APPENDIX

BUILDING AMERICA **FY 2016 ANNUAL REPORT**

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

Sara Farrar, Stacey Rothgeb, Ben Polly, Lieko Earle, and Tim Merrigan
National Renewable Energy Laboratory

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Summary

The U.S. Department of Energy (DOE) Building America Program enables the transformation of the U.S. housing industry to achieve energy savings through 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.

The National Renewable Energy Laboratory (NREL) has 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) cooperative agreement contracting mechanism managed by DOE's Golden Field Office. The Program is also experiencing an enhanced strategic direction centered on the Building America Research-to-Market Plan that includes Technology-to-Market Roadmaps (Roadmaps) and reformulated energy-savings goals.

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

Appendix A: Evidence of Performance Levels Achieved in Past Building America Projects

DOE's Buildings Technologies Office (BTO) recently updated its goals and published them in the BTO Multi-Year Program Plan.[1] The Residential Building Integration (RBI) Program Performance Goal related to Whole-House Technology Integration and Demonstration is closely linked to Building America Program activities. The goal language 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.*

As a part of developing the whole-house component of this goal and assessing progress that has already been made toward the goal since 2010, the National Renewable Energy Laboratory (NREL) reviewed technical publications from past Building America new construction and existing home upgrade projects. When available, NREL extracted information about the model-predicted and measured consumption of homes built or upgraded in connection to the Building America Program activities. Source energy use intensity (EUI) values (kBtu/sf/yr) were calculated through this process and compared to 2010 baseline levels and the 40% and 60% EUI reduction targets.

Some findings from the review NREL conducted are presented in this appendix to demonstrate the high levels of performance Building America has achieved in past new construction and existing home upgrade projects. Because this EUI-based goal is new and past Building America projects were not required to collect all of the data necessary to calculate EUI values,[2] the results here are not a comprehensive catalog of all past Building America project savings results.

Development of 2010 Baseline Values

The Energy Information Administration 2009 Residential Energy Consumption Survey (RECS) microdata and 2015 Annual Energy Outlook (AEO) microdata were used to develop baseline and target EUI values for the Building America climate regions. The AEO data serve as the baseline across many of the BTO goals. However, the AEO microdata do not allow results to be separated by Building America climate regions. Thus, the 2009 RECS data were used to investigate the variation of EUIs for single-family homes across Building America climate regions.[3] For each climate region, the following ratio was calculated using the RECS data: $EUI_{regional}/EUI_{national}$. All calculations are in source energy using ASHRAE Standard 105 site-source conversion factors, which are the same multipliers used in BTO's standard definitions for zero energy buildings.[4]

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[1] http://energy.gov/eere/buildings/downloads/multi-year-program-plan

[2] Previous Building America goals were stated as a percent reduction in source energy use relative to 2009 IECC efficiency levels for new homes and relative to the pre-upgrade efficiency levels for existing homes. Thus, some past reports only document the percent reduction in source energy, not the absolute source energy consumption values necessary to calculate EUIs.

[3] RECS collapses the Building America climate regions slightly (they combine Cold with Very Cold; they combine Hot-Dry with Mixed-Dry). Thus, the targets are the same for those combined regions.

[4] https://energy.gov/eere/buildings/downloads/common-definition-zero-energy-buildings

Those ratios were then applied to the 2010 national EUI value calculated from the 2015 AEO microdata, yielding the baseline and reduction targets shown in Table A.1.

Table A.1. 2010 EUI Baselines and Target Values (kBtu/sf/yr)

Climate	**EUI 2010 Baseline** (kBtu/sf/yr)	**Existing Home 40% Reduction EUI Target** (kBtu/sf/yr)	**New Home 60% Reduction EUI Target** (kBtu/sf/yr)
Very Cold/Cold	112.9	67.7	45.1
Hot-Dry/Mixed-Dry	115.4	69.3	46.2
Hot-Humid	124.9	74.9	50.0
Mixed-Humid	117.4	70.4	47.0
Marine	111.8	67.1	44.7

Past Building America Existing Home Upgrade Projects

Figures A.1–A.4 show results from past Building America whole-house retrofit studies for single-family homes with sufficient data to calculate a post-retrofit EUI. Not all projects had sufficient data to calculate a pre-retrofit EUI, or some conditions may have existed that made the value unreliable, such as a change in occupancy at the time of retrofit. The x-axis labels indicate whether the EUI value is based on model-predicted consumption data ("pred") or measured consumption data ("meas"). The x-axis also shows the percent reduction relative to the pre-retrofit EUI when that value can be calculated. The projects are spread across the Cold/Very Cold, Hot-Dry/Mixed-Dry, Hot-Humid, and Marine climates. Some observations from these data include:

- Twelve homes have post-retrofit EUI values below the target for their climate (i.e., EUI reductions of at least 40% relative to the 2010 consumption of an average home in their climate).
- Of the eight homes where pre-retrofit EUI values can be calculated, five have a post-retrofit EUI value at least 40% lower than the pre-retrofit EUI.

These results demonstrate that Building America is already achieving substantial reductions in energy use intensity through whole-house upgrades to existing homes.

