Building AMERICA
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BUILDING AMERICA **FY 2016 ANNUAL REPORT**

BUILDING AMERICA IS DRIVING REAL SOLUTIONS IN THE RACE TO ZERO ENERGY HOMES

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EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) Building America Program helps the U.S. housing industry to achieve energy savings for Americans with energy-efficient, high-performance homes with improved durability, comfort, and health for occupants. Building America bridges the gap between the development of emerging technologies and the adoption of codes and standards by engaging industry partners in applied research, development, and demonstration of high-performance solutions. Building America is driving real solutions in the race to net zero energy homes.

For the past six years, the National Renewable Energy Laboratory (NREL) provided research coordination, technical monitoring, and contract administrative support to the Building America industry research teams. As these subcontracts have concluded, new Building America team projects are being selected through an annual funding opportunity announcement (FOA), a cooperative agreement funding mechanism managed by DOE's Golden Field Office. NREL continues to provide research coordination and technical monitoring support to the program. Building America strategic direction has also been enhanced, as described in the *Building America Research-to-Market Plan* that includes Technology-to-Market Roadmaps (Roadmaps) and reformulated energy-savings goals.

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For this report, NREL analyzed research results to synthesize knowledge gained during the past six years into useful insights, documenting program successes and informing future strategic planning.

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The Building America Program is meeting its objectives by developing innovations, knowledge, and tools that help the housing industry to profitably improve home performance and reduce energy use in both new and existing homes throughout the U.S. These critical resources help builders and contractors to improve building systems, more quickly adopt new technologies, reduce business risks, and better serve customers with homes that cost less to own and are more comfortable and healthier to live in. Building America has made substantial progress toward its strategic plans with significant impacts in specific projects. An initial review of whole-house case studies demonstrates that Building America industry team projects are already achieving very low energy-use intensities in new construction and retrofits.

Building America industry teams have demonstrated advanced technologies and systems and overcome integration issues that can impact whole-building performance in new and existing single-family and multifamily homes. Major system improvements have resulted from the industry team strategy in the areas of high-performance thermal enclosures, optimal comfort systems for low-load houses, high-performance ventilation and indoor air quality systems, and efficient domestic hot water systems. Advancements to codes and standards have been adopted as a result of the Building America work to identify higher performance potential, resolve risks, and demonstrate solutions. Manufacturers have made design changes to improve product performance as a result of field-testing with the Building America industry teams.

Additional technology and building science knowledge gaps remain along with market barriers. Recommendations are given for future work needed to address the gaps or opportunities that are not already captured by the latest Building America Roadmap strategy.

This document has a companion set of appendices presenting technical discussion and references: *Building America FY 2016 Annual Report – Building America is Driving Real Solutions in the Race to Zero Energy Homes – Appendix*.

INTRODUCTION

Since 1995, the U.S. Department of Energy (DOE) Building America Program has been partnering with industry to bring cutting-edge housing research on energy efficiency to the residential building industry and the public. Market-ready energy solutions have improved the efficiency of new and existing homes in each U.S. climate zone while increasing comfort, safety, and durability. The program has demonstrated more than 100 energy-efficient housing innovations and accelerated the adoption of energy-savings technologies. This work has helped households across the nation save up to $54 billion[1], while improving indoor air quality and comfort for homeowners and enhancing competitiveness of U.S. construction businesses. Substantial opportunities for continued progress remain, including optimizing the comfort, durability, and indoor air quality (IAQ) of American homes while reducing their associated energy use and costs.

The Building America industry teams are consortia comprised of building scientists, consultants, academics, engineers, builders, architects, manufacturers, and others that represent the residential industry among various stakeholder communities and regions. Summaries of the 15 past and present teams are provided in Appendix D: Description of Building America Industry Teams.

1 http://energy.gov/sites/prod/files/2016/02/f29/BTO Multi-Year Program Plan - Final.pdf, p. 12.

