U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

BUILDING TECHNOLOGIES OFFICE
Peer Review Report 2018

2018 PROJECT PEER REVIEW
U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

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The U.S. Department of Energy's (DOE) Building Technologies Office (BTO) collaborates with industry, academia, national laboratories, and other leaders across the building sector to develop innovative, cost-effective, energy-saving solutions for U.S. buildings, which are the single largest energy-consuming sector in the nation. Residential and commercial buildings account for more than 74% of the nation's electricity use and 39% of total energy demand, resulting in an estimated national energy bill totaling more than $395 billion annually.[1,2,3] BTO's long-term goal is to reduce the energy intensity of homes and commercial buildings by 50% or more through the application of cost-effective efficiency technologies that reduce energy waste and yield substantial net economic benefits.

Reducing building energy use per square foot, or energy use intensity (EUI), helps conserve valuable natural resources and strengthen the U.S. economy by creating jobs, improving the productivity of businesses, and helping make energy more affordable for families and businesses. In addition to saving energy, certain BTO technologies and activities also benefit the United States in other ways. For example, BTO's early-stage research and development (R&D) of advanced and transactive controls helps enable industry to develop and deploy Grid-Interactive Efficient Buildings that are capable of connecting with the power grid in new and increasingly adaptive manners to help with overall energy system efficiency, resiliency, and reducing energy prices. BTO's collaborative research activities also spurs U.S. energy dominance and economic competiveness through scientific and engineering leadership and supports workforce development for researchers and other in STEM fields.

To ensure BTO projects are relevant, effective, and productively assisting the Office in meeting its goals, BTO conducts an annual Peer Review. Peer Review is a formal, documented evaluation process that uses objective criteria and qualified independent reviewers to judge the technical, scientific, or business merit; the actual or anticipated results; and the productivity and effectiveness of BTO-funded projects. Knowledge about the quality and effectiveness of current BTO projects and programs is essential in enhancing existing efforts and designing future programs. The BTO Peer Review is open to the public and provides an opportunity to learn more about BTO's portfolio as well as promote collaborations and partnerships.

A zero energy building on NREL's campus.
Image courtesy of National Renewable Energy Laboratory

Mission and Goals

BTO's mission is to support the R&D, validation, and integration of affordable, energy-saving technologies, techniques, tools, and services, to enable industry and others to develop and deploy novel technologies that can improve the efficiency and reduce the energy costs of the nation's homes, offices, schools, hospitals, and other commercial and residential buildings in both the new and existing buildings markets. BTO seeks to overcome the high degree of fragmentation across the heterogeneous buildings industry—spanning from construction to appliance and equipment manufacturing—which contributes to the building sector consistently and significantly under-investing in R&D compared to the U.S. industry average.[4]

BTO's employs a three-pronged strategy to advance its missions, encompassing:

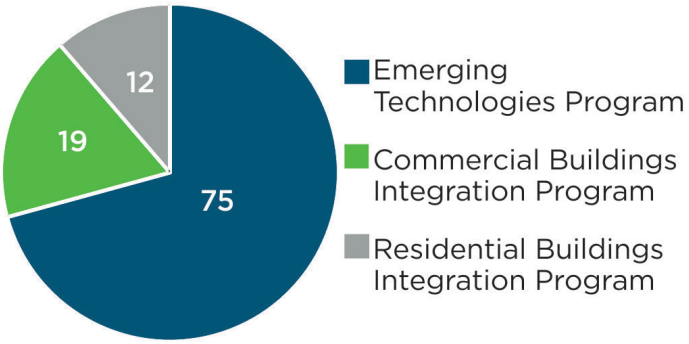
- Pre-competitive, early-stage investment in the R&D of innovative, next-generation building energy technologies, as well as their effective integration into efficient, resilient, grid-connected, and secure building systems.
- Validation, verification, and integration of energy-saving solutions that help building owners and homeowners reduce energy waste by improving understanding of efficient building operational practices and technologies, as well as their costs and benefits.
- Collaboration with (1) industry and other stakeholders to test and implement statutorily-mandated appliance and equipment efficiency standards and (2) development bodies and implementing states to support industry processes related to building codes.

BTO's overarching long-term goal is to reduce the energy use per square foot of U.S. buildings by 50% compared to 2010 levels, potentially saving over $200 billion annually in national energy costs. Based on current analysis of the building sector and BTO program planning, BTO has established a sectoral goal of reducing building EUI 30% by 2030. BTO's Multi-Year Program Plan outlines the activities BTO has pursued to enable these outcomes and provide compelling, affordable energy efficiency options for our nation's homes and buildings.

Introduction

2018 BTO Peer Review

The 2018 BTO Peer Review was held April 30–May 3, 2018, at the DoubleTree Crystal City in Arlington, Virginia. The review was attended by more than 480 participants and included presentations on 115 projects representing three of BTO's five technology programs. Of these projects, 106 were formally evaluated, including:



The Appliance and Equipment Standards Program and Building Energy Codes Program are typically excluded from the BTO Peer Review process, as the majority of their work and stakeholder input processes is directed by statute.[5,6]

The objectives of the 2018 Peer Review were to:

1. Conduct an independent evaluation of current BTO projects and performers, their efforts over the past year toward BTO goals, and their future plans;
2. Provide a forum to promote collaborations and partnerships among project performers and other stakeholders; and
3. Demonstrate DOE's role in energy efficiency.

Independent reviewers were drawn from a variety of building-related backgrounds and included experts from industry, academia, government, and other stakeholder groups. Each reviewer was screened for conflicts of interest and assigned to projects based on their area of expertise and interests. Reviewers evaluated each assigned project according to five criteria—approach, impact, progress, collaboration and coordination, and remaining project work—providing a numerical score for each criterion and then substantiating these scores with additional comments. The Appendix provides a complete list of reviewers, as well as a detailed description of the evaluation criteria and scoring methodology.

Informational Discussions

For the third year, BTO hosted several non-reviewed sessions at the Peer Review on key R&D subjects and other areas of interest, providing attendees with an opportunity to learn about and engage with priority topics that were not fully addressed or covered as part of project review sessions. Topics covered during these discussions included a variety of issues related to Grid-interactive Efficient Buildings, the latest technologies driving updates to model U.S. building energy codes and typical construction practices, the various fellowships available at DOE, and the findings of BTO's most recent third-party program evaluations. In addition, nine projects were presented during review sessions but were not formally evaluated by reviewers. Presentation materials delivered during these non-reviewed sessions can be found on the 2018 BTO Peer Review webpage.

BTO Peer Review Report

This report summarizes the scores and comments submitted by reviewers for the 106 projects that were formally evaluated at the 2018 BTO Peer Review. The following sections present an overview of the goals and activities for BTO's various technology program areas, a summary of project scores for each program, and a brief analysis of general evaluation trends and highlights for each program area or its constituent sub-programs. Individual project scores and comments, as well as BTO's response to reviewer comments, are available on the 2018 BTO Peer Review webpage or in the Appendix.

A zero energy ready home in Brookfield, IL.
Image courtesy of BrightLeaf Homes

BTO's Emerging Technologies (ET) Program works with large industry, small businesses, academia, DOE national laboratories, and other DOE offices to advance the research and development (R&D) of pre-commercial, energy-efficient, cost-effective building technologies and systems, as well as key enabling technologies that can further increase the energy efficiency of buildings. ET also conducts R&D around Grid-Interactive Efficient Buildings (GEB) in order to identify and develop energy-efficient building technologies and measures that support grid services, while leveraging improvements in the connectivity, communications, and "intelligence" of various devices to further BTO's energy-efficiency mission.[7] The ET Program focuses on six major technology areas:

- Heating, Ventilation, and Air Conditioning (HVAC); Water Heating; and Appliances
- Windows and Building Envelope
- Solid-State Lighting (SSL)
- Sensors and Controls (S&C)
- Building Energy Modeling[8]
- Transactive Energy Management

Three of these technology areas—HVAC, water heating, and appliances; windows and building envelope; and SSL—together represent approximately 60% of the energy used in buildings today, and thus a significant source of potential efficiency gains over the next several decades.[9] Advancements in S&C technologies and energy modeling can further improve the base efficiency of these other building technologies, both in design and operation.

In carrying out its R&D agenda, the ET Program contributes to DOE's Grid Modernization Initiative (GMI) through the Grid Modernization Laboratory Consortium (GMLC) and supports the U.S.-China Clean Energy Research Center (CERC).[10] ET also participates in DOE's Technology Commercialization Fund (TCF) and Small Business Vouchers (SBV) programs, as well as the Small Business Administration's Small Business Innovation Research (SBIR) program.[11]

High-Level Summary of Reviewer Comments

The ET Program peer reviewed 75 projects across six sub-programs: Sensors and Controls; Transactive Energy Management; HVAC, Water Heating, and Appliances; Building Envelope; Building Energy Modeling; and Solid-State Lighting. 11 of these projects were initiated as part of the GMLC, while four of these projects were carried out as part of the CERC program.[12] One project received TCF funding, and two projects each participated in the SBV and SBIR programs.[13]

This section discusses the high-level evaluation trends by technology area. Table 1 provides a high-level summary of project scores broken out by sub-program. Projects had a maximum potential score of four and a minimum potential score of one. For individual project scores and comments, please visit the 2018 BTO Peer Review webpage or see the Appendix.

Table 1. High-Level Summary of ET Project Scores

Sub-Program	Project Count	Average Score	Low Score	High Score
HVAC, Water Heating, & Appliances	18	3.19	2.86	3.89
Building Envelope	5	3.21	2.82	3.49
Solid-State Lighting	16	3.64	3.35	3.83
Building Energy Modeling	8	3.36	2.75	3.82
Sensors & Controls	21	3.18	2.73	3.62
Transactive Energy Management	7	3.65	3.18	4.00
Overall	75	3.35	2.73	4.00

HVAC, Water Heating, and Appliances

HVAC, water heating, and appliances account for an estimated 21 quads of primary energy consumed in the United States, with HVAC representing the largest energy end use in both residential and commercial buildings.[14,15] The HVAC, Water Heating, and Appliances sub-program seeks to accelerate the development of technologies that have the potential to save significant amounts of energy. This includes conducting R&D on novel heat exchanger designs and manufacturing techniques; researching and evaluating alternative refrigerants and developing compatible HVAC and refrigeration (HVAC&R) systems; and researching thermally-driven compressors used in fuel-fired applications, including natural gas or propane. In the long-term, the sub-program seeks to develop next-generation technologies that 'leapfrog' existing technologies and result in dramatically improved energy efficiency. Next-generation technologies currently being researched by the sub-program include HVAC&R and water heating systems and appliances that utilize magnetocaloric, thermoelectric, and electrochemical materials and processes.

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Each of these research thrusts were represented among the 18 projects reviewed under the HVAC, Water Heating, and Appliances sub-program at the 2018 BTO Peer Review. HVAC&R projects represent the largest category of reviewed projects in this sub-program with 14; these projects are further segmented into Advanced HVAC (three projects) and Assorted HVAC&R (11 projects) technologies for better disaggregation of evaluations trends. The remaining four projects under this sub-program are divided between appliances (three projects) and water heating technologies (one project). Each of these technology areas and sub-areas are discussed in the sections that follow.