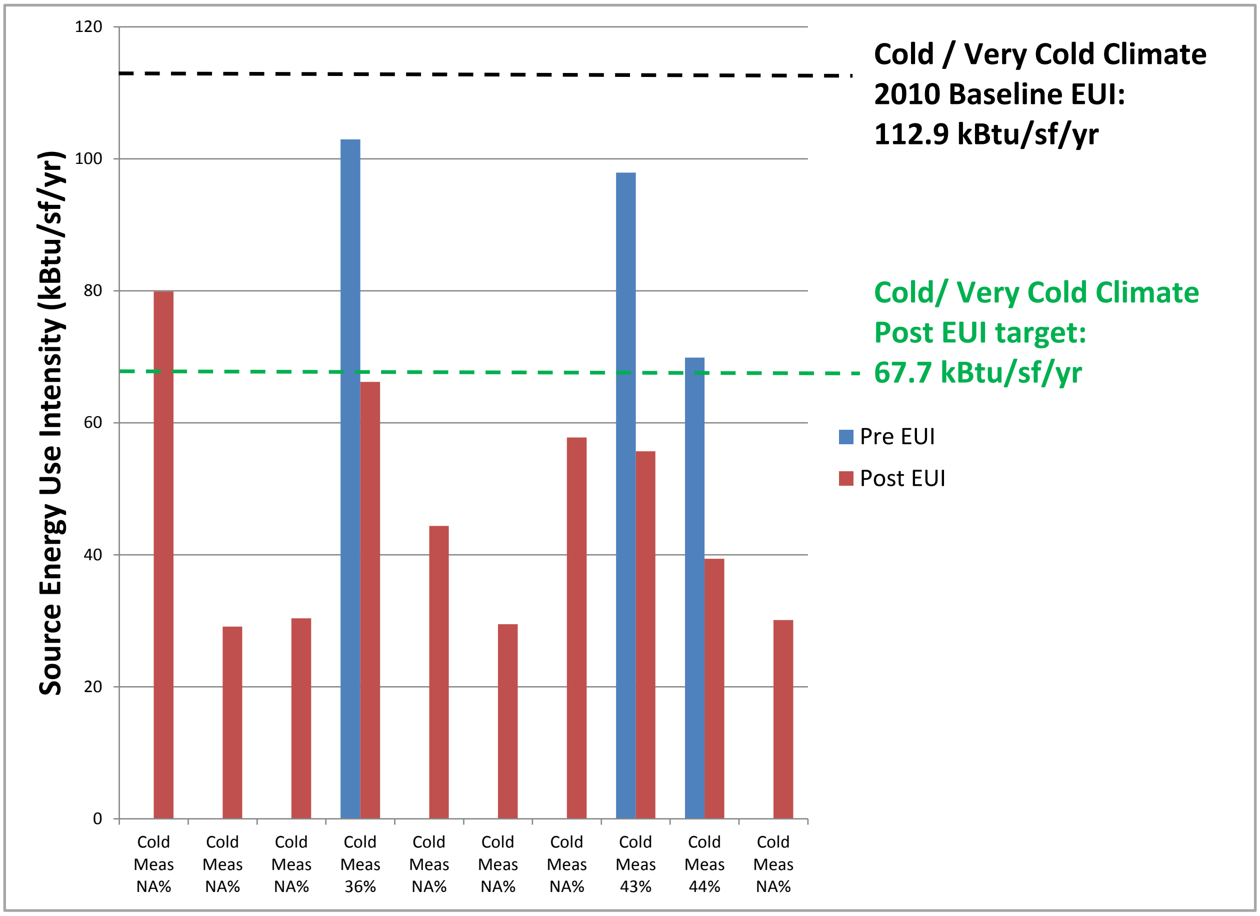

Figure A.1 Measured EUI values for Cold/Very Cold climate projects (x-axis labels: "meas" = measured, % reduction versus pre-retrofit EUI, when applicable)