Continued technical innovation and demonstration offer substantial opportunities to optimize the comfort, durability, and indoor air quality (IAQ) of American homes while reducing their associated energy use and costs. Photo from iStock 77074615

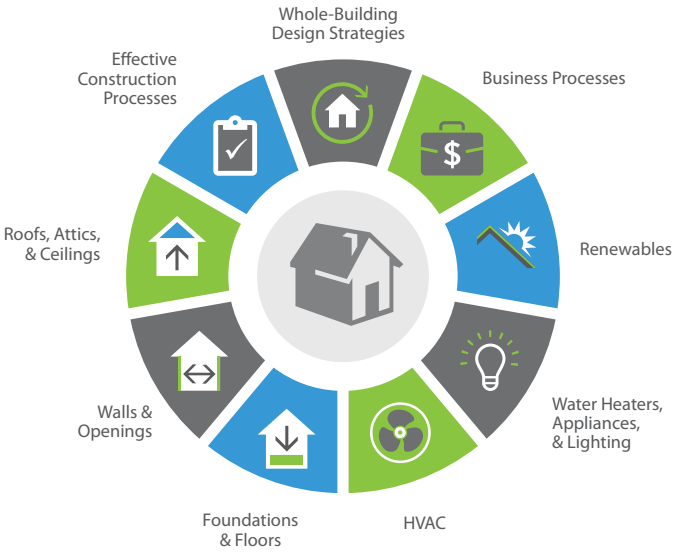

Figure 1. Building America Solution Center Technology icons

Results from Building America—including proven innovations and lessons learned from applied research, development, and demonstration projects—are made available through technical reports and the Building America Solution Center (BASC). The BASC is an online repository for Building America's best practices to help builders, contractors, installers, raters, and others in the building industry apply the latest results from Building America teams and national laboratories. The BASC utilizes graphic icons as a key to the technical guides and code compliance briefs, as shown in Figure 1. These icons are used throughout this report to similarly show the applicability of topical findings and ties to industry outreach.

The recent *Building America Research-to-Market Plan* presents Building America Technology-to-Market Roadmaps (Roadmaps) to guide project strategy. These Roadmaps elucidate the strategy with graphics indicating the key objectives of Research & Development, Market Engagement, and Codes & Standards, as shown in Figure 2. These component icons are used throughout this report to show the types of strategic activities leading to or resulting from the program accomplishments.

For more information on Building America or to access program updates, visit the Building America website and the Building America publications library.

Roadmap Key

Figure 2. Strategic activities

Photo from iStock 98621467

PROGRESSING ENERGY SAVINGS GOALS

In 2010, Building America established a set of multiyear energy-savings goals for new and existing homes, as summarized in Table 1. Requirements were established for energy-use simulations, standard operating conditions, a baseline benchmark, energy-savings calculations, climate regions, and current best practices. The goals were stated as a percentage reduction in source energy use relative to the 2009 International Energy Conservation Code (IECC) efficiency levels for new homes and relative to the pre-upgrade efficiency levels for existing homes. Progress toward achieving the goals was evaluated by the studies of new and existing demonstration house projects through a mix of measuring and modeling energy performance. Building America has demonstrated and validated cost-effective solutions meeting these whole-house performance goals.

Table 1. 2010 Building America Multiyear Target Energy-Savings Validation Goals

Energy Savings	Mixed-Dry, Hot-Dry, and Marine	Mixed-Humid and Hot-Humid	Cold and Very Cold
Existing Homes			
Current Best Practice: 15%	2011	2011	2011
30%	2012	2013	2014
50%	2015	2016	2017
New Homes			
Current Best Practice: 20%	2010	2011	2011
30%	2011	2012	2013
50%	2014	2015	2016

The development of a strategic planning process was initiated in 2011. Standing technical committees (STCs) were established to identify and track research and market gaps and barriers requiring resolution to achieve Building America goals.

In 2012, DOE began implementing an integrated research-to-market strategy targeting the transformation of the housing markets to a competitive, high-performance, technology-focused industry by 2030. The goals were revised to a single target:

- Achieve 50% energy savings in all climates through energy-efficient, high-performance new and existing homes with improved durability, comfort, and health for occupants.

Building America further refined its program goals in the Building America Research-to-Market Plan, published in November 2015. These new program goals are also addressed in the draft *DOE Building Technologies Office (BTO) Multi-Year Program Plan (MYPP)*, dated February 2016. Progress toward these goals is determined by the measured energy performance of actual Building America projects. The Building America performance goal expressed in these documents is as follows:

- By 2020, develop and demonstrate cost-effective bundles of technologies and practices in each of the seven climate zones that can reduce the energy use intensity of new single-family homes by at least 60% and existing single-family homes by at least 40%, relative to the average homes in each of the seven climate zones in 2010 with a focus on reducing heating, cooling, and water heating loads.