Table 2 provides a high-level summary of project scores; projects had a maximum potential score of four and a minimum potential score of one.

Table 2. High-Level Summary of HVAC, Water Heating, and Appliance Project Scores

Technology Area	Project Count	Average Score	Low Score	High Score
HVAC, Water Heating, & Appliances	18	3.19	2.86	3.89
↳ *Assorted HVAC&R*	11	3.21	2.86	3.89
↳ *Advanced HVAC*	3	3.12	2.96	3.34
↳ *Appliances & Water Heating*	4	3.19	3.09	3.38

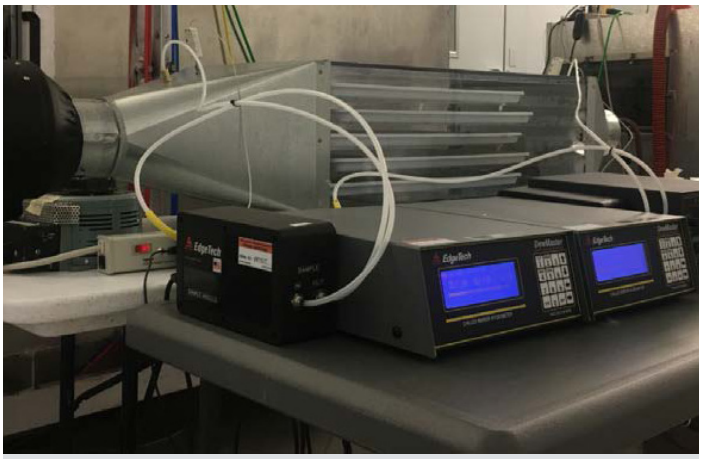
Advanced HVAC Technologies

HVAC systems presently represent the largest energy end-use in buildings, requiring almost 13 quads of primary energy annually, or approximately one-third of all energy used in U.S. commercial and residential buildings.[16] Given this energy usage, as well as the harmful environmental impacts of conventional refrigerants used in traditional vapor-compression equipment, BTO is working with several partners to develop advanced HVAC technologies that improve energy performance while transitioning away from the use of conventional refrigerants and towards low- or zero-global warming potential (GWP) alternatives. Advanced vapor compression (AVC) projects aim to reduce the cost and improve the energy performance of air conditioning systems in buildings using low-GWP refrigerants that have minimal effect on the global environment. Non-vapor compression (NVC) projects seek to develop innovative new classes of highly-efficient HVAC technologies that do not use refrigerants and can achieve cost-effectiveness in the long-term.

Prototype system for using natural-gas for on-site electricity production and HVAC without commercial refrigerants or a compressor. *Image courtesy of Be Power Tech, Inc. and Blue Frontier, LLC*

Three advanced HVAC projects were reviewed at the 2018 BTO Peer Review. All of these projects were generally held in high regard by the reviewers for their potential impacts, but reviewers also generally felt that the design and execution of these projects showed room for improvement. In particular, reviewers expressed some concern about one or more specific technical elements of each projects' approach (e.g., safety of working fluids, the HVAC system power supplies, need for HVAC system redesigns), commenting that some of these technical issues could limit the resulting technologies' market acceptance and subsequent impact.

Generally, reviewers remarked that all three projects had made sufficient progress on their stated project goals and milestones. Reviewers were concerned, however, about these projects' remaining work, calling out the challenge that several of the projects faced in order to meet their technology's efficiency targets.



Prototype solar absorption cooling system.
Image courtesy of Oak Ridge National Laboratory

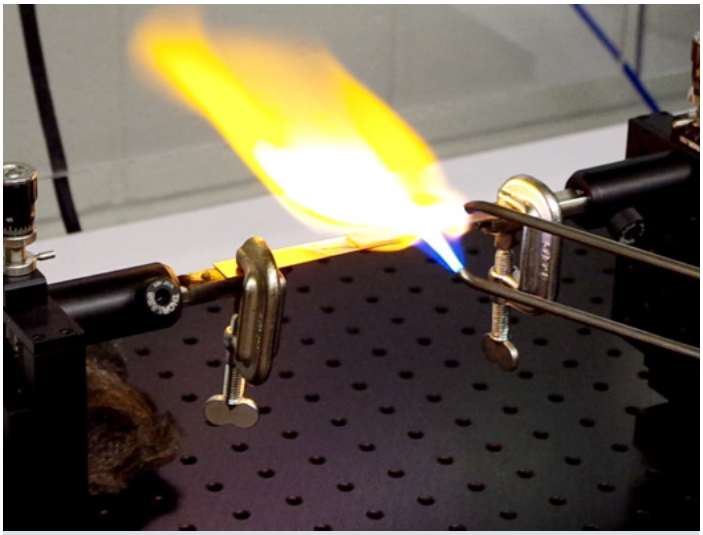
Each of these projects earned reviewers' praises for its collaboration and coordination efforts, though not without some disagreement. For example, one project's close partnership with an original equipment manufacturer (OEM) was lauded by some reviewers as a potential boon for its technology's ultimate commercialization; this relationship was concerning to other reviewers, however, because it effectively locked out other collaborators and limited the dissemination of key project findings to just this OEM, potentially hindering the project's long-term impact.

Assorted HVAC&R Technologies

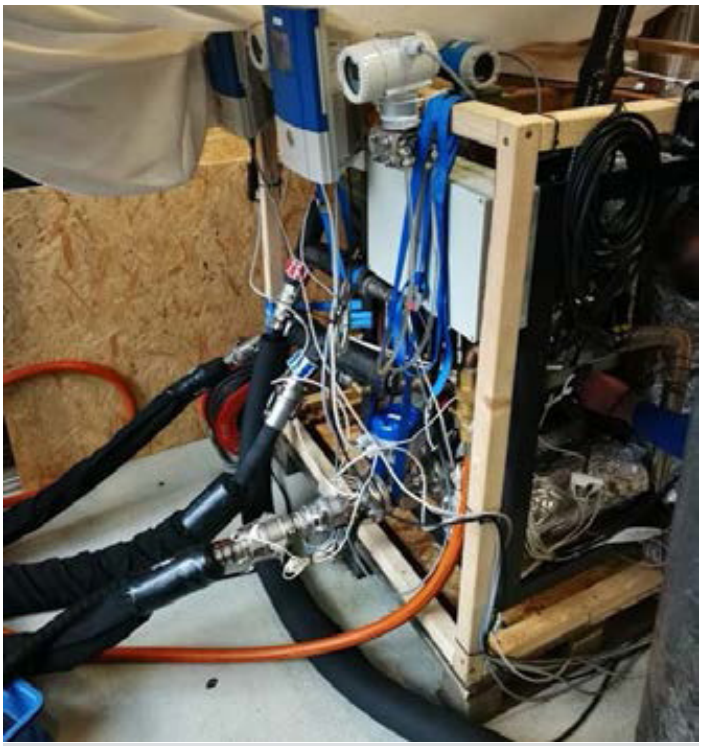
Components such as heat exchangers (HXs), dehumidification and ventilation systems, and sensors and controls can heavily influence energy consumption and performance in common HVAC&R equipment. BTO seeks to take advantage of unrealized opportunities to increase the efficiency of HVAC&R equipment by improving the design and engineering of individual system components, as well as the integrated performance of such components within packaged HVAC and refrigeration equipment.

Eleven projects reviewed at the 2018 BTO Peer Review were focused on assorted HVAC&R technologies, including novel HX designs, manufacturing processes, and joining techniques; novel dehumidification processes to reduce latent loads; a "stick-on" sensor for detecting refrigerant leaks; and a smart ventilation system. One project in this category also sought to advance international collaboration around key HVAC&R research topics.

Reviewers highly regarded those projects whose approaches were found to be driving toward the project's overall goals, as well as those projects found to be employing innovative approaches to overcome existing technical obstacles or challenges. Reviewers also positively remarked on projects that were conducting mid-stream verification and/or validation of interim R&D outcomes, as well as projects with explicit risk mitigation strategies (e.g., exploring multiple pathways to achieving project objectives in case one pathway fails).



Testing the interaction between braze material and modified copper surfaces. *Image courtesy of Trane US Inc., a company of Ingersoll Rand*



Testing prototype components of a residential gas-fired cost-effective triple-state sorption heat pump.
Image courtesy of Oak Ridge National Laboratory

Reviewers had high hopes for both the significance and scale of potential impacts of many of these projects, particularly those aspiring to develop entirely novel technical approaches to common building technology services. Reviewers also positively commented on projects whose outcomes were expected to achieve ancillary benefits beyond energy savings. For many projects, however, reviewers expressed concern that the novelty of the resulting technologies—and thus the lack of familiarity with these technologies by market actors—could limit their market uptake once commercialized.

Reviewers generally agreed that most projects were proceeding well and making progress towards scheduled milestones. For numerous projects that were relatively new and still in the early stages, however, reviewers acknowledged that full evaluation of progress would be challenging until more work was completed and more milestones were either achieved or missed. For many projects, regardless of age, reviewers also highlighted specific project components or elements for which there was concern. Reviewers were less in agreement about projects' remaining

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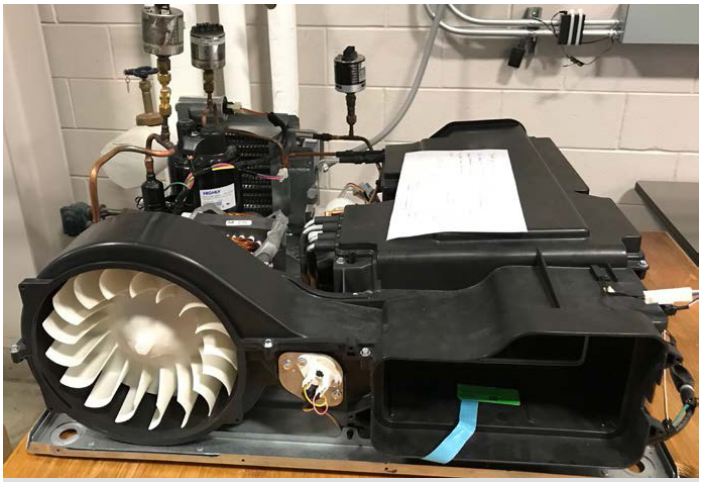


Modified heat pump dryer system using adhesive bonding. *Image courtesy of Oak Ridge National Laboratory*

work than they were about project work already completed. For several projects, for example, reviewers were split on whether proposed future work was appropriate and would be completed on time, or whether delays or challenges related to specific project components would hinder or complicate successful project completion.

As a whole, reviewers felt that the collaborations, partnerships, and stakeholder engagements pursued by these projects were appropriate and effective, and featured appropriate blends of skills, expertise, and good coordination. Even for particularly well-reviewed projects in this evaluation criteria, however, reviewers still offered specific recommendations for additional partners or stakeholder groups with whom additional engagement would be valuable. Reviewers were more critical, however, when they had trouble discerning the exact nature and depth of the collaborations and engagements that were described.