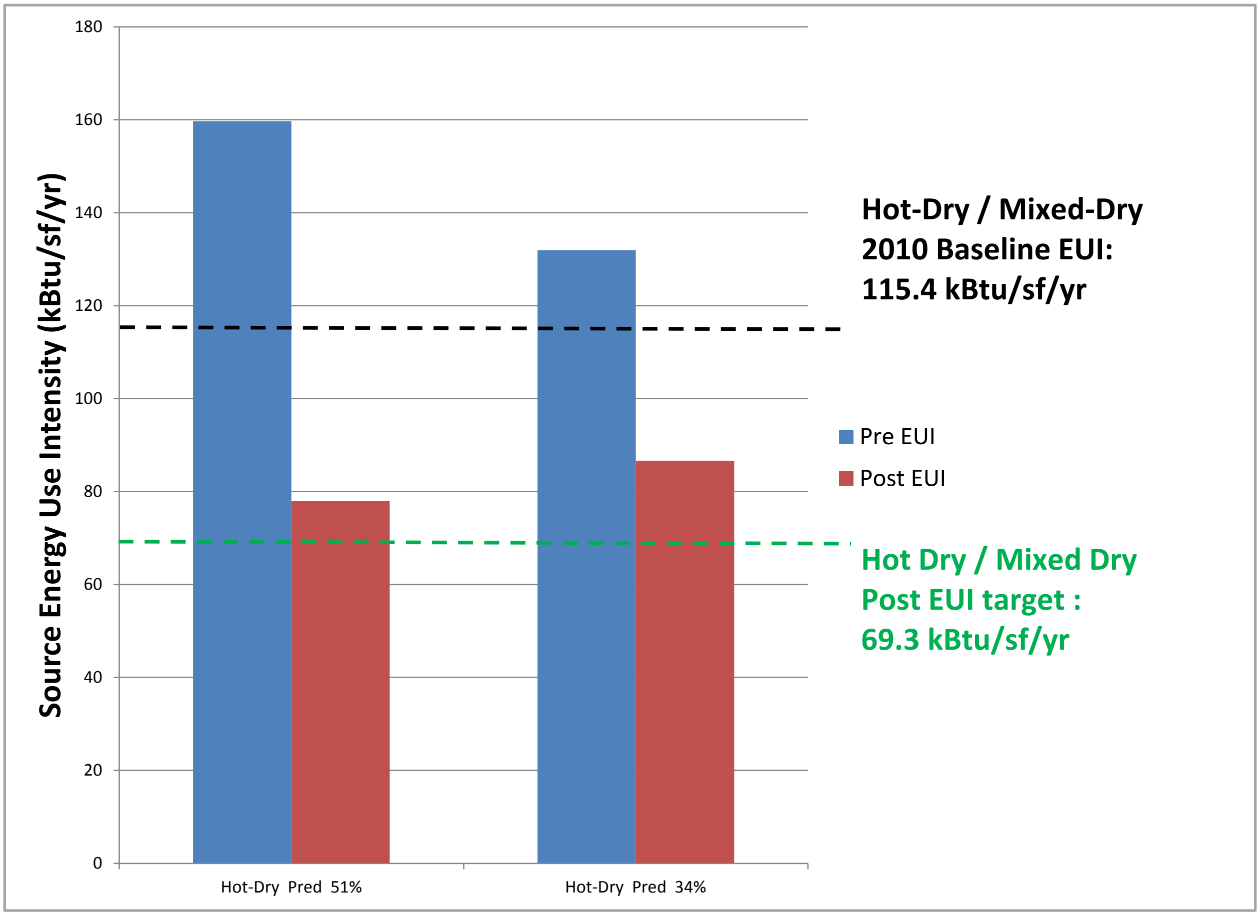

Figure A.2 Modeled EUI values for Hot-Dry/Mixed-Dry climate projects (x-axis labels: "pred" = model-predicted, % reduction versus pre-retrofit EUI)

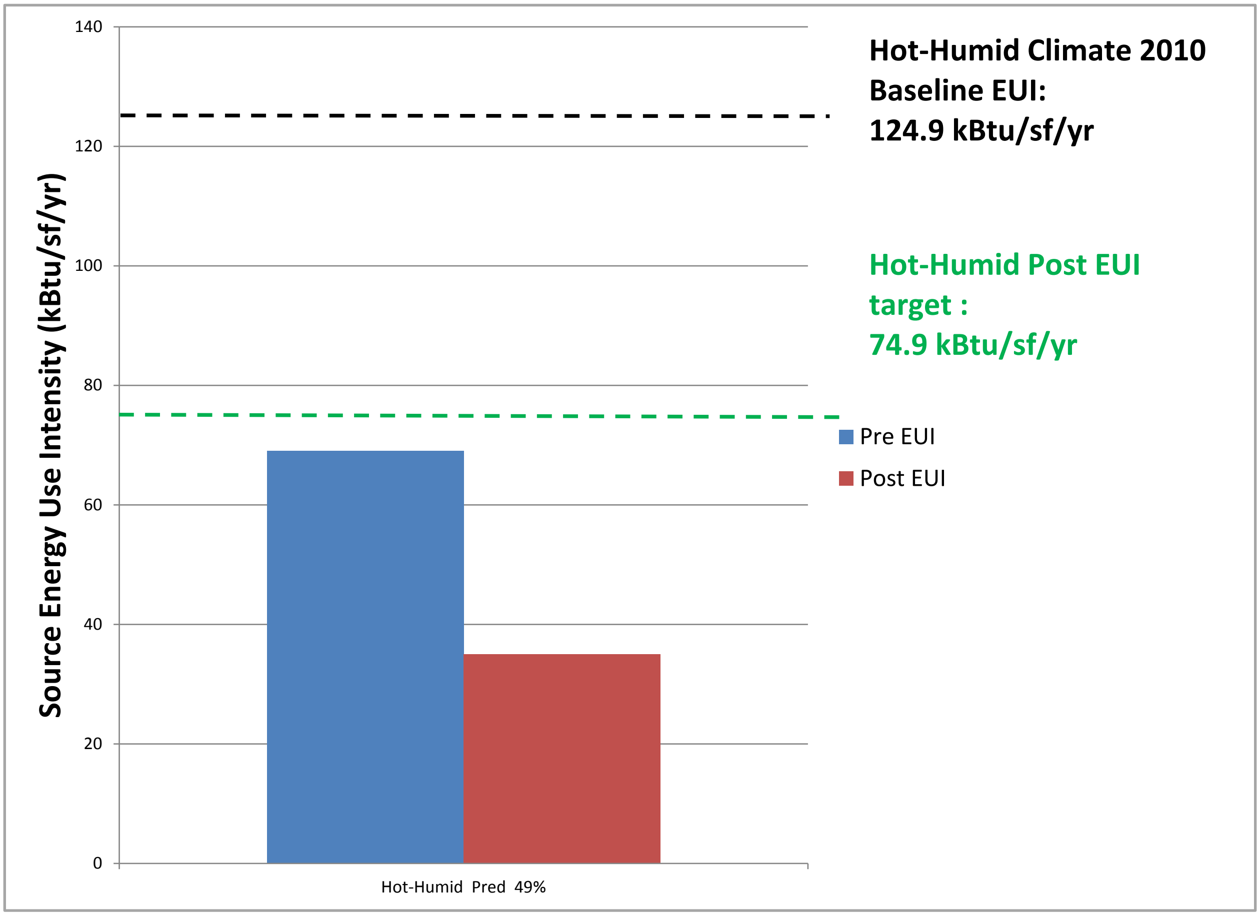

Figure A.3. Modeled EUI values for Hot-Humid climate projects (x-axis label: "pred" = model-predicted, % reduction versus pre-retrofit EUI)