Building America supports the following BTO Residential Buildings Integration Program goal, along with other subprograms:

- By 2025, reduce the energy used for space conditioning and water heating in single-family homes by 40% from 2010 levels.

INDUSTRY PARTNERS DRIVING ENERGY SAVINGS

Research & Development

Market Engagement

The Building America Program is meeting its goals by reducing energy use in both new and existing homes through applications with the industry teams. NREL staff conducted an initial review of approximately 90 technical publications covering five years of Building America new construction and whole-house existing home upgrade projects.

The findings of this review include 39 demonstration projects with data results published in terms that could be compared to the newest energy use intensity or EUI (kBtu/ft^2/yr) reduction targets and are presented in Appendix A: Evidence of Performance Levels Achieved in Past Building America Projects. Because this EUI-based goal is new and previous Building America projects were not required to collect all of the data necessary to calculate absolute EUI source energy values, the results here are not a comprehensive catalog of all past Building America project-savings results. As further described in Appendix A, this review includes a combination of measured and simulated data.

The initial case study review shows that 23 new demonstration homes among six climate zones achieve 23%–81% EUI reduction relative to 2010 EUI baselines. Eight new construction homes have EUI values that are less than the 2020 target for their climate (i.e., achieved EUI values at least 60% less than average EUI of single-family homes in 2010), as shown in Table 2. Six more homes have EUI values that are 50%–60% less than the baseline for their climate (i.e., they came very close to achieving the 2020 target EUI).

The initial case study review also shows that 16 existing home retrofits among six climate zones achieved 23%–51% savings compared to pre-

The Building America industry team BA-PIRC partnered with Habitat for Humanity for performance and cost demonstration of ductless heat pumps for a community of marine climate high-performance homes in Pierce County, Washington

Table 2. Number of New Home Case Studies Achieving EUI Reduction Goal

Climate	EUI 2010 Baseline (kBtu/ft^2/yr)	New Home 60% Reduction 2020 EUI Target (kBtu/ft^2/yr)	Number of Case Studies Exceeding 2020 Target
Very Cold/Cold	112.9	45.1	4
Hot-Dry/Mixed-Dry	115.4	46.2	1
Hot-Humid	124.9	50.0	2
Mixed-Humid	117.4	47.0	1
Marine	111.8	44.7	0

retrofit EUI. Twelve homes have post-retrofit EUI values that are less than the 2020 target for their climate (i.e., EUI reductions of at least 40% relative to the 2010 consumption of an average home in their climate), as shown in Table 3.

The MYPP 2020 targets include five new single-family homes per climate zone that meet a 60% EUI reduction and five existing single-family home retrofits per climate zone that meet a 40% EUI reduction. To count toward the MYPP 2020 targets, Building America should require that EUIs be validated with measured data. These initial findings indicate that Building America is well on the way to meeting these targets for several climate regions based on measured data.

Table 3. Number of Existing Home Retrofit Case Studies Achieving EUI Reduction Goal

Climate	EUI 2010 Baseline (kBtu/ft²/yr)	Existing Home 40% Reduction 2020 EUI Target (kBtu/ft²/yr)	Number of Case Studies Exceeding 2020 Target
Very Cold/Cold	112.9	67.7	9
Hot-Dry/Mixed-Dry	115.4	69.3	0
Hot-Humid	124.9	74.9	1
Mixed-Humid	117.4	70.4	0
Marine	111.8	67.1	2

The case study project results demonstrate that Building America is already achieving very low energy use intensities in new home construction and whole-house upgrades to existing homes.

STRATEGIC DIRECTION

The Building America Program is enabling higher performance in residential building systems and technologies. To accelerate progress toward multiyear goals, research has been conducted to facilitate the rapid adoption of new system solutions. Evaluations of individual measures, individual test houses, and community-scale housing have validated the reliability, performance, cost-effectiveness, and marketability of the packages of energy measures designed to meet the Building America whole-house energy use reduction targets.