Appliances and Water Heating

Residential appliances consume large amounts of energy within the United States; the daily use of refrigerator/freezers, dishwashers, laundry equipment, and cooking equipment accounts for approximately 14% of residential building primary energy consumption.[17] The appliances used in commercial buildings for cooking and refrigeration are another potential source of energy savings, particularly for buildings such as grocery stores and hotels. Water heaters, which provide buildings with continual sources of hot water, currently account for approximately 9% of primary building energy consumption.[18] BTO's appliance research primarily focuses on refrigerator and freezers and clothes washers and dryers, which have the most opportunity for energy savings, while BTO research on water heating seeks to improve the efficiency of new water heaters for both residential and commercial buildings.

Of the three appliance projects reviewed at the 2018 BTO Peer Review, two focused on refrigeration while one addressed clothes drying technology. The sole water heating project sought to develop a hybrid water heater using electrochemical compression. Most of these projects were well regarded for their innovative technical approaches, which reviewers found to be applying novel technologies to the development, manufacture, and commercialization of higher-performing appliances and water heating products, and working to overcome existing or emerging technical barriers to these technologies' use. Reviewers did raise concerns about specific technical issues for all projects, however. One reviewer was also particularly critical of a project that was described as having a "shotgun" style to addressing technical problems, whereas this reviewer felt a more targeted approach would have been more appropriate.

Reviewers positively remarked on the potential energy savings and other ancillary benefits (e.g., reduction in use of harmful refrigerants) of all but one of these projects' technologies. For several projects, however, reviewers raised concerns about issues with cost-effectiveness preventing the resulting technologies from achieving significant market adoption. Reviewers were most critical when technical concerns compounded reviewers' concerns about cost-effectiveness.

All projects were perceived to be making good progress, and to be meeting project objectives in alignment with project schedules. In terms of remaining future work, reviewers were more confident about projects where continued progress was expected, and remained critical of projects which reviewers felt had lingering technical and/or cost-effectiveness issues to work through.

All projects' collaboration and coordination efforts also were highly regarded by reviewers. For two projects, reviewers especially called out the likelihood that industry partnerships could facilitate the eventual commercialization of project technologies; for one project, however, reviewers felt that the industry partner could have been more deeply engaged with the project's core R&D work.

Testing air cleaning materials and air quality sensors for use in smart ventilation systems. *Image courtesy of Lawrence Berkeley National Laboratory*

The Glint Daylight Concentrator brings natural daylight deep into the interior of buildings. *Image courtesy of Glint Photonics Inc*

Building Envelope

Space heating and cooling represents approximately 28% of the primary energy consumed in residential and commercial buildings;[19] the building envelope forms the main thermal barrier between interior and exterior spaces—when it fails to adequately control the transfer of heat and moisture between these spaces, it can greatly impact how much energy is required to heat or cool the interior to meet occupant preferences.

To reduce the energy required to heat and cool a building, the Building Envelope sub-program supports the development of next-generation residential and commercial building technologies that reduce the unintentional amount of air and moisture that is exchanged, and the thermal energy lost and gained, through the building envelope. Specific R&D areas of interest include high-R insulation materials, air sealing technologies, and smart building materials.[20,21]

Five projects were reviewed under this sub-program at the 2018 BTO Peer Review. Table 3 provides a high-level summary of scores among building envelope projects; projects had a maximum potential score of four and a minimum potential score of one.

Table 3. High-Level Summary of Building Envelope Project Scores

Technology Area	Project Count	Average Score	Low Score	High Score
Building Envelope	5	3.21	2.82	3.49

Generally, reviewers found that Building Envelope projects addressed critical market barriers through sound approaches. The most well-regarded project had well-formulated approaches that were well-positioned to overcome technical and manufacturing barriers for building envelope technologies. Reviewers also valued approaches that were realistic, while cautioning projects that were deemed to have ambitious targets, and were critical where they observed unaddressed potential weaknesses or under-addressed problems.

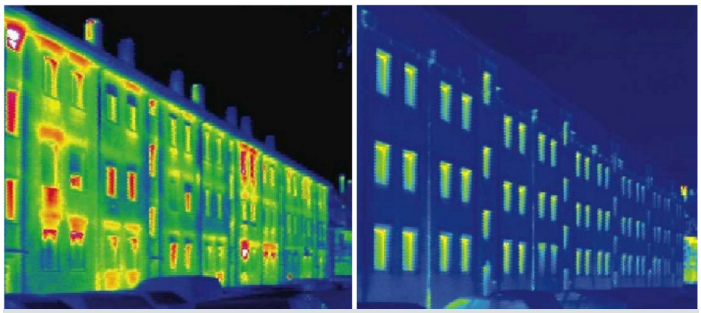
Reviewers generally awarded high scores for impact to projects that significantly contributed to the state-of-the-art or served an area of high commercial interest. Reviewers awarded lower scores to projects that did not address potentially insurmountable issues (e.g., data limitations, feasibility of material development). Reviewers highlighted barriers to market acceptance in some instances, and made recommendations for overcoming them.

Reviewers were generally pleased with the ongoing work of the envelope projects. Although reviewers voiced recommendations for the projects moving forward, they found the projects to be well planned with achievable goals. Reviewers were particularly complimentary of projects that had already surpassed their goals to date, as well as projects that were positioned to hit all targets and milestones on time. For projects with identified roadblocks or challenges, reviewers noted how these challenges could hinder project progress moving forward. Reviewers were most critical of projects that had already experienced significant delays, or had already expended a seemingly-disproportionate amount of total project funding.

Reviewers highly regarded projects featuring strong collaboration with industry, particularly industry partners that appeared likely to lead to manufacturing opportunities and market adoption. Reviewers noted the risks that companies face when participating in early-stage R&D, however, remarking that several projects did not appear to sufficiently de-risk their research activities, potentially imperiling efforts to recruit private sector partners.

Solid-State Lighting

Light-emitting diodes (LEDs) and organic LEDs (OLEDs) have the potential to be ten times more efficient than incandescent lighting and twice as efficient as fluorescent lighting products. If the Solid-State Lighting (SSL) sub-program reaches its goals, SSL technology has the potential to reduce U.S. energy consumption by 395 Terawatt-hours (TWh) annually by 2030, relative to a scenario in which LEDs do not exist. This would translate to annual cost savings of $40 billion.[22] The efficacy of



New insulation technology dropped the energy demand by 90% after refurbishment.
Image courtesy of Lawrence Berkeley National Laboratory

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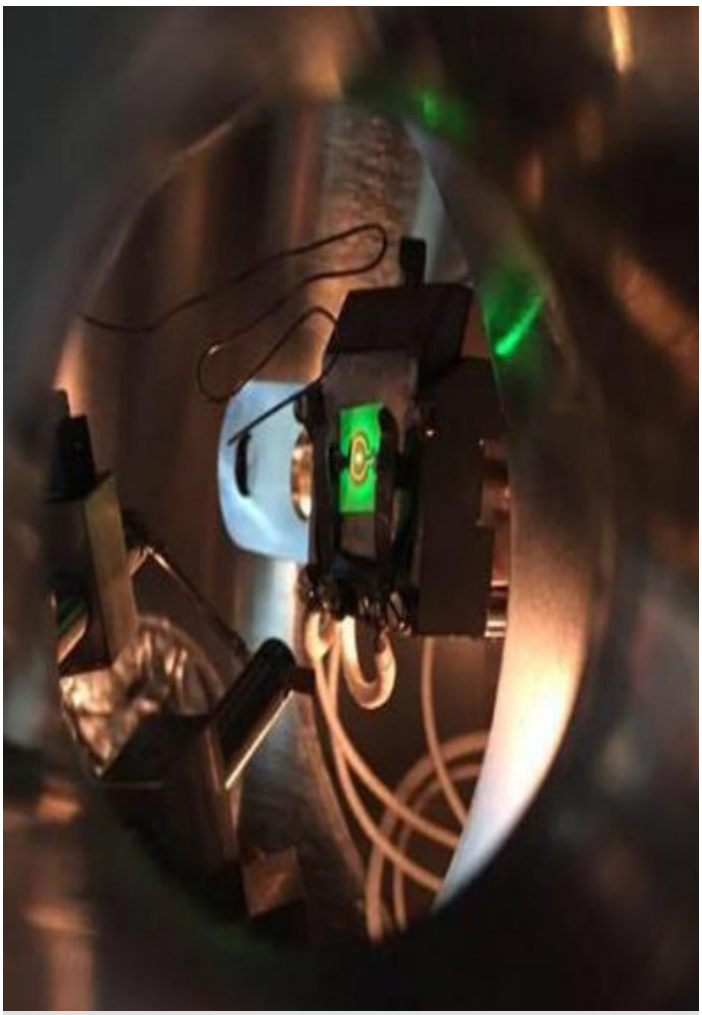
LED light sources has already surpassed that of incandescent, halogen, high-intensity discharge, and linear fluorescent lamps, and will continue to improve. However, continued innovation and breakthroughs in materials, processes, control systems, and manufacturing are still needed to realize the technology's full potential. SSL also presents a huge opportunity to improve the performance and value of lighting through enhanced controllability, new functionality, application-specific lighting performance, novel form factors, and targeted improved wellbeing and productivity.

Sixteen projects were reviewed under the SSL sub-program at the 2018 BTO Peer Review, with six focused on next-generation LED technologies, eight focused on OLEDs, and two focused on human-light interactions. Table 4 provides a high-level summary of scores among SSL projects; projects had a maximum potential score of four and a minimum potential score of one.



Testing GaN-Based LEDs to identify the droop mechanism.
Image courtesy of UC Santa Barbara

Table 4. High-Level Summary of SSL Project Scores

Technology Area	Project Count	Average Score	Low Score	High Score
Solid-State Lighting	16	3.64	3.35	3.83
↳ *LED*	6	3.62	3.35	3.75
↳ *OLED*	8	3.65	3.47	3.83
↳ *Human-Light Interactions*	2	3.69	3.60	3.78

Across the portfolio of SSL projects reviewed, every project's approach earned nearly unanimous support from reviewers. In almost every instance, reviewers credited the projects' approaches for their novelty, for precisely targeting significant market barriers, and for delivering advancements that overcame—or were almost certain to overcome—those barriers. In four instances, reviewers directly linked the project's experimental designs with producing results that had already, essentially, solved long-standing scientific conundrums. Reviewers often described these projects' approaches as novel, unique, and well designed. Several projects were also commended for their scientific rigor, though for a few reviewers offered recommendations on how project teams could further improve experimental control to yield more quantifiable and precise results.

In most instances, reviewers expressed confidence that these projects' approaches would produce impacts that would achieve BTO's goals. Most reviewers also speculated on the ultimate, longer-term impacts of this portfolio's technological advances—including advances in understanding about the physiological responses of people to SSL luminaires—with respect to manufacturing costs, luminaire performance, and the science of SSL lighting in general. Reviewers posited that these advances would improve the performance and efficiency of SSL products enough to substantially change the SSL marketplace.