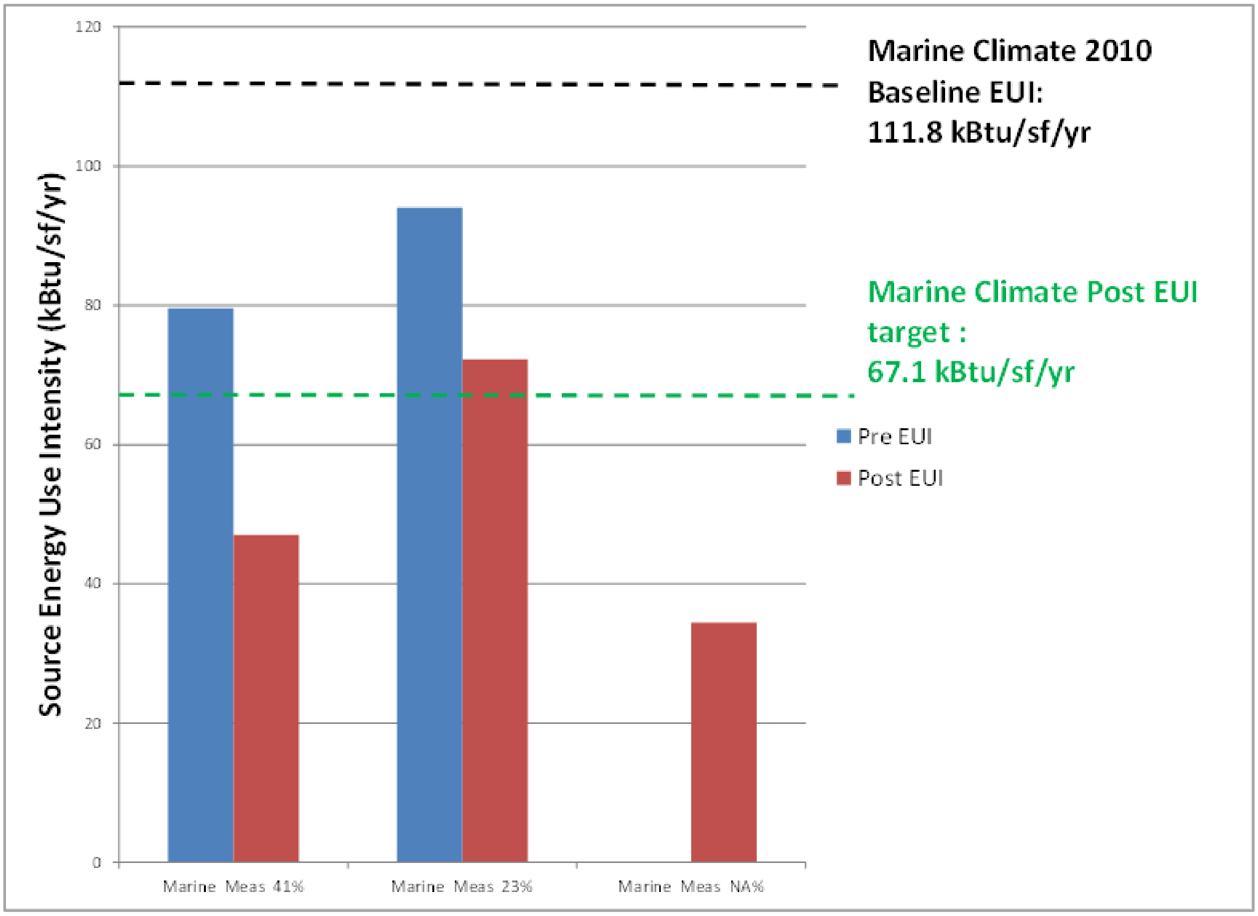

Figure A.4. Measured EUI values for Marine climate projects (x-axis labels: "meas" = measured, % reduction versus pre-retrofit EUI, when applicable)

Past Building America New Construction Projects

Figure A.5 shows results calculated from past Building America single-family new construction projects with sufficient data to calculate an EUI value. The x-axis labels indicate:

- The climate region
- Whether the EUI value is based on model-predicted consumption data ("pred") or measured consumption data ("meas")
- The percent reduction relative to the 2010 climate-specific baseline value.

The dashed boxes represent the span of the climate-specific 2010 baseline values and the 60% new home reduction targets.