Research & Development

Standing Technical Committees

To achieve Building America goals, STCs were established to identify and track research and market gaps and barriers that needed resolution. The STCs were a public forum for specific technology topics with representation from residential market stakeholders: builders, manufacturers, researchers, program operators, etc. The STC topics with the most extensive participation were as follows:

1. High-Performance Thermal Enclosure Assemblies
2. Optimal Comfort Systems for Low-Load Houses
3. High-Performance Ventilation Systems and IAQ Strategies
4. Efficient Domestic Hot Water Systems
5. Automated Home Energy Management Systems.

The strategic plans for these STCs each established up to six key goals. These specific goals, along with progress updates, technical reports, and associated outreach (meetings, webinars, and BASC publications), were documented and are summarized in Appendix C: FY14–FY16 Progress toward STC Goals. The STCs guided the resulting accomplishments that improved the performance of various residential building system technology applications, influenced building codes and standards revisions, and set the stage for the subsequent Roadmap strategy.

Research & Development

PROVEN SOLUTIONS

NREL reviewed nearly 250 technical publications from Building America industry team projects and found 14 groups of technology topics with significant outcomes, including building science advancements, top innovations, measure guidelines, building code impacts, and future research needs. The review findings are summarized in Appendix B: Technology Summaries. The technology applications cover new construction, existing home retrofits, and multifamily building applications. They are grouped into four residential building system categories:

1. Enclosures, including high-R attics, walls, and foundations
2. Space conditioning, including simplified space conditioning for low-load homes, forced-air distribution systems, existing building upgrades, humidity control, and hydronic systems
3. IAQ, including ventilation, combustion safety simplified test protocols, and multifamily compartmentalization
4. Hot water, including heat pump water heaters, tankless hot water, and hot water distribution.

Research & Development

Market Engagement

Codes & Standards

Roadmaps Going Forward

The Building America Research-to-Market Plan includes integrated Building America Technology-to-Market Roadmaps to guide research, development, and demonstration activities going forward. These Roadmaps, informed by the progress of the STCs, were also vetted with industry leaders and subject matter experts through convening meetings and a public request-for-information process.

The Roadmaps focus the current industry team projects on developing solutions to the most important building science challenges for high-performance homes, as follows:

1. Moisture-managed high-R envelopes

- High-performance homes with increased insulation, reduced infiltration, reduced risk of condensation, and adequate drying potential inside building assemblies

2. Optimized low-load comfort solutions

- High-efficiency comfort systems for homes with low thermal loads, including optimal efficiency and managed airflow and relative humidity control at all part-load conditions

3. Smarter IAQ solutions

- Added envelope tightness with improved source control, dilution, and high-efficiency filtration, with little or no energy penalty.

FOA projects have been selected and awarded that align with the Roadmaps and future research needs.

Photo from Building Science Corporation

MAJOR ACCOMPLISHMENTS

Indoor Air Quality Strategy and Results

One example of strategic progression to improve performance—from STCs through technology development to Roadmaps—is in IAQ.

Building America research and support were instrumental in developing and gaining the adoption of American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 62.2, a residential ventilation standard that is critical to transforming the U.S. housing industry to high-performance homes. A subsequent performance gap was recognized: A majority of production-scale homes voluntarily achieving 30% whole-house energy savings were not ventilated as prescribed by ASHRAE 62.2-2010. The STC for High-Performance Ventilation Systems & IAQ Strategies sought to document best-practice guidelines for effective, reliable, and climate-specific whole-house mechanical ventilation systems for new and existing single-family homes as well as new and existing multifamily buildings.

Several Building America teams researched the technical effectiveness of various strategies and system interactions with outreach resulting in expert meetings, top innovations, four best-practice guides, a code compliance brief, two webinars, and many technical reports. Techniques and specifications for eliminating thermal bypass helped inform further airtightness requirement proposals and led to increased airtightness requirements in the 2012 IECC and 2015 IECC.

IAQ performance has been studied with increased understanding of the complex system interactions that challenge optimizing for low pollutant levels, comfort (including relative humidity), and energy efficiency. Building America has found that there is not a direct correlation between pollutant levels and ventilation rates, as was commonly believed in the past. Also, there is no single solution. For example, exhaust-only ventilation has been proven not to be ideal due to unintended makeup-air pathways. Optimal solutions for IAQ, along with relative humidity control and comfort, require a solid understanding of climate and space-conditioning system interactions.