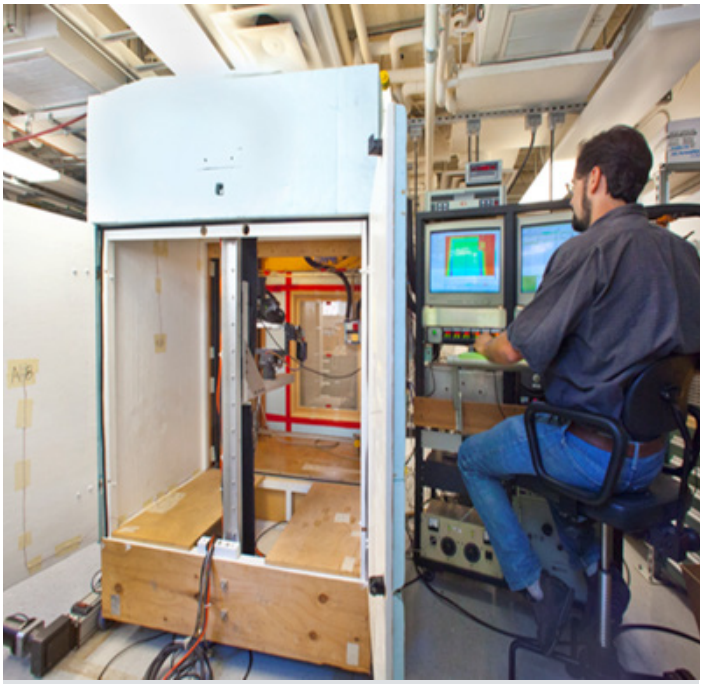
Despite reviewers' positive expectations for future impact, however, reviewers' remarks were somewhat mixed around projects' progress-to-date and future work. Specifically, while reviewers assessed that all but one project in the SSL portfolio had achieved a satisfactory amount of progress, most projects' planned future work engendered a significant amount of reviewer skepticism. Most reviewer concerns were about the project teams' abilities to finish their work before the projects were planned to end, but a few concerns were related to the achievability of project goals.

Reviewers generally commented sparingly on the SSL portfolio's project collaboration and coordination efforts, other than to express general satisfaction, lament the omission of a specific class of partner (e.g., industry, academic), or to praise the diversity and engagement of a project's collaborators. In some cases, the strength of project partners was a source of reviewer optimism for projects with substantial work ahead.

Building Energy Modeling

BTO's Building Energy Modeling (BEM) portfolio has been jointly managed under BTO's Commercial Buildings Integration (CBI) and Emerging Technologies (ET) Programs. Whole-building energy modeling is a versatile, multipurpose tool that is used in new building and retrofit design, performance-based code compliance, certification, qualification for tax credits and utility incentives, and real-time building control. BEM programs calculate a building's thermal load, system responses to those loads, and resulting energy use, along with related metrics like occupant comfort and energy costs. Use of BEM can increase building energy efficiency by as much as 50% before construction even begins.

The BEM sub-program seeks to characterize and implement models of the physical phenomena for building components and systems that enable increased use of building energy modeling tools for the design and operation of energy-efficient buildings in the U.S. The BEM sub-program also seeks to accelerate the use of energy modeling in both new and established use cases.



Validating models of dynamic heat and moisture transfer in building envelopes.

Image courtesy of Lawrence Berkeley National Laboratory and Oak Ridge National Laboratory

LBNL's FLEXLAB is a specialized testing facility where experiments are performed to produce data sets that can be used to validate BEM engines.

Image courtesy of Lawrence Berkeley National Laboratory

Eight BEM projects were reviewed during the 2018 BTO Peer Review, including five under the purview of the ET Program and two under the purview of CBI. Table 5 provides a high-level summary of project scores; projects had a maximum potential score of four and a minimum potential score of one.

Table 5. High-Level Summary of BEM Project Scores

Technology Area	Project Count	Average Score	Low Score	High Score
BEM	8	3.36	2.75	3.82
↳ *ET*	5	3.40	2.75	3.82
↳ *CBI*	3	3.27	3.13	3.43

Reviewers highly valued those BEM projects whose approaches operated in an open-source environment; leveraged existing DOE tools and resources; established and demonstrated strong BEM use cases; and engaged stakeholders to identify new BEM features and priorities. In some instances, however, reviewers questioned project teams' abilities to manage certain elements of their approach, even if the approach appeared strong on paper and other elements of the project were being effectively managed.

When evaluating BEM projects' impacts, reviewers highly regarded projects that they perceived to be foundational to DOE's BEM research and/or private sector BEM adoption and use; those projects that were developing products or services which provided complementary function to other BEM tools; and those project whose application had large-scale potential in terms of the number of buildings that could be influenced. Reviewers were more critical of projects where the reviewers questioned whether project efforts would ultimately translate

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into actual energy savings, as well as where reviewers questioned whether greater impact could be achieved from investing federal dollars elsewhere in DOE's BEM ecosystem.

All but two projects were observed to be making good progress, particularly where reviewers felt that all milestones were being met. Both projects that were considered "long-term" (i.e., projects operating for 8 years or longer) were complimented for having created systems and processes to ensure that long-term progress was sustained and well directed. Projects that received lower scores for progress often suffered from noticeable delays in the project schedule, or engendered disagreement among reviewers over the progress being made relative to the project plan. Looking forward, reviewers observed appropriate scopes of work, realistic timelines, a "legacy of solid progress," and good project plans, leading to reviewer expectations that remaining project work would be successfully completed on time and within budget. In some instances, however, reviewers warned of potential challenges that were upcoming.

In terms of the project collaboration, the highest score was given to a project where excellent strategic collaboration and coordination was demonstrated with relevant stakeholders, and where this collaboration was perceived to be well organized and highly effective. Good scores were also assigned to projects that benefited from an "impressive" or broad list of collaborators, or where collaborators were observed to be working well together to develop project deliverables. For a few projects, reviewers concluded that a certain type of stakeholder voice (e.g., BEM end users, industry) was either missing, underrepresented, or not being engaged sufficiently well.

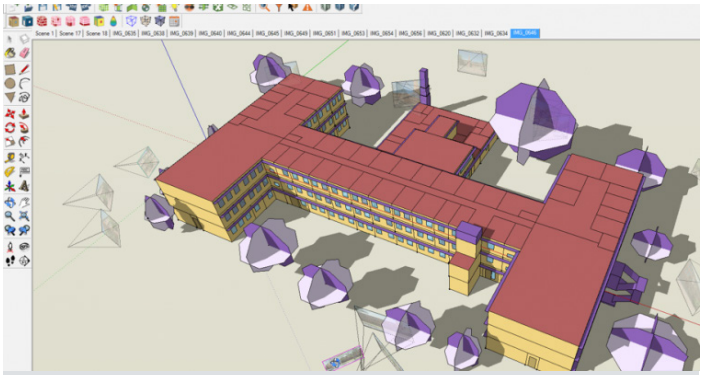
Sensors and Controls

Studies have shown energy savings ranging from 23% to 30% in most commercial building types as a result of the proper deployment of accurate sensors as well as basic and advanced controls, including automated fault detection and diagnostics.[23] The goals of the Sensors and Controls (S&C) sub-program are (1) to enable low-cost approaches to accurately detecting and diagnosing faults, failures, and resulting inefficiencies in building equipment and subsystems, while also allowing for optimal and localized whole-building control opportunities to improve occupant comfort while reducing energy use, and (2) to effectively integrate building energy loads with the rest of the electric grid and support energy-related transactions outside the building envelope. The sub-program is organized around the following four focus areas:

- Adaptive and fault tolerant controls
- Whole-building sub-metering
- Multifunction plug-and-play wireless sensors
- Occupant-centered and -comfort sensors and controls

Advancements in these sensor and control strategies will improve the efficiency—and enable energy savings—for other building technologies, including HVAC, water heating, lighting, windows, and the building envelope.

Twenty-one projects were reviewed under this sub-program at the 2018 BTO Peer Review, covering each of the sub-program's four focus areas. Table 6 provides a high-level summary of scores among these projects; projects had a maximum potential score of four and a minimum potential score of one.



OpenStudio was used to model and evaluate the conversion of a 1950s Army barracks to a zero net energy office building.
Image courtesy of National Renewable Energy Laboratory/Matt Leach

Table 6. High-Level Summary of S&C Project Scores

Technology Area	Project Count	Average Score	Low Score	High Score
S&C	21	3.18	2.73	3.62
↳ *Adaptive and Autonomous Controls*	9	3.09	2.73	3.53
↳ *Advanced Sub-Metering*	4	3.12	2.88	3.62
↳ *Multi-Function Wireless Sensor Networks*	4	3.38	3.03	3.50
↳ *Occupant-Centric S&C*	4	3.23	3.09	3.43

Adaptive and Autonomous Controls

The approach for each of nine projects reviewed under this focus area convinced at least one reviewer that it had been designed sufficiently to overcome barriers, technical challenges, and

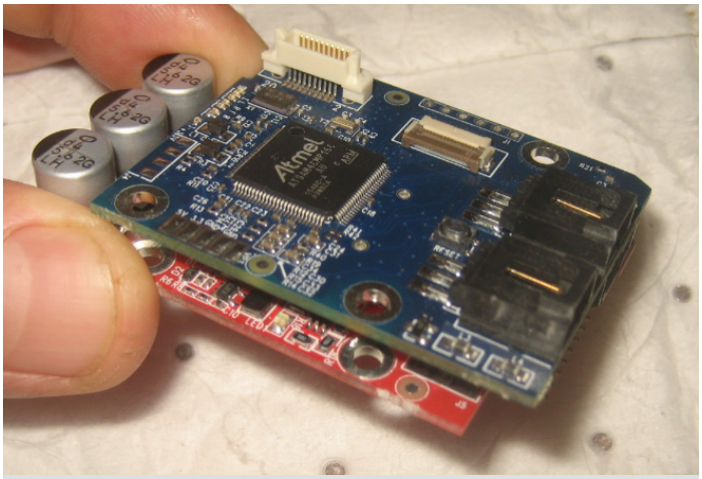
mitigate risks; this contention, however, was often disputed by the remaining reviewers.

Projects' approaches to modeling were among the project elements most vigorously discussed by reviewers. Reviewers made supportive remarks about project approaches that used real data to ground-truth or calibrate their results, as well as projects that emphasized simplicity over complexity. On the flip side, reviewers frequently expressed concern about specific technical issues related to a project's approach to modeling, including model accuracy, building optimization via model predictive control, or fault detection.

Reviewers also focused their evaluations on whether or not a project's approach would, in their estimation, actually address market barriers. For example, reviewers positively called out projects that targeted underserved sectors like small commercial buildings, and they also expressed optimism with regard to the open-source nature of VOLTTRON, and the tweaks made to VOLTTRON to improve its commercial viability and ease of use. Reviewers were not always convinced that every projects' results would improve the dynamics for greater market adoption of advanced control systems, however, often pointing to persistent behavioral obstacles, including stakeholder awareness of, comfort with, and ability to use such systems.