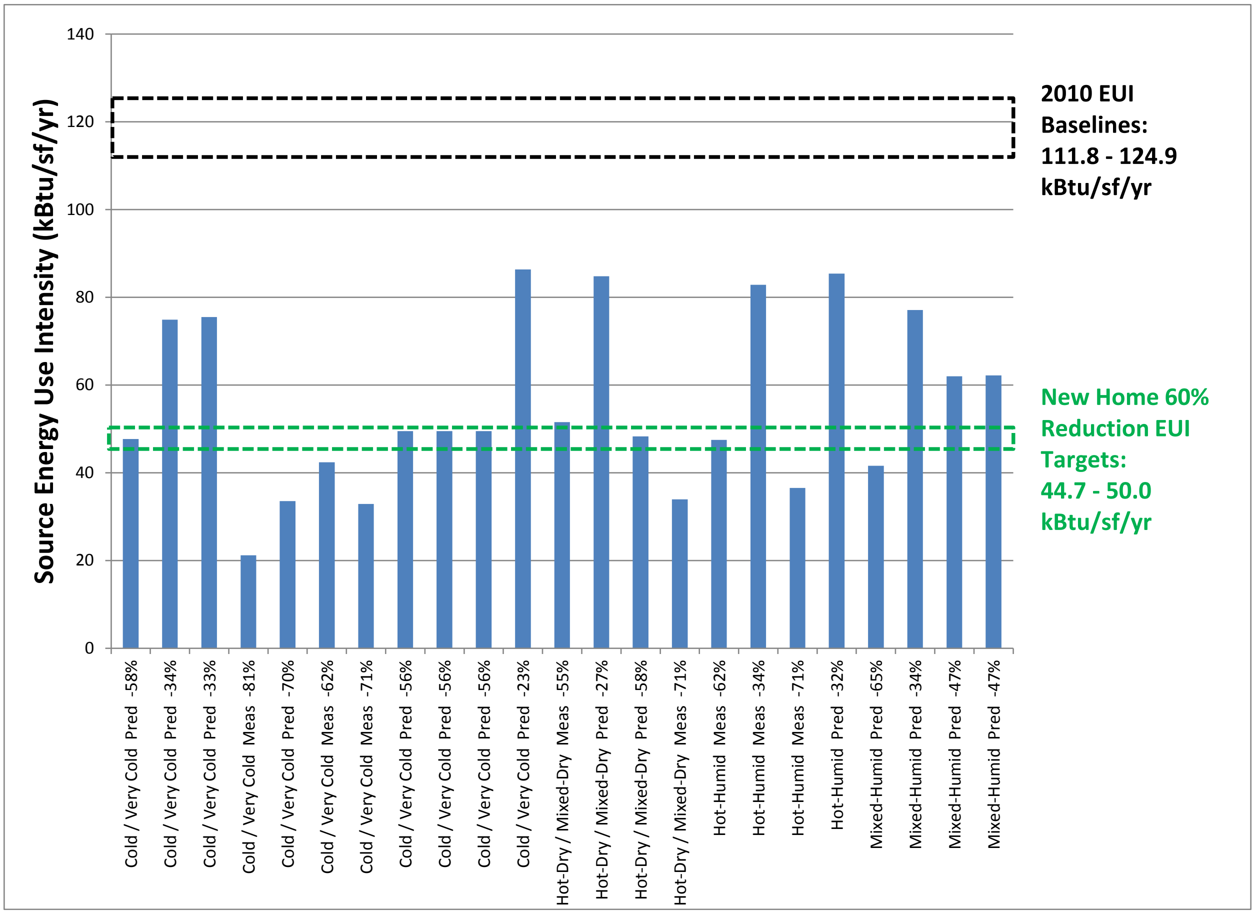

Figure A.5. Calculated results from past Building America single-family new construction projects with sufficient data to calculate an EUI value (In the x-axis labels: "meas" = measured, "pred" = predicted, % reduction versus climate-specific 2010 EUI baseline)

The projects are spread across the Cold/Very Cold, Hot-Dry/Mixed-Dry, Hot-Humid, and Mixed-Humid climates. Some observations from these data include:

- Eight homes have EUI values below the target for their climate (i.e., achieved EUI values at least 60% lower than average single-family home EUI values in 2010).
- Six homes have EUI values 50–60% below the target for their climate (i.e., came very close to achieving the target EUI).

These results demonstrate that Building America is already achieving very low energy use intensities in new home construction projects.

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Existing Homes

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- P. Kerrigan and H. Loomis, BSC, "Evaluation of the U.S. Department of Energy Challenge Home Program Certification of Production Builders," September 2014.
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Appendix B: Technology Summaries

For this report appendix, NREL reviewed nearly 250 technical publications from Building America Program industry team projects and found 14 technology topics with significant outcomes, including building science advancements, top innovations, measure guidelines, building code impacts, and identifications of future research. The technologies are grouped into four residential building system categories, as shown in the table of contents below.

Appendix B Table of Contents

See Appendix D for the name and profile of each of the Building America industry teams.

B.1 Enclosures

B.1.1 Attics

Attics are a critical component of the building envelope because if not carefully constructed, they can cause moisture condensation problems resulting in structural damage and mold growth. Historically, attics have been used to house space-conditioning equipment and ductwork.

Unvented attics with insulation at the roof deck are an accepted method of bringing comfort system equipment and ductwork installed within the attic into the conditioned space, reducing heating and cooling energy use by 10%[1]. Although the energy savings benefits of unvented attics are widely accepted, concerns related to the moisture performance at the roof deck and cost barriers that inhibit widespread adoption are still outstanding.

[1] Ueno, K. 2003. *Unvented Roof Summary Article*. RR-0301e, Building Science Corporation. https://buildingscience.com/documents/reports/rr-0301-unvented-roof-summary-article/view

Roofs and attics are among the most cost-effective areas to air seal because the pressures exerted by the stack effect are greatest at the top and bottom of a building. Field studies show that airtightness is important for the overall thermal resistance and comfort performance of the building envelope.

Progress and Results

Field studies have shown that air leakage between the house and the roof or attic is a critical air leakage pathway. Building America has developed guidance for air sealing attics to provide high cost savings and continues to collect supporting data on this topic, including methods to minimize moisture problems in attics.

Conditioned attics have advantages. They create a space inside the thermal and air barrier planes of the envelope for the installation of space-conditioning equipment and ductwork, offer additional usable space, and can provide better moisture performance if done correctly. Building America research has developed several effective strategies for creating conditioned space in the attic; these include moving the insulation to the roof deck, sealing ventilation openings, and providing space-conditioning by installing registers between the house and the attic. Several approaches focus on bringing the ducts inside the conditioned space by creating dedicated chases either above or below the ceiling plain.