Although the STC goal of best-practice guidelines was met, the effort to characterize the interactions among different mechanical ventilation system types, indoor and outdoor temperature and humidity conditions, and indoor and outdoor pollutants revealed more complexities. The research and field-testing of the Building America industry teams advanced the building science knowledge, debunked common assumptions, and showed that additional work is needed to

Several Building America teams researched the technical effectiveness of various strategies and system interactions with outreach resulting in expert meetings, top innovations, four best-practice guides, a code compliance brief, two webinars, and many technical reports.

The HIRL Building America team has demonstrated the thermal, moisture, construction, and cost performance of the extended plate and beam framing and insulation system with industry partners including Dupont and McIntyre Builders.

achieve the right balance between healthy IAQ levels, space-conditioning comfort, and energy consumption.

An emerging research need identified from this work is to further explore the efficacy of various ventilation systems and disaggregate the ventilation rate from system type, which is necessary to understand how to apply these findings in the field and achieve optimum IAQ and occupant comfort for the least cost and lowest energy impacts. A further opportunity is to investigate the use of advanced controls in smart ventilation systems to provide variable ventilation rates that respond to changes in house and external conditions.

The Roadmap for Optimal Ventilation Systems and IAQ Solutions for Low-Load Homes picks up the reins to improve technologies and industry standards in the focus areas of targeted pollutant solutions, smart ventilation, and IAQ valuation. FOA projects have been awarded that align with both the Roadmap and future work identified in the technology summaries. Additional leading research is planned to include a field-based IAQ baseline study with measured data to address remaining uncertainties in whole-house IAQ efficacy and ventilation strategies.

Lessons Learned in New Homes

Market Engagement

Codes & Standards

New homes today are approximately twice as efficient as older homes in the United States on a per-square-foot basis. Building America industry teams and research played a critical role in making that happen, alongside builders, Home Energy Rating System (HERS) professionals, trades, manufacturers, code officials, utilities, efficiency advocates, and other government programs such as ENERGY STAR®.

Building America encourages market transformation in the residential building sector by providing building science solutions to both the construction and home performance industries via BASC and industry codes and standards. Building America research has provided more than 200 guidance documents and case studies to the BASC. Research results have had significant historical influence on improved performance requirements found in the IECC and ENERGY STAR program requirements.

Building America industry teams demonstrate advanced technologies and building systems and overcome integration issues that can impact whole-building performance. Building America new home demonstration projects have formulated, validated, and documented EUI reductions greater than 60% in a number of cases, as provided in Appendix A.

Demonstrating the performance of cost-effective, advanced, energy-efficient

The Building America Program contributed to major progress at the recent ICC committee hearings for the 2018 IECC to achieve less expensive unvented attic construction.

technologies and practices and properly integrating them is essential to reducing market risk to home builders, contractors, and homeowners. Building America provides technology-specific research in new homes, investigating innovative approaches to energy savings with improved performance attributes. Progression of the research results is summarized in Appendix B and Appendix C. Following are several highlights from this work:

- **Attics**: The Building America Program contributed to major progress at the recent International Code Council (ICC) committee hearings for the 2018 IECC. The committee action hearings accepted the addition of vapor diffusion port/vent applications in unvented attics, which in turn allows for the use of fiberglass batts, blown cellulose, and blown fiberglass insulation alternatives (which are less expensive than foam) in unvented attic assemblies in climate zones 1, 2, and 3. This code change is a direct result of Building America research and demonstrated field experience. Also, the associated elimination of eave and ridge vents provides additional reduction of moisture risk from water intrusion during extreme weather events. The pending code change awaits final hearing proceedings.

- **Walls**: Building America has been advocating the use of rigid foam sheathing insulation for years as a means to improve a home's thermal envelope by increasing the R-value while minimizing moisture risks. Field-test results and best practices related to exterior insulation addressed International Residential Code structural and fire code issues associated with added insulation, enabling higher insulation levels in the 2012 IECC and 2015 IECC. A BASC code compliance brief supported by Building America research addresses continuous insulation cladding/furring attachments and provides additional guidance for code-compliant installations. Further, Building America supported the development of an innovative wall design called the extended plate and beam system, which integrates foam sheathing insulation with wall framing such that wood structural panels are installed exterior to the foam sheathing. Initial evaluations indicate that extended plate and beam enables wall system construction with R-values that are 50% or more above standard code requirements at a similar cost using methods and materials already common in the industry today. Next steps in this work include developing a design guide to encourage adoption.