Reviewers were generally satisfied with the progress of these projects, though reviewers often sought more granular metrics to substantiate this progress (e.g., the number of adopters of a technology rather than latest technology developments, results of an algorithm test rather than confirmation that the test

Automated fault detection and diagnostic algorithms can be used to identify operational and equipment-related faults in common HVAC equipment.
Image courtesy of Pacific Northwest National Laboratory and JouleSmart



ANL's compact submeter hardware. *Image courtesy of Argonne National Laboratory*

was conducted). With regard to this portfolio's future work, reviewers often questioned how some of the software being developed would receive technical support and updates moving forward. Reviewers also encouraged project teams to clearly document project outcomes and make them freely available for public use. On several occasions, reviewers asked project teams to continue to refine their software in pursuit of greater modeling accuracy, either by tweaking their algorithms, calibrating with real-world data, or expanding the range of test bed types.

Reviewers did not say much about these project's collaborations and coordination efforts, other than to recommend for a few projects that advisory board members be engaged more around the development of test procedures.

Advanced Sub-Metering

Within this focus area, reviewers commended project approaches for various elements (e.g., modeling and techno-economic analysis, dashboard and analytics, natural language processing, algorithm validation), even calling one project's approach novel and potentially transformative. With this praise, however, also came a variety of reviewer concerns, including project-specific technical concerns, concerns about the maturity of technologies, and/or concern that there was similar work occurring elsewhere. Cost was also a focus of reviewer comments, with reviewers remarking on whether a project had concentrated on reducing installed costs, or whether the full cost of the technology had been considered.

In a majority of projects, reviewers explicitly remarked that the project would contribute to BTO's advanced sub-metering goals. For most projects, reviewers also pointed to multiple other important project impacts (e.g., maximizing local generation and storage, energy reporting and optimization, addressing miscellaneous energy loads). For projects receiving lower scores for impact, reviewers noted that energy-savings impacts were

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Testing wireless sensor power consumption and data transmission range. *Image courtesy of Palo Alto Research Center, Inc.*

unclear, and/or that project impacts would ultimately depend on outside factors (e.g., sub-meter application, affordability of distributed energy resources).

Across all projects in this focus area, reviewers noted that progress appeared to be on track, and generally found work to be well-planned to meet project-specific goals. For all projects, however, reviewers identified items that still needed to be addressed as part of future work, including development of technology-to-market pathways as well as resolution of technical issues that could impact final project deliverables.

Reviewers remarked on most projects' good collaboration, though in some instances reviewers questioned the project-specific value of specific collaborations. Reviewers also positively commented on strong project partnerships that could facilitate the transition of project technologies to the market.

Multifunction Plug-and-Play Wireless Sensors

Many of the projects reviewed in this focus area were well regarded for their approach, with reviewers referring to these approaches as sound, innovative, or "right on target." Robust cybersecurity, interoperability, and flexibility in the application of wireless sensors were all perceived to be positive technical characteristics being pursued. However, reviewers negatively observed when a project appeared to be aggregating and applying existing technologies rather than producing novel technical improvements and innovations, and power consumption issues also engendered disagreement or concern where there were questions about sufficiency.

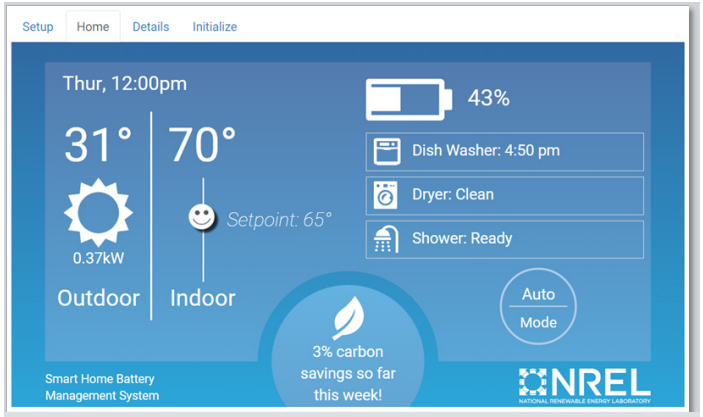
For all projects, reviewers highlighted that the potential energy-savings impacts of the sensor networks being developed would ultimately depend on the scale of market adoption and the application of the sensor system. Interoperability, cybersecurity, and open-source architecture were all technical characteristics that reviewers expected to encourage market adoption. For one project, cost-competitiveness was also seen as a key factor that would affect market adoption, and for another it was scalability of the sensor network.

Reviewers agreed that all four projects demonstrated clear progress and looked to be meeting scheduled plans. Furthermore, reviewers generally agreed that projects' future work was appropriate, logically planned, and expected to be completed within the envisioned timeframe. For some well-regarded projects, however, reviewers still had concerns regarding project completion by the scheduled end date, citing challenging upcoming activities that could cause some delay. For one project in particular, some reviewers expressed concerns about key technical issues that had not been accounted for as part of work completed to date.

While reviewers saw most projects as having an appropriate and good mix of stakeholders, projects varied in how reviewers appraised their level of industry engagement. The project receiving the highest score for collaboration, for example, was still perceived to have weak industrial engagement. In contrast, one reviewer saw another project's industry partnerships as a major project strength, such that this reviewer waved off concerns about cost because the reviewer had faith that the manufacturing partner would ensure cost issues were addressed.

Occupant-Centric Sensors & Controls

Across the four projects reviewed under this focus area, reviewers observed strong approaches to be well-structured to meet project goals, as well as highly likely to contribute to overcoming barriers and technical challenges. Even for well-regarded projects, however, reviewers raised concerns about specific technical elements of the projects' approaches, (e.g., methodology for stress-testing sensors, model predictive control), as well as non-technical elements (e.g., preserving occupant privacy, barriers to technology deployment, technology applications, and technology costs).



Occupant dashboard for NREL's Smart Home Batter Management System. *Image courtesy of National Renewable Energy Laboratory*

In projects with higher scores for impact, reviewers agreed that projects would contribute to overarching goals, whether these were BTO's goals or energy-related impacts more broadly. In lower rated projects, reviewers still highlighted projects' contributions to energy savings impacts, but there was some disagreement about the scale of potential energy savings. Reviewers remarked on some projects' value to the grid, and for others reviewers also noted the possibility for projects to accelerate the adoption of advanced building controls.

Reviewers commented positively on projects that demonstrated significant progress toward the achievement of project-specific goals, and assigned lower scores when reviewers raised concerned about a project's progress-to-date relative to its planned schedule. All projects in this portfolio were well-regarded for their remaining work, with reviewers commenting that future work appeared to be well-planned and on-schedule. Some reviewers none-the-less recommended adjusting the scope of work for a few projects, advising one project to down-scope in order to finish on time, and other projects to shift their focus to incorporate and/or address cybersecurity and resiliency.

Across the board, projects received high marks for collaboration, with reviewers noting the extensive involvement of diverse stakeholders and meaningful collaborations. The project receiving the highest mark in this category was lauded for it excellent collaboration between national labs and industry partners across two different countries, as well as the integration of project work with standards committees. Reviewer concerns about project collaborations focused on the perceived depth of stakeholder engagements, or the lack of coordination with specific classes of stakeholders.

Transactive Energy Management

As part of its Transactive Energy Management focus area, BTO conducts Grid-Interactive Efficient Buildings research to enable industry to develop and deploy energy-efficient buildings that can automatically and dynamically change their energy use and demand patterns in response to signals from the grid. As part of this effort, BTO works with industry partners, national labs, and other stakeholders to conduct R&D on key building blocks for cyber-physical building systems that address the integration and optimization of homes and commercial buildings with the nation's energy grid, and also to explore the fundamental concepts of transaction-based energy systems.

Through its Transactive Energy Management portfolio, as well as projects in the Sensors & Controls sub-program, BTO also contributes to DOE's Grid Modernization Initiative (GMI), which works across DOE to develop the concepts, tools, and technologies to measure, analyze, predict, protect, and control the power grid of the future. In particular, BTO sponsors a number of projects under the Grid Modernization Lab Consortium (GMLC), which was established under GMI as a strategic partnership between DOE and the national laboratories to support critical R&D in advanced storage systems, clean energy integration, standards and test procedures, and a number of other key grid modernization areas.

Economic dispatch and supervisory control software can be deployed on the VOLTTRON™ distributed control platform.
Image courtesy of Pacific Northwest National Laboratory

Seven projects were reviewed under the Transactive Energy Management topic at the 2018 BTO Peer Review, all of which were initiated as part of the GMLC.[24,25] Table 7 provides a high-level summary of scores among these projects; projects had a maximum potential score of four and a minimum potential score of one.

Table 7. High-Level Summary of Transactive Energy Management Project Scores

Technology Area	Project Count	Average Score	Low Score	High Score
Transactive Energy Management	7	3.65	3.18	4.00

Reviewers positively evaluated Transactive Energy Management projects that were conducting foundational, original, and "needed" research for transactive controls in buildings, particularly when this research was complemented by efforts to identify "bottleneck[s] for optimization" and related challenges (e.g., interoperability of devices and systems) for specific implementations of transactive energy management. Substantively, research approaches were lauded for both their analytical value and their framing of stakeholder engagements. Procedurally, approaches were highly regarded where they were observed to be sound, well-matched with project objectives, clearly defined, and well-designed. In a few instances, reviewers questioned specific technical choices that reviewers believed

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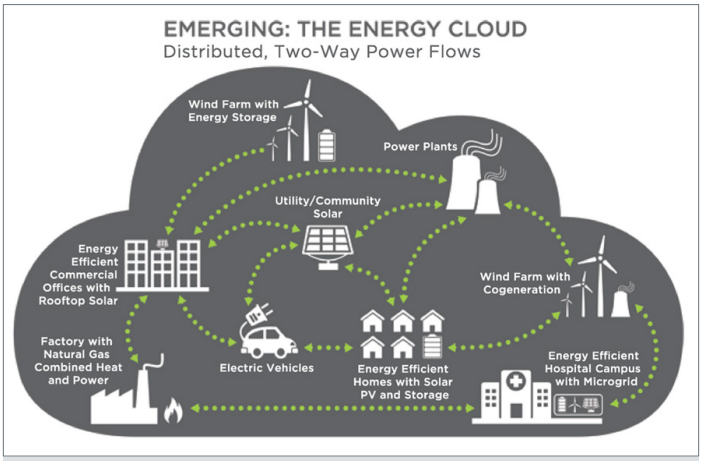
could reduce the speed and cost-effectiveness of research processes; in other instances, reviewers observed that certain technical considerations were lacking. In one case, a project's research plan was well regarded by reviewers, but the reviewers were concerned about the magnitude of the project's scope (i.e., too many variables and too many applications of a technology being considered).

Reviewers highly regarded projects that they felt had potential to impact BTO's overall energy savings goals, as well as BTO's goal of demonstrating energy saving technologies. Reviewers also highly rated project that were expected to contribute to improvements in grid robustness and efficiency. In all cases, special mention was made for projects whose potential outcomes would have impact on a national scale. Reviewers were more critical if project objectives were perceived to be "quite lofty and broad," as some reviewers questioned whether these projects could deliver the desired results.

Reviewers were impressed or satisfied with the progress demonstrated to date by most projects, assigning high scores for this evaluation criteria. Lower scores for progress were assigned where certain project elements or the performance of deliverables lagged behind expectations. The lowest scores were given where projects were perceived to have "significant challenges" (e.g., interoperability) and "non-trivial hurdles" still ahead. Looking to the future, high scores were assigned for projects' remaining project work where reviewers expressed confidence in project teams' abilities, particularly in light of the solid progress already demonstrated. The lowest score was assigned where certain project elements were found to be "far from completion," and where reviewers were concerned that the project schedule left insufficient time for the appropriate analysis of research findings.