Building America experienced major progress at the recent International Code Council committee hearings for the 2018 International Energy Conservation Code (IECC). The committee action hearings accepted the addition of vapor diffusion port/vent applications in unvented attics. A vapor diffusion port is an open slot at the ridge and hips (the highest points in the roof assembly) that is covered with a water-resistant but vapor open air barrier membrane to allow wintertime release to moisture to safe levels. This strategy addresses the ridge condensation and moisture accumulation problems that have been seen with unvented attics that use only air-permeable fibrous insulation, and 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 acceptance is a direct result of Building America research and demonstrated field experience. Also, the elimination of eave and ridge vents provides an additional reduction of risk from extreme weather events.

Background Research

- IBACOS completed an initial analysis of moisture damage risk in unvented (cathedralized) attics insulated with closed-cell spray polyurethane foam (ccSPF). The ccSPF was chosen for this analysis because it is, in theory, the best insulation for this application (and other types of insulation would likely do worse). Data from three houses retrofitted from vented to unvented attics demonstrated air leakage from the attic to the outdoors, which could result in moisture accumulation leading to localized damage because of the reduced airflow (due to the ccSPF) near the leakage pathway. However, hygrothermal analysis suggests that moisture accumulation is localized to an area 5 inches from the crack and can dry naturally before the next winter.

- The Consortium for Advanced Residential Buildings (CARB) conducted research aimed at gathering cold-climate field-measurement data for model validation and to support design guidelines for durable unvented roof assemblies. Data sets from three test homes indicate that duct leakage and building (not attic) infiltration have the greatest impact on how closely the attic tracks the living-space conditions. In general, they found that an unvented attic is unlikely to be at the same conditions as the living space unless it is directly or indirectly conditioned. When ducts are located in the attic, wintertime conditions of the unvented attic track fairly well with the living-space conditions.

- Building Science Corporation (BSC) investigated the effects of rainwater leakage on the hygrothermal performance and durability of spray polyurethane foam roof strategies. Modeling was conducted in a hot climate with significant rain (Miami), a cold climate (Minneapolis), and a marine climate with significant rain (Seattle), covering the expected range of in-service conditions for unvented roof assemblies. Modeling and field data demonstrated that roof sheathing with spray foam insulation will dry after a roof leakage event. The results suggest that there are no moisture and durability risks with installing spray foam under plywood and oriented strand board roof decks as long as the installation complies with the 2012 International Residential Code (IRC), a fully adhered leak-free roof membrane is installed, the roof sheathing is dry below 18% before spray polyurethane foam installation, and a low-perm Class II vapor retarder is installed where required when using open-cell spray polyurethane foam.

- While much research and effort has focused on conditioning the attic space, sealing and insulating the attic floor continues to be a viable strategy both for new construction and retrofits. BSC conducted a case study of eight homes in Chicago comparing retrofits: air sealing and insulating the attic floor compared to creating an unvented, conditioned attic. These test homes demonstrated that the two different strategies achieve similar air leakage and energy performance improvement relative to the pre-retrofit conditions even though the unvented roof strategy enclosed a larger volume and resulted in a larger thermal enclosure area.

- If thermal and air barriers are installed poorly or not at all, air can readily move from unconditioned attic spaces into quasi-conditioned interstitial spaces (called "wind washing"). Wind washing can result, for example, when an attic space over first-floor portions of a house abuts the second story, and the floor cavity of the second story is open to the attic space. The Building America Partnership for Improved Residential Construction (BA-PIRC)/Florida Solar Energy Center (FSEC) studied the impact of poorly sealed and insulated floor cavities adjacent to attic spaces in 56 Florida homes. Wind-washing repairs (made by either spray application of low-density, insulating foam or by careful placement of kraft paper-faced insulation batts) were demonstrated to be cost-effective, with a mean predicted annual space-conditioning savings of 1,034 kWh per home.

- The Alliance for Residential Building Innovation (ARBI) conducted a *Retrofit Your Attic* program with a community partner in Davis, California. The home energy upgrade program used a strategy that focused on attics—including air sealing, duct sealing, and attic insulation—and prices were kept to less than $4,000 after incentives. Pre- and post-retrofit utility data collected for additional demonstration projects successfully exhibited an average estimated total household electricity savings of 570 kWh (6.9%) and total natural gas savings of 53 therms (9.7%). ARBI found that there are significant market barriers to retrofit uptake: (1) a broad-based public awareness campaign is needed to increase understanding of the makeup and benefits of residential retrofits, and (2) a dramatic shift is needed in the economic playing field so that efficient homes are appraised and valued at higher levels than standard homes.

- Fraunhofer evaluated the cooling energy savings and cost-effectiveness of radiation control attic retrofit strategies in cooling-dominated climates as an alternative to the addition of conventional bulk insulation such as fiberglass or cellulose insulation. Radiation control techniques include reflective insulation, radiant barriers, and Interior Radiation Control Coatings (IRCC), and in residential applications are typically applied below the roof deck or on top of the attic floor insulation. Modeling results showed inconclusive payback periods; these ranged from 3.5–16 years in Miami and from 5–22 years in Phoenix.

Future Research Areas

Building America continues to investigate moisture risk management for high-performance envelope solutions, including the attic and roof assemblies. Significant system interactions occur with space heating and cooling equipment and air distribution systems installed in attics such that optimal comfort and indoor air quality (IAQ) solutions must also consider the roof and attic assembly performance. High-efficiency roof and attic assembly solutions developed by Building America are ready for the industry, including vented attics that are insulated over the ceiling deck with blown fiberglass or blown cellulose, unvented attics that are insulated on the underside of the roof deck with blown spray foam, and unvented attics that are insulated above the roof deck with rigid foam. Further market engagement is needed to encourage adoption.

Projects/Timeline

FY12

- Top Innovation: Unvented, Conditioned Attics
- BSC conducted a case study in Chicago comparing retrofits in eight homes: air sealing and insulating the attic floor compared to creating an unvented, conditioned attic.
- CARB published a measure guideline on air sealing attics in multifamily buildings.