Building America research contributed to the advancement of furnace efficiency and air-conditioning SEER, as well as spurred equipment manufacturers to tighten the air leakage from residential heating and air-conditioning system cabinets.

- **Space-conditioning equipment**: Building America research has contributed to the advancement of furnace efficiency and air-conditioning seasonal energy efficiency ratio (SEER), as well as spurred equipment manufacturers to tighten the air leakage from residential heating and air-conditioning system cabinets. The state-of-the-art space-comfort systems for low-load houses are rapidly evolving, with promising solutions in the areas of heat pumps, ductless mini-split systems, combined heating and hot water systems (combi systems), point-source strategies, and supplemental dehumidification.

- **Air distribution systems**: Building America has proven the energy benefits associated with solutions developed to seal and insulate ducts or install ducts within conditioned space. New construction techniques were demonstrated to bring ducts into conditioned space in a raised ceiling chase or with an inexpensive, quick, and effective method of building a fur-down or dropped ceiling chase. Alternatively, similar levels of air-distribution performance can be achieved with buried and encapsulated ducts. In dry climates, air sealing and burying ducts in several inches of loose-fill insulation provide excellent results without condensation concerns. In humid and mixed climates, the ducts should be air sealed and encapsulated in closed-cell polyurethane spray foam insulation before being covered with loose-fill insulation. The 2018 ICC committee action hearing has approved a package for ducts buried within ceiling insulation and deeply buried effective R-value, now pending final hearing.

- **Domestic hot water**: Because improved thermal enclosures and higher efficiency space-conditioning systems dramatically reduce heating and cooling energy consumption, the importance of water-heating load continues to grow. Heat pump water heaters, tankless water heaters, and combi systems in residential buildings are now well understood as a result of Building America research. Combi control system improvements with a set-point temperature reset or full modulation of the tankless heater allows operation at a lower-capacity stage with decreased water temperature and increased efficiency, and upgrades have been made by manufacturers with feedback from field-testing. These mature appliance technologies are ready for market uptake.

Combi control system improvements with a set-point temperature reset or full modulation of the tankless heater allows operation at a lower-capacity stage with decreased water temperature and increased efficiency, and upgrades have been made by manufacturers with feedback from Building America field-testing.

Lessons Learned in Existing Homes

There are more than 114 million existing homes in the United States, all of which are an important market segment to achieve nationwide energy savings. In 2010, Building America allocated approximately half of its resources to improving the energy efficiency of existing homes.

Building America divides existing home upgrades into four categories: (1) Shallow retrofits, which involve investing a few hundred dollars in typically do-it-yourself projects. Also, shallow retrofits can be easily completed by home performance experts during home energy assessments and can be a gateway to deeper retrofits. (2) Home performance contracting or weatherization projects take a more holistic approach to assessing home energy-savings upgrade opportunities. Home Performance with ENERGY STAR, utility rebate programs, and low-income weatherization programs promote these types of upgrades, which typically involve a professional who assesses the home and works with the homeowner to develop a scope of work for upgrading equipment, adding attic air sealing and insulation, and other cost-

The BSC Building America industry team, working with David Weekley Homes in Orlando, Florida, demonstrated the installation and performance of an unvented tile roof assembly, insulated with air-permeable insulation and integrated with a vapor diffusion ports.

effective upgrades. Often, the upgrades improve comfort and reduce health risks in addition to providing energy savings. (3) Deep energy retrofits usually require the largest investment by the homeowner. Deep energy retrofits use a whole-house system approach and require a home performance contractor or engineer, and the professional is usually hired to achieve radical reductions in energy use. (4) Energy efficiency upgrades integrated in conventional home improvement transactions (e.g., add exterior insulation during siding replacement).

Building America projects have validated and documented energy savings of more than 40% in a number of cases, as shown in Appendix A.