The emerging power system features distributed, two-way power flows. *Image courtesy of Navigant*

Reviewers were generally supportive of projects' collaborations and coordination efforts, highlighting that for several projects the partners were well-chosen and well-coordinated. For some projects, reviewers noted especially strong involvement of certain key interests, while for others reviewers recommended further outreach to additional stakeholders groups. Lower scores were assigned for projects' collaborations where reviewers not only recommended additional stakeholder outreach, but questioned the project team's understanding of existing stakeholder values and motivations.

Hybrid electric water heater installed in a test bed home to validate hardware used in transactive energy in residential buildings in neighborhoods. *Image courtesy of Oak Ridge National Laboratory*

BTO's Commercial Buildings Integration (CBI) Program conducts research, development, and evaluation activities help to advance a range of innovative building technologies and solutions, paving the way for industry to deploy high-performing commercial buildings that use 50-70% less energy than typical buildings. The U.S. commercial buildings market is comprised of almost 91 billion square feet of floor space.[26] These are buildings of all sizes, ages, and construction types; are located in all climate zones; and are used for a broad range of purposes, including commercial and government offices, retail, education, health care, warehousing, and sometimes large multi-family buildings, among others uses. Commercial buildings account for more than 18% of total U.S. energy consumption and nearly 37% of U.S. electricity consumption, and cost more than $169 billion to power each year.[27,28,29] This is a growing sector, with more than four billion square feet of net new floor area expected to be added over the next four years.[30]

The CBI Program executes three primary strategies to achieve its goal of reducing the energy-use intensity of U.S. commercial buildings:

- verifying and validating the energy performance and costs of building technologies and systems, informing R&D based on in-depth study of these technologies and systems in dynamic, real-world environments;
- innovating through a systems approach, focused on optimizing building systems (rather than individual building components) through original R&D that uncovers holistic, cost-effective approaches to whole building efficiency; and
- improving understanding of technical and structural barriers to greater energy efficiency in commercial buildings and identifying R&D requirements based on existing operational conditions.

High-Level Summary of Reviewer Comments

Reviewers provided feedback on 19 projects within the CBI Program during the 2018 BTO Peer Review. These projects are divided among three program areas: Energy Performance & Tools, Field Validation & Data Frameworks, and Technology Systems & Packages.[31] Table 8 provides a high-level summary of CBI project scores; projects had a maximum potential score of four and a minimum potential score of one.

Table 8. High-Level Summary of CBI Project Scores

Sub-Program	Project Count	Average Score	Low Score	High Score
Energy Performance & Tools	6	2.96	2.50	3.30
Field Validation & Data Frameworks	6	3.09	2.56	3.57
Technology Systems & Packages	7	3.53	2.70	3.93
Overall	19	3.21	2.50	3.93

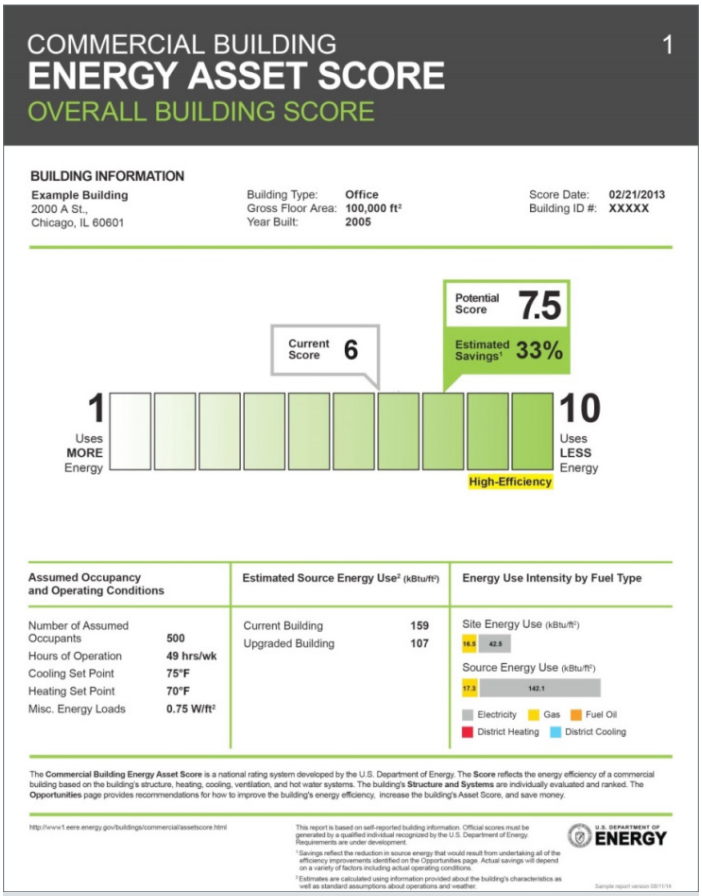
Energy Performance & Tools

The CBI Program works to develop data infrastructure and framworks that can be used by building owners and operators, utilities, scientists, manufacturers, architects/engineers, and policymakers for a variety of purposes. These purposes include collecting, managing, and analyzing "apples to apples" information about buildings' energy performance; informing and implementing energy efficiency programs and policies; and better understanding the potential for, and impacts of, energy efficiency investments.

At the 2018 BTO Peer Review, six projects were reviewed under the Energy Performance & Tools track. Among these projects, reviewers tended to express support for project approaches that directly "attacked" challenging and long-standing market barriers in various corners of the commercial buildings market, such as the retail industry and local chambers of commerce. In contrast, reviewers were less supportive of approaches that seemed to inadequately account for the key marketplace dynamics which the projects were designed to influence.

The Mayo Clinic Hospital in Rochester, MN piloted a performance-based procurement process for expansion of its Saint Marys Hospital campus. *Image courtesy of Seventhwave and National Renewable Energy Lab*

Commercial Buildings Integration


COMMERCIAL BUILDING
ENERGY ASSET SCORE
OVERALL BUILDING SCORE

1

BUILDING INFORMATION

Example Building
2000 A St.,
Chicago, IL 60601

Building Type: Office
Gross Floor Area: 100,000 ft²
Year Built: 2005

Score Date: 02/21/2013
Building ID #: XXXXX

Potential Score 7.5
Estimated Savings¹ 33%
Current Score 6

1 Uses MORE Energy
10 Uses LESS Energy
High-Efficiency

Assumed Occupancy and Operating Conditions		Estimated Source Energy Use² (kBtu/ft²)		Energy Use Intensity by Fuel Type
Number of Assumed Occupants	500	Current Building	159	Site Energy Use (kBtu/ft²)
Hours of Operation	49 hrs/wk	Upgraded Building	107	Source Energy Use (kBtu/ft²)
Cooling Set Point	75°F			Electricity, Gas, Fuel Oil, District Heating, District Cooling
Heating Set Point	70°F			
Misc. Energy Loads	0.75 W/ft²			

The **Commercial Building Energy Asset Score** is a national rating system developed by the U.S. Department of Energy. The **Score** reflects the energy efficiency of a commercial building based on the building's structure, heating, cooling, ventilation, and hot water systems. The building's **Structure and Systems** are individually evaluated and ranked. The **Opportunities** page provides recommendations for how to improve the building's energy efficiency, increase the building's Asset Score, and save money.

http://www1.eere.energy.gov/buildings/commercial/assetscore.html

This report is based on self-reported building information. Official scores must be generated by a qualified individual recognized by the U.S. Department of Energy. Requirements are under development.

¹Savings reflect the reduction in source energy that would result from undertaking all of the efficiency improvements identified on the Opportunities page. Actual savings will depend on a variety of factors including actual operating conditions.

²Estimates are calculated using information provided about the building's characteristics as well as standard assumptions about operations and weather.

U.S. DEPARTMENT OF ENERGY

Commercial Building Energy Asset Score.

A persistent point of contention and confusion among reviewers was whether certain projects were meant primarily to develop tools, or instead to encourage market acceptance of such tools. While reviewers often expressed a general level of satisfaction with projects' progress and remaining work, they often qualified their statements by noting that a more clearly defined project approach (i.e., tool development versus diffusion) would allow them to evaluate projects' progress more effectively. In a few cases, reviewers also offered specific commentary, including that one tool's scale of demonstration was potentially not sufficient to fully evaluate its effectiveness, and that another tool's impact evaluation metrics were not clear enough.

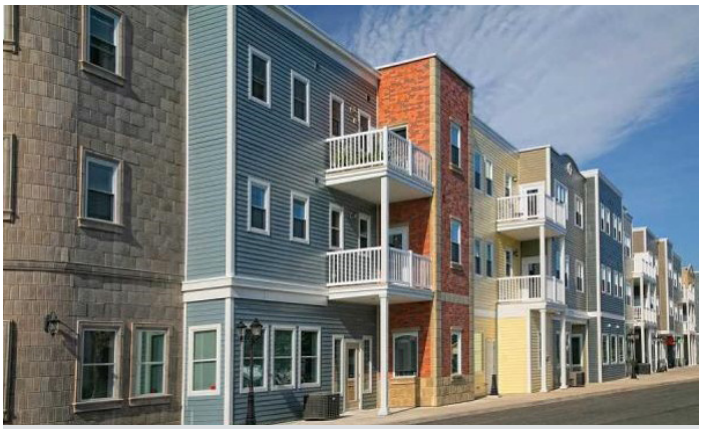
In terms of collaboration and coordination, a few projects were commended for their collaborations with the retail industry and community-level decision makers—which reviewers often credited for enabling project successes. Overall, however, reviewers were relatively unsatisfied with this portfolio's chosen stakeholder groups, often describing them as mis-targeted or not sufficiently inclusive. One notable stakeholder group whose absence was cited by reviewers on numerous occasions were building owners. Even when projects engaged the "right" set of stakeholders, however, reviewers still cautioned that a diverse set of stakeholders could pull the project team in too many directions, thereby enabling scope-creep. In one instance, reviewers expressed concern that the project team's engagement efforts were so substantial that they could become burdensome and endanger the project's sustainability.

Field Validation & Data Frameworks

One of the CBI Program's main activities is to validate technology performance by working with building owners, engineers, and operators to conduct third-party, objective evaluation of energy-efficient technologies and practices under dynamic conditions, collecting real building performance data and taking into account human interactions. The information generated by these efforts provides a feedback loop that can help answer critical R&D questions, while also informing technology performance, installation, commissioning, operation, and maintenance requirements.