FY13

- IBACOS simulation study shows moisture damage potential in unvented, conditioned attics insulated even with ccSPF. Lab and field studies are needed to validate findings.

FY14

- CARB collected field data to validate Oak Ridge National Laboratory’s unvented, conditioned attic modeling methodologies and results.
- BSC published a measure guideline on attic floor air sealing.

FY15

- A BSC field study showed that roofs with diffusion vents experience more drying and less wintertime moisture accumulation than unvented roofs.

- ARBI published results on its Retrofit Your Attic program.

FY15 Funding Opportunity Announcement (FOA) Selected Project

- HIRL, Attic Retrofits Using Nail-Base Insulated Panels

FY16 FOA Selected Project

- BSC, Insulated Roof Assemblies to Reduce Condensation Risk

Publications

- Top Innovations
    - 2011: Attic Air Sealing Guidelines
    - 2012: Unvented, Conditioned Attics
    - 2014: Cost-Optimized Attic Insulation Solution for Factory-Built Homes.
- Code Compliance Briefs
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    - Sealing and Insulating Existing Vented Attics, May 2016.
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B.1.2 High-R Walls

Building America has pursued research on two main approaches to increasing the R-value of wall systems: the application of rigid foam sheathing on the exterior and increasing the framing dimension to create more space for insulation. In retrofit situations that require an internal application of insulation, careful consideration of moisture-management details is paramount for long-term durability.

Progress and Results

Rigid exterior insulating sheathing provides increased thermal resistance, cuts off thermal shorts from framing elements, reduces condensation risk, 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.

Field-test results and best practices related to exterior insulation helped overcome IRC structural and fire code issues associated with added insulation and enabled higher insulation levels in the 2012 and 2015 IECC. A Building America Solution Center code compliance brief 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 (EP&B) system, which integrates foam sheathing insulation with wall framing such that wood structural panels are installed exterior to the foam sheathing. This system provides adequate moisture performance because it maintains warmer cavity temperatures and allows uninterrupted drying of oriented strand boards to the outside. Initial evaluations indicate that EP&B enables wall system construction with R-values that are 50% or more above standard code requirements using methods and materials common in the industry today and at a cost similar to that of code-minimum walls.

The program is continuing to develop water management details to integrate exterior insulation strategies with other building envelope elements and connections.

Background Research

Exterior Insulation

Rigid exterior insulating sheathing is a leading technology in high-performance enclosures for both new construction and retrofits. It provides increased overall thermal resistance, reduces thermal bridging at framing members, improves water management, and can increase airtightness of the enclosure. Exterior sheathing also enables a retrofit process with minimal disruption to the interior finishes in existing homes.

BSC conducted baseline engineering analysis to support the installation of thick layers of exterior insulation on existing masonry walls and wood-framed walls. Based on their analysis of gravity load deflections, they concluded that for lap sidings and panel claddings with joints (metal, vinyl, wood, and fiber cement), movement is aesthetic and not a safety issue. For brittle claddings (such as stucco and cultured stone), movement could lead to cracking and potentially spalling of the material. For heavier cladding systems, there is insufficient data about potential thermal and moisture expansion/contraction, as well as creep effects of insulation in exposed environments, to predict long-term service deflection; more research is needed. As part of this work, BSC also developed guidance on how to effectively maintain the continuity of the water management when installing exterior insulation. These results were discussed at a BSC-led expert meeting in 2012.

The exterior retrofit of frame assemblies can be risky when impermeable insulating sheathings of relatively low thermal resistance are used. Basic hygrothermal analysis demonstrates that removing the existing cladding and installing foam board insulation with low vapor permeance directly on top of the sheathing membrane beneath a replacement cladding (such as vinyl siding) is likely to cause moisture problems in cold climates. There is also a perception that when water is intentionally drained in a drainage cavity between the exterior insulation and the existing structure following an energy retrofit, moisture-related durability concerns exist for the sheathing and wood structure. BSC conducted a literature study and some lab testing to investigate these concerns. The team found that there is virtually no moisture durability risk to the sheathing when water is drained repeatedly in the drainage gap between the exterior insulation and the sheathing membrane, provided there are no other moisture-related issues unrelated to the drainage cavity, such as air leakage condensation or bulk rain water leakage.

Partnership for Home Innovation (PHI) also developed an innovative wall design called the extended plate and beam (EP&B) 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 EP&B enables wall system construction with R-values that are 50% greater, or more, than standard code requirements, with a major advantage because it is straightforward, using methods and materials common in the industry today. Next steps in this work include developing a design guide to encourage adoption.

These and additional Building America research findings have demonstrated both the structural and hygrothermal performance of rigid exterior insulating sheathing. Results and installation guidance are described in various case studies, measure guidelines, and in the Building America Solution Center. Multiyear structural testing of wind and gravity load impacts contributed to expanded provisions included in the 2015 IECC prescriptive code requirements for rigid insulation.

During this period Building America also completed the Building America Enclosures Standard Technical Committee Critical Milestone #1: “By end of 2015, have adopted code language defining the requirements for attaching cladding over typical thicknesses of insulating sheathing (i.e., 1", 1.5", 2", and 4" for both 16" and 24" on-center framing).