In addition to better understanding the whole-house approaches needed to reach a wide range of energy-savings targets and homeowner budgets, Building America also invested in technology-specific research in existing homes, studying different innovative approaches to energy-savings and retrofit cost reductions and determining how to retrofit homes safely. Some of the research results are summarized in Appendix B and Appendix C. Following are a few highlights from this work:

- **Foundations**: Building America research explored innovative ways to transform wet, cold basements into more comfortable, habitable spaces and reduce home energy losses from the basement. Building America has developed a method to avoid full-scale excavation by using a high-pressure water system to break apart the soil in a narrow trench around the exterior of a foundation wall and install rigid insulation and liquid expanding foam insulation. This method provides moisture and thermal performance that is superior to interior insulation solutions.

- **Exterior wall insulation**: Rigid exterior insulating sheathing provides increased thermal resistance and can increase airtightness. Building America research identified the best methods for sheathing and cladding with exterior insulation to improve envelope performance and also address wind and gravity loads. The program is continuing to develop water management details to integrate exterior insulation strategies with other building envelope elements and connections.

- **Attic air sealing**: Field studies have shown that airtightness in a building is equal to or more important than overall thermal resistance (R-value) in determining the performance of the building envelope and that air leakage between the house and the roof or attic is a critical pathway. Leakage at the ceiling plane is critical because of a high pressure differential across the ceiling and the potential risk posed by warm, moist air contacting the underside of the roof deck. Building America has developed guidance for air sealing ceilings to provide high cost savings, and it continues to collect supporting data on this topic, including methods to minimize moisture problems in attics.

Building America has developed a method to avoid full-scale excavation by using a high-pressure water system to break apart the soil in a narrow trench around the exterior of a foundation wall and install rigid insulation and liquid expanding foam insulation. This method provides moisture and thermal performance that is superior to interior insulation solutions.

- **Ducts in attics**: Duct work in unconditioned attics can cause a large amount of heat loss and gain. Building America research has developed effective, unvented, conditioned attic solutions to address this problem. Several approaches bring the ducts inside the conditioned space by moving the insulation to the roof deck, sealing the attic penetrations to the outside, and conditioning the attic. Duct system improvements alone can result in heating and cooling energy savings from 5%–20% or more.
- **Existing equipment**: Building America field studies show that many installed air-conditioning systems are operating with significant defects, and proper commissioning and maintenance of cooling systems can reduce their energy use by up to 50%. Simple tune-ups to existing furnaces and ducts can also result in a 23% increase in system efficiency.
- **Combustion Safety Simplified Test Protocol**: Home performance professionals perform combustion safety testing on natural gas appliances before and after they perform energy-efficiency upgrades on homes; homes that fail these tests are often rejected for upgrades. Building America supported the development of a simplified test protocol for combustion safety that saves time and more accurately identifies unsafe installations that require remediation (e.g., reduces the number of false positive test results and increasing the number of upgrades).

Several approaches bring the ducts inside the conditioned space by moving the insulation to the roof deck, sealing the attic penetrations to the outside, and conditioning the attic. Duct system improvements alone can result in heating and cooling energy savings from 5%–20% or more.

Lessons Learned in Multifamily Buildings

Building America industry teams have also researched the application of building science principles to improve the energy performance of higher density housing types.

- **Hydronic systems**: Improving the performance of hydronic systems is of particular interest to multifamily buildings where a large stock of low-rise apartment buildings employs central hot water or steam heating. Controls and distribution systems are often faulty in older systems, and many apartment dwellers resolve overheating by opening their windows—a common practice when residents don't pay for their own heating energy use. Upgrading the entire boiler system is often cost prohibitive, so more practical retrofit strategies are needed. Increasing flow to an underheated zone via a booster pump was found to be one effective

Building America supported the development of a simplified test protocol for combustion safety that saves time and more accurately identifies unsafe installations that require remediation.

The NorthernSTAR Building America industry team has demonstrated that improved controls have the potential to reduce the complexity and improve upon the measured performance of combined space and water heating systems.

method of improving an extreme imbalance issue. Condensing boilers are well suited to accept lower return water temperatures and therefore take maximum advantage of outdoor temperature reset control.

- **Multifamily compartmentalization**: Multifamily building developers are challenged with constructing to significantly tighter infiltration levels, addressing compartmentalization issues among units, and adopting test procedures to demonstrate compliance. Building America field tests show that achieving the three ACH50 code requirement (used for both single-family and multifamily) in multifamily buildings is very difficult. Attaining the airtightness target of 0.30 CFM50/ft^2 is achievable and may be a better metric for the smaller floor areas of conditioned space found in apartments. The development of an empirical model is complete. In addition, an innovative aerosol air-sealing technology has been developed that shows promising cost-effectiveness for multifamily applications. This Building America innovation is ready to be handed off to industry engagement activities for code definition of party walls and UL listing of the aerosol air-sealing technology.