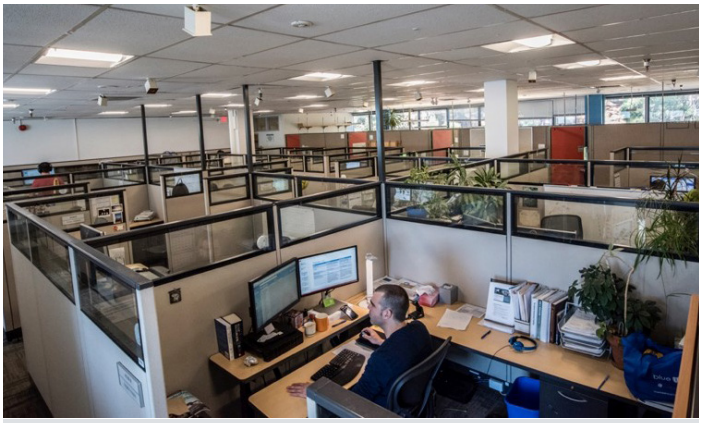
At the 2018 BTO Peer Review, six Field Validation & Data Framework projects were reviewed. Among these projects, reviewers valued projects that had a clear direction towards market adoption and penetration, as well as the tools and partnerships needed to get there. Reviewers gave high scores where the different aspects of projects' approaches were clearly articulated, but they were somewhat critical if projects did not address barriers or uncertainties around technology costs, markets, energy performance, and/or regulatory issues.

Reviewers applauded projects that addressed market barriers and challenges, demonstrated plans to traverse the "technology valley of death" to fill critical market gaps and needs, and/or advanced market models. Reviewers were more critical of projects that reviewers were concerned would not have significant impact, as well as where reviewers felt that projects did not address BTO goals or did not specifically improve energy performance directly.



Small apartment properties are an underserved and untapped market for energy efficiency retrofits.

Image courtesy of the International Center for Appropriate and Sustainable Technology



Combining lighting upgrades with plug load occupancy controls can yield significant energy savings.
Image courtesy of Lawrence Berkeley National Laboratory

When considering progress, reviewers gave high marks to projects that were on track to hit their scheduled milestones and deliverables. If the future direction of a project was unclear, or a project was not perceived to be addressing key challenges, reviewers were more critical.

Across this portfolio, reviewers found that project teams generally collaborated well with their partners. Reviewers commented positively on projects with many key stakeholders across diverse fields of work, and were more critical of projects with partners that did not seem directly incorporated into the project's efforts. Reviewers frequently recommended further project engagement with relevant stakeholders (e.g., utilities, commercial partners), while also encouraging projects to develop strategic plans for the transfer of project outputs from R&D to market adoption through further collaboration.

Technology Systems & Packages

CBI conducts systems integration and optimization R&D and field validation of multi-technology efficiency packages that can improve the efficiency across two or more commercial building end uses (e.g., combining solid-state lighting, dynamic windows, sensors, and advanced lighting controls in one room to maximize overall daylighting benefits and energy savings). Preliminary research shows that—relative to component-based retrofits—integrated systems-based retrofit packages can yield additional energy savings of greater than 50%.[32]

At the 2018 BTO Peer Review, seven projects were reviewed under the Technology Systems & Packages track. When evaluating these projects' approaches, reviewers highly regarded projects that not only addressed BTO's goals, but also provided foundational information for future energy projects. Similarly, they considered the degree to which research projects addressed the wider market and wide-scale adoption of technologies. On the flip side, reviewers also pointed out when projects did not consider the cost, convenience, or use of the technologies by end users, as reviewers believed these omissions could impede market adoption.

Reviewers valued projects that had an impact beyond the scope of the project, either by demonstrating the different levels of energy savings that could be achieved through retrofit packages targeting the integration of different building system combinations; by developing multi-use technologies that could be easily integrated; or by providing data that can be used beyond the scope of one project. Projects that had limited impact potential, or which served a niche market, were less well reviewed.

When considering the project's progress and future work, reviewers positively commented on well-managed projects that remained on schedule and met outlined goals. Similarly, reviewers valued projects that demonstrated a future focus on market adoption, market saturation, or collaborative work efforts. Reviewers negatively reviewed projects that had fallen behind schedule, did not meet milestones adequately, or did not clearly outline completion dates.

Reviewers gave the highest scores to projects with a variety of partners, particularly private sector partners that could to aid in market penetration. Often reviewers recommended additional engagement with building owners and managers, and were critical of projects that did not collaborate beyond national laboratories and government research agencies.

Validating integrated systems packages for commercial building energy savings. *Image courtesy of Lawrence Berkeley National Laboratory*

Residential Buildings Integration

BTO's Residential Buildings Integration (RBI) Program collaborates with the residential building industry to accelerate energy performance in existing and new homes by integrating energy-efficient technologies and practices to optimize residential energy performance; providing data, design, and decision support tools; and partnering with building professionals, energy service providers, and other stakeholders. The U.S. residential housing market is comprised of more than 118 million single-family homes, multi-family units, and mobile homes.[33] While approximately 3.8 million of these homes were built between 2010 and 2015, more than half were constructed prior to 1980.[34] Residential buildings account for approximately 20% of total U.S. energy consumption and 37% of all U.S. electricity consumption, costing consumers over $225 billion in natural gas and electricity bills each year.[35,36,37]

The RBI Program's R&D efforts focus on identifying building integration technology areas and technical solutions that offer the potential for large energy savings, and then conducting research to resolve major technology and system integration challenges. In addition to energy efficiency, the RBI Program's R&D activities also address other technology integration and installation issues that can affect total home performance, including issues related to durability, comfort, and indoor air quality and moisture control. Building America is one of the principal platforms through which RBI conducts this innovative research on home energy performance and related issues; for more than 20 years, Building America has researched, developed, and validated innovative residential energy-saving solutions in partnership with expert building science research teams.

The RBI Program also seeks to improve the energy efficiency of new and existing homes through other pathways, leveraging and learning from industry partnerships to achieve impact on a national scale. These partnerships revolve around a variety of RBI Program activities, including the Race to Zero Student Design Competition (Race to Zero) which offers students an opportunity to develop real-world skills by creating cost-effective, market-ready building designs that meet DOE's Zero Energy Ready Home program requirements; the Home Energy Score, which can be used to evaluate the energy performance of existing homes and compare energy use across any housing market; and research and analysis around the capitalization, design, and impact of energy efficiency financing programs.[38]

The walls and floors of this zero energy ready home were constructed in a factory and brought to the site for quick assembly.
Image courtesy of Unity Homes

High-Level Summary of Reviewer Comments

At the 2018 BTO Peer Review, 12 RBI projects were presented and reviewed, including nine under the auspices of Building America and three representing other RBI initiatives or residential building topics, including Home Energy Score, the Race to Zero, and residential Property Assessed Clean Energy (R-PACE) financing.[39] A high-level summary of scores for the 12 RBI projects can be found in Table 9 below; projects had a maximum potential score of four and a minimum potential score of one.

Table 9. High-Level Summary of RBI Project Scores

Sub-Program	Project Count	Average Score	Low Score	High Score
Building America	9	3.43	3.23	3.64
Other RBI Initiatives	3	3.37	3.07	3.65
Overall	12	3.41	3.07	3.65

Building America

Among the nine Building America projects reviewed, reviewers agreed that a majority were addressing pressing issues facing both the building industry and energy efficiency programs. Reviewers lauded elements of the approach for most projects (e.g., careful experimental protocols, effectively leveraging partner resources), but for each project there were also certain technical elements or scope issues for which reviewers recommended improvements or modifications.

In terms of project impact, reviewers highly regarded those projects that were producing deliverables which reviewers identified as potentially "game-changing," or which reviewers felt represented the only coordinated effort to identify and develop solutions to existing problems. Several projects engendered disagreement or uncertainty amongst reviewers about their impact—uncertainty about how to attribute or evaluate project impacts, about how much of the total market the innovation was applicable to, or about what the eventual market uptake would be for innovations. Several projects were perceived by reviewers to be conducting seminal work in

Validating the hygrothermal models that will be used to provide guidance on minimizing moisture-related risks in high-performance homes. *Image courtesy of Oak Ridge National Laboratory*

important areas, but reviewers none-the-less flagged that these projects would not directly affect energy savings themselves, but would instead enable other energy-saving technologies.

Reviewers highly regarded projects that demonstrated persistent progress, as well as projects that appeared to be on track according to their work plan and had positive outcomes or successful products to demonstrate. Reviewers also positively rated projects whose future work was found to be well planned and on track to meet project goals in line with expected timelines. Lower scores were assigned for planned future work when there was some concern among reviewers about the timely completion of project elements, or where reviewers were concerned about the feasibility or viability of the innovation being developed.

Top scores for collaboration and coordination were assigned to projects where project teams were seen to be working with the right groups via the right channels for the right reasons. This was particularly true for those projects whose partnerships and collaborations were seen to be a driving force behind the project's success.

Other RBI Initiatives

When considering the approaches of projects focused on Home Energy Score, Race to Zero, and R-PACE, reviewers highly rated approaches that were perceived by reviewers to be leading to projects' desired outcomes. Other project approaches were considered to be sound, and were lauded for various project design elements (e.g., clear project plans, reasonable scopes of work), but reviewers still raised concerns about specific project characteristics (e.g., the generalizability of research findings).

Reviewers agreed that each of these projects was contributing to the achievement of BTO's various residential building goals, assigning each a good score for its potential impact. Two of the projects, however, received slightly lower scores, as at least one reviewer for each project questioned whether project outcomes or outputs could substantively influence the market or generate the desired long-term impacts.

Reviewers agreed that each of these projects appeared to be on track with their project plans, and was making progress towards project goals. Reviewers similarly agreed that these projects' would likely continue to make progress and complete their remaining work.

Reviewers highly regarded projects whose collaborations were perceived to be relevant, diverse, and effective. Another project was considered to have strong partner coordination, but reviewers commented that the project's stakeholder involvement was too geographically limited. For all projects, reviewers recommended additional outreach or more direct engagement with other stakeholder groups.

Participating students, sponsors, faculty, jurors, and staff at the 2017 Race to Zero. *Image courtesy of National Renewable Energy Laboratory*

Building Energy Codes

The mission of BTO's Building Energy Codes Program (BECP) is to provide technical assistance supporting the development and implementation of U.S. building energy codes and standards. In fulfilling its statutory responsibilities, BECP works with established industry code development bodies, providing technical analysis to help ensure energy codes deliver practicable and cost-effective improvements in energy efficiency while providing safe and healthy buildings for occupants.[40] In addition, BECP provides technical assistance to states to support the implementation of their building energy codes.

Today's building energy codes enable new buildings to cost-effectively use 30% less energy compared to typical codes that were in place less than 10 years ago.[41] Building energy codes establish minimum energy efficiency requirements for new residential and commercial construction, as well as for additions or substantial renovations. In addition to helping ensure satisfactory levels of energy use, these codes also substantially reduce consumer utility expenditures over the lifespan of buildings. Implementation is key, however, and state and local jurisdictions must formally adopt and comply with their model codes to realize the anticipated energy and utility cost savings.

