofits in the Philadelphia Region
Valuing Energy Efficient Buildings

## Education and Workforce Development

Finding: Advanced Commercial Buildings Workforce Competency Models
Asset Score Online Training and Certificate of Proficiency
Broker Training Final Report and Supporting Materials
Building Re-Tuning Automated Report Generator
Building Re-Tuning Training Deployment Model
Building Re-Tuning Updated Case Studies
Certificate of Proficiency in Benchmarking (online.njit.edu/cbk/)

Certificate of Proficiency in Benchmarking Training and Credentialing Program
Education and Workforce Programs Report
Finding: Building Re-Tuning Training
Why Educate Commercial Brokers

## Market Deployment, Commercialization and Demonstration

Finding:  CAV to VAV AHU Retrofit
Shading and Window Attachment Market Report
The Corner Store Retail AER Packaged Retrofit and Utility Incentive Program Final Findings
Three Case Studies On Design, Construction and Initial Operation of a High Efficiency, Small Building Retrofit
Two Case Studies: Getting Value from Retrofit Demonstrations
CBEI Final Report and Accomplishments