RECOMMENDATIONS FOR PROGRAM PLAN AND IMPLEMENTATION

Progress toward attaining the STC goals were reviewed along with the future work identified in the technology summaries. The Roadmaps have prioritized topics on which the latest FOA projects continue to address the industry needs as new or follow-on work from previous Building America team results. Additional technology and building science knowledge gaps remain along with market barriers. The following are recommendations for future work needed to address the remaining gaps or opportunities that are not already captured by the Roadmap strategy.

- **Walls**: An outstanding issue remains from the STC goals using insulating sheathing over wood framing where fire-rated wall assemblies are required. The model energy codes do not address minimum insulation requirements for common walls because the common wall is not defined as part of the building thermal envelope. Also, modeling tools available today do not yet accurately predict the risk of moisture damage in wall assemblies; more field data and testing on various wall assembly types is needed to improve the moisture modeling capability.

- **Foundations**: Building America research has made important progress in studying the moisture transport issues in basement walls. The next step to facilitate the optimal selection of thermal insulation strategies in new construction and existing home retrofits is to obtain more field data to validate existing modeling capabilities.

- **Humidity control**: Existing models of humidity control systems in building simulation tools are limited to stand-alone dehumidifiers. Air conditioners with variable-speed blowers, multistage compressors, or condensing reheat for built-in humidity control need to be added to these simulation tools to better understand the economics and operation of

Mutual Housing (MH) California's community at Spring Lake in Woodland, California, is the first multifamily affordable rental development in the nation to receive the U.S. Department of Energy's Zero Energy Ready Homes certification. The Building America team ARBI worked with MH for the optimal package of energy efficiency measures to achieve ZERH certification. Photo courtesy of Mutual Housing California.

humidity control systems for low-energy homes. Although this equipment is fairly well understood, its performance is not yet integrated into the building simulation tools that can be used to systematically answer questions related to building design and performance rating programs. Also, humidity loads from occupant activities need to be better understood to inform decisions about the need for, and the sizing of, humidity control equipment and/or other strategies. More work is needed to quantify this load and its variability from one day to the next, as well as varying occupant patterns.

- **Space conditioning**: Multiple Building America teams and laboratories researched the technical effectiveness of a variety of strategies (e.g., point-source or limited distribution systems, variable refrigerant flow systems, small duct systems, precooling, and economizers), yet the challenge to achieve cost-effectiveness remains. More cost-effective, higher efficiency equipment, systems, and integrated strategies are required, including supplemental dehumidification. Sensible capacities less than 1.5 tons and sensible heat ratios less than 75% may also be required. Many residential air-conditioning systems have been identified as being improperly installed, and resolving residential HVAC system installation problems would make a significant step toward achieving Building America goals. Future tasks could include supporting RESNET in adopting installation quality into HERS, assessing current smart verification systems to develop best-practice guidance on their use, or working with ASHRAE and/or Air Conditioning Contractors of America to develop a standard test method to ensure that smart verification systems accurately assess performance.

- **Domestic hot water**: One opportunity for additional energy savings with domestic hot water end use is in distribution systems. Compact distribution systems have been studied by the Building America research teams such that further market engagement is ready for uptake in the areas of energy modeling capability, residential codes, and the WaterSense program. Multifamily buildings have particularly good potential for energy savings with improved hot water heating and distribution systems.

- **Reporting research and demonstration results**: It is recommended that new FOA award projects with energy-savings demonstration activities report on results that demonstrate progress toward the MYPP goals in terms of EUI reduction and relative to consistent end-use or whole-house 2010 baselines.

- **Demonstration single-family homes**: According to the MYPP, Building America expects to build 100 demonstration homes by 2020, with a specific target for the demonstration of five new single-family homes per climate zone that meet a 60% EUI reduction, and five existing single-family home retrofits per climate zone that meet a 40% EUI reduction relative to climate-specific 2010 baselines. It is recommended that Building America utilize the industry team structure to produce these demonstration homes with new home builders and existing communities.

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