To advance its mission, BECP participates in the industry processes through which energy codes are developed, discussed, or approved. Most commonly, this work centers on the processes administered by the International Code Council (ICC) to develop the International Energy Conservation Code (IECC), and Standard 90.1, the *Energy Standard for Buildings Except Low-Rise Residential Buildings*, developed by ASHRAE. DOE evaluates the energy- and cost-saving impacts of changes to model building energy codes, and provides guidance to states who are considering updating their own energy efficiency codes for residential and commercial buildings.[42]

Because the energy code is frequently one of the least understood building codes, and must continually update to accommodate evolving technologies and building practices, BECP also plays a critical role in supporting code implementation. BECP commonly develops training curricula and provides popular compliance resources, such as the REScheck™ and COMcheck™ software, to aid in demonstrating energy code compliance and reducing enforcement burden on local building departments. BECP and its partners have developed tools, state-specific analyses, and informational resources for use across the nation. DOE has also previously contracted with national and regional energy efficiency organizations to provide additional technical assistance that is further tailored and responsive to the needs of regions and individual states.

BECP participates in the industry processes through which energy codes are developed, discussed, or approved, including the International Energy Conservation Code (IECC) and ASHRAE Standard 90.1. *Image of the 2017 the International Code Council (ICC) Annual Conference courtesy of ICC*

BTO's Appliance and Equipment Standards Program, hereafter referred to as the Appliance Standards Program, helps consumers save billions of dollars on their utility bills and delivers energy and water savings by testing and implementing statutorily-mandated energy and water efficiency requirements for a wide range of covered products, including home appliances, heating and cooling equipment, lighting, electric motors, and distribution transformers.[43]

The Department of Energy (DOE) currently implements standards for more than 60 types of appliances and equipment, in accordance with the Energy Policy and Conservation Act of 1975 (EPCA), as amended. These products represent about 90% of home energy use, 60% of commercial building energy use, and 30% of industrial energy use.[44]

On behalf of DOE, the Appliance Standards Program promulgates energy conservation standards and test procedures in a rulemaking process in which decisions are based on technical merit; economic analysis; the full consideration of impacts on consumers, manufacturers, and the environment; and stakeholder feedback. The Program also works with research and development (R&D) organizations, including those funded by BTO, to gain insights into future technologies in the R&D pipeline, as well as potential improvements that will reduce the cost of current technologies. As new, cost-effective technologies are commercialized and adopted in the market place, the Appliance Standards Program can consider them as the basis for future standards.

In fulfilling its statutory responsibilities, the Appliance Standards Program works closely with a broad range of stakeholders, including manufacturers, states, utilities, energy efficiency advocates, and others. Each rulemaking process provides opportunities for stakeholder review and comment, and the Program has established the Appliance Standards and Rulemaking Federal Advisory Committee as another means of facilitating stakeholder engagement by allowing for negotiated rulemakings under the guidelines set forth in the Federal Advisory Committee Act. The Appliance Standards Program works with other federal, state, and utility programs to continually increase the energy efficiency of covered appliances and equipment.

To meet statutory requirements, the Program has developed new strategies to help meet the schedules set forth in EPCA, the Energy Policy Act of 2005 (EPAct 2005), and the Energy Independence and Security Act of 2007 (EISA). These strategies include:

- **Test Procedure Development:** Establish test procedures that capture innovative designs and are resistant to "gaming."
- **Standards Development:** Establish minimum standards and expand the scope of covered products to meet statutory obligations.
- **Enforcement:** Enforce certification and compliance with standards and product representation requirements.

The Appliance Standards Program produces semi-annual reports to Congress that cover past, present, and future DOE rulemaking activities, detailing DOE's plans for the issuance of new or amended energy conservation standards.

Standards implemented by the Appliance Standards Program cover a range of appliances and building equipment, including consumer products like dishwashers, microwaves, ovens, and refrigerators. *AdobeStock/88166512*

End Notes

1. U.S. Energy Information Administration. March 2018. Electric Power Monthly, Table 5.1. Accessed April 2, 2018: https://www.eia.gov/electricity/monthly/archive/march2018.pdf.
2. U.S. Energy Information Administration. March 2018. Monthly Energy Review, Table 2.1. DOE/EIA-0035(2018/03). Washington, DC: U.S. Department of Energy, March 2018. Accessed April 2, 2018: https://www.eia.gov/totalenergy/data/monthly/archive/00351803.pdf.
3. U.S. Energy Information Administration. "U.S. Natural Gas Summary." Accessed April 2, 2018: https://www.eia.gov/dnav/ng/ng_sum_lsum_dcu_nus_a.htm.
4. Private investment in R&D to improve building energy performance is minimal; while other private industry sectors invest 3 percent in R&D, construction R&D lags at 0.3 percent. Wolfe, Raymond M. (2018). Business Research and Development and Innovation: 2014 Detailed Statistical Tables. NSF 18-302. Arlington, VA: National Center for Science and Engineering Statistics (NCSES). Accessed June 25, 2018: https://www.nsf.gov/statistics/2018/nsf18302/.
5. The Appliance and Equipment Standards Program works closely with a large range of stakeholders to ensure its energy conservation standards, test procedures, and certification and compliance regulations are based on technical merit. Decisions are also made based on economic analyses, and the consideration of impacts on consumers, manufacturers, and the environment.
6. The Building Energy Codes Program works with established industry development bodies and participates in the industry processes through which energy codes are developed, discussed, or approved.
7. In the context of buildings, grid services represent any action that buildings can take in response to real-time grid conditions that provide value through avoided electricity generation or delivery costs.
8. The ET Program works to advance the state-of-the-art in Building Energy Modeling in conjunction with the Commercial Buildings Integration Program.
9. U.S. Energy Information Administration. *Annual Energy Outlook 2018 with projections to 2050*. Washington, DC: U.S. Department of Energy, February 2018. Accessed June 25, 2018: https://www.eia.gov/outlooks/aeo/pdf/AEO2018.pdf.
10. CERC is a pioneering R&D consortium to develop a long-term platform for sustainable U.S.-China joint R&D. CERC's building sector strategy to achieve real-world impacts is implemented through a collaborative research agenda organized around numerous topics, including building design and operation, the building envelope, building equipment, and policy and market promotion. See the Transactive Energy Management section of this report for more information about GMI and the GMLC.
11. TCF is a funding opportunity that leverages R&D funding in DOE's applied energy programs to mature promising energy technologies with the potential for high impact. SBV facilitates access to DOE's national labs for American small businesses. SBIR is a competitive awards-based program that encourages domestic small businesses to engage in Federal R&D that has the potential for commercialization; eleven Federal agencies currently participate in the SBIR program, including DOE.
12. One HVAC project, one Building Envelope project, and two S&C projects were carried out as part of the CERC program. The entire Transactive Energy Management portfolio, as well as two S&C projects, contributed to GMI.
13. One BEM project received TCF funding, two S&C projects participated in the SBV program, and one S&C and one Water Heating project participated in the SBIR program.
14. One quad is a unit of energy equal to one quadrillion (10^{15}) British thermal units (BTUs). The U.S. consumes approximately 100 quads of energy each year.
15. Supra 9; Annual Energy Outlook 2018; Accessed June 25, 2018.
16. Supra 9; Annual Energy Outlook 2018; Accessed June 25, 2018.
17. Supra 9; Annual Energy Outlook 2018; Accessed June 25, 2018.
18. Supra 9; Annual Energy Outlook 2018; Accessed June 25, 2018.
19. Supra 9; Annual Energy Outlook 2018; Accessed June 25, 2018.
20. The R-value is a measurement of a material's capacity to resist heat flow from one side to the other (i.e., the effectiveness of insulation).
21. Smart building materials are materials or systems that can dynamically adjust or control the transfer of heat, air, or moisture through the building envelope in response to ambient conditions, occupant preferences, or some other control signal.
22. BTO Multi-Year Program Plan: Fiscal Years 2016 – 2020. Accessed June 25, 2018: https://energy.gov/eere/buildings/downloads/multi-year-program-plan.
23. Fernandez N, S Katipamula, W Wang, Y Xie, M Zhao, and C Corbin. 2017. *Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction.* PNNL-25985. Richland, WA: Pacific Northwest National Laboratory, 2017. Accessed June 25, 2018: https://buildingretuning.pnnl.gov/publications/PNNL-25985.pdf.
24. GMLC supports research on (1) fundamental knowledge and technologies related to grid modernization, (2) individual grid technologies, and (3) crosscutting topics that impact multiple technology areas. All GMLC projects reviewed at the 2018 BTO Peer Review were specific to building technologies. In addition to Transactive Energy Management projects, two S&C projects in the Adaptive and Autonomous Controls focus area were also initiated as part of GMLC.
25. GMI conducts its own peer review to evaluate the foundational and crosscutting projects that are carried out under GMLC.
26. Supra 9; Annual Energy Outlook 2018; Accessed June 25, 2018.
27. Supra 2; Monthly Energy Review. March 2018; Accessed April 2, 2018.
28. Supra 1; Electric Power Monthly. March 2018; Accessed April 2, 2018.
29. Supra 3; U.S. Natural Gas Summary; Accessed April 2, 2018.
30. Supra 9; Annual Energy Outlook 2018; Accessed June 25, 2018.
31. One project in the Energy Performance & Tools track was carried out as part of the CERC program.
32. Regnier et al., *Energy Savings of Systems-Based Building Retrofits: A Study of Three Integrated Systems (DRAFT)*. Lawrence Berkeley National Laboratory.
33. U.S. Energy Information Administration. Residential Energy Consumption Survey 2015, Housing Characteristics (Table HC2.1). Accessed June 25, 2018: https://www.eia.gov/consumption/residential/data/2015/
34. Ibid.
35. Supra 2; Monthly Energy Review. March 2018; Accessed April 2, 2018.
36. Supra 1; Electric Power Monthly. March 2018; Accessed April 2, 2018.
37. Supra 3; U.S. Natural Gas Summary; Accessed April 2, 2018.
38. Beginning in 2019, DOE is joining two student building design competitions—Race to Zero and Solar Decathlon—into one new Solar Decathlon competition.
39. In late 2015, Building America completed a Research-to-Market Plan (pdf) which detailed three "Technology-to-Market Roadmap" strategies focused on solving three primary technical challenges over the next five years: (1) high performance, moisture-managed envelope systems; (2) optimal comfort systems for low-load homes; and (3) optimal ventilation systems and indoor air quality (IAQ) solutions for low-load homes. Together, the nine RBI projects presented at the 2018 BTO Peer Review addressed each of these three technical challenges.
40. BECP did not conduct any project reviews at the 2018 Peer Review due to the statutory nature of its activities.
41. Athalye, R.A.; Sivaraman, D.; Elliott, D.B.; Liu, B.; Bartlett, R. *Impacts of Model Building Energy Codes*. PNNL-25611 Rev. 1. Richland, WA: Pacific Northwest National Laboratory, 2016. Accessed June 25, 2018: https://www.energycodes.gov/sites/default/files/documents/Impacts_Of_Model_Energy_Codes.pdf.
42. DOE is directed by statute to participate in industry model code development processes and to review updated editions of model codes for residential and commercial buildings (42 USC 6833).
43. The Appliance Standards Program did not conduct any project reviews at the 2018 Peer Review.
44. U.S. Department of Energy. Saving Energy and Money with Appliance and Equipment Standards in the United States. Washington, DC: U.S. Department of Energy, 2017. Updated January 2017. Accessed June 25, 2018: https://energy.gov/eere/buildings/downloads/appliance-and-equipment-standards-fact-sheet.

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