Moisture Durability
Moisture continues to be a key topic of concern in the pursuit of any high R-value enclosure design. BSC developed a report summarizing moisture-related concerns for high R-value wall assemblies based on hygrothermal simulations for several common approaches to high R-value wall construction in six U.S. cities: Houston, Atlanta, Seattle, St. Louis, Chicago, and International Falls. All of the wall assemblies performed well under idealized conditions, but only the walls with exterior insulation—or cavity insulation that provides a hygrothermal function similar to exterior insulation—performed adequately when exposed to moisture loads. None of the walls performed well when a precipitation-based bulk water leak was introduced to the backside of the sheathing, emphasizing the importance of proper flashing and draining details. Efforts to collect field data on moisture characteristics of different wall systems in multiple climate zones are underway; Home Innovation Research Labs (HIRL) leads this work.

BSC also conducted a literature review and experiments to investigate the hygrothermal behavior of moisture-sensitive wood beams or joists that are embedded in the load-bearing masonry. Wood members that are embedded in a masonry structure are colder after an interior retrofit, and the team measured moisture content and relative humidity (RH) in joist pockets higher than recommended for long-term durability; however, disassembly of these systems revealed no structural decay, making it difficult to formulate definitive guidance based on this work alone.

Although exterior insulation is best for building durability, many buildings cannot be retrofitted with insulation on the exterior for reasons such as historic preservation, cost, zoning, space restrictions, or aesthetics. Both BSC and CARB published measure guidelines outlining current best practices (including careful moisture-management considerations) to add insulation interior to brick walls.

In several Building America projects the field/lab-measured moisture content was much less than the modeled moisture content, and the damage predicted by simulations not seen, suggesting that further work in accurate moisture-modeling capabilities or a reevaluation of industry criteria may be needed. For example, CARB evaluated several configurations of wall assemblies to determine the accuracy of WUFI and THERM2 moisture-modeling and make recommendations to ensure durable, efficient assemblies. Nearly every wall studied failed the ASHRAE 160-2009 30-day criteria, and RH levels generated with this method were found to be higher than recorded in actual studies, resulting in overly pessimistic predictions for mold growth on assembly interiors.

Advanced Framing
Advanced framing techniques were also investigated. PHI investigated the feasibility of designing load-bearing wall systems that minimize or eliminate the use of traditional headers within the wall plane. The goal was to develop framing system designs based on 2 × 6 framing members that simplify and limit cost increases when builders and remodelers switch from traditional 2 × 4 framing methodologies. The integrated rim header system design successfully maintained window serviceability throughout typical residential service load levels from the floor, wall, and roof systems.

Future Research Areas
Modeling tools available today do not yet accurately predict the risk of moisture damage in wall assemblies. More field data on various wall assembly types is needed to improve the moisture-modeling capability.

The next step for EP&B wall system construction is to verify the field performance and development of a design guide to encourage adoption.

Projects/Timeline
FY11–FY14

- In-depth lab testing of moisture and structural performance of wall assemblies with exterior insulating sheathing

FY15 FOA Selected Projects

- HIRL, Moisture Performance of High-R Wall Systems
- HIRL, Extended Plate and Beam Wall System

FY16 FOA Selected Projects

- University of Minnesota, Innovative Solid Panel Wall System
- HIRL, Structural Testing of Window Installation Techniques for Walls with Continuous Insulation

Publications

- Top Innovations
  - 2011: Advanced Framing Systems and Packages
  - 2012: High-R Walls
  - 2013: Next Generation Advanced Framing
  - 2013: Exterior Rigid Insulation Best Practices
- Code Compliance Briefs
  - Air Sealing and Insulating Garage Walls
  - Continuous Insulation – Cladding/Furring Attachment
  - Double Wall Framing
  - Insulated Interior Exterior Wall Intersections
  - Insulating and Sealing Structural Headers
  - Sealing and Insulating Existing Exterior Walls, May 2016
- Technical Reports
  - *Structural testing*
    - DeRenzis and V. Kochkin, NAHB Research Center, "High-R Walls for New Construction Structural Performance: Wind Pressure Testing," January 2013.
    - P. Baker, BSC, "External Insulation of Masonry Walls and Wood Framed Walls," January 2013.

        - P. Baker, BSC, "Expert Meeting Report: Cladding Attachment Over Exterior Insulation," October 2013.
        - P. Baker, P. Eng, and R. Lepage, BSC, "Cladding Attachment Over Thick Exterior Insulating Sheathing," January 2014.
        - P. Baker, BSC, "Initial and Long-Term Movement of Cladding Installed Over Exterior Rigid Insulation," September 2014.
        - J. Wiehagen and V. Kochkin, PHI, "Extended Plate and Beam Wall System: Concept Investigation and Initial Evaluation," August 2015.
        - DeRenzis, V. Kochkin, and J. Wiehagen, NAHB Research Center, "High-R Walls for New Construction Structural Performance: Integrated Rim Header Testing," January 2013.
        - Grin and J. Lstiburek, BSC, "Moisture and Structural Analysis for High Performance Hybrid Wall Assemblies," September 2012.
    - *Moisture testing*
        - J. Smegal and J. Lstiburek, BSC, "Water Management of Noninsulating and Insulating Sheathings," April 2012.
        - J. Smegal and J. Lstiburek, BSC, "Hygric Redistribution in Insulated Assemblies: Retrofitting Residential Envelopes Without Creating Moisture Issues," January 2013.
        - R. Lepage, C. Schumacher, and A. Lukachko, BSC, "Moisture Management for High R-Value Walls," November 2013.
        - J. Wiehagen and V. Kochkin, NAHB Research Center, "High-R Walls for Remodeling: Wall Cavity Moisture Monitoring," December 2012.
        - R. Lepage and J. Lstiburek, BSC, "Moisture Durability with Vapor-Permeable Insulating Sheathing," September 2013.
        - K. Ueno, BSC, "Analysis of Joist Masonry Moisture Content Monitoring," October 2015.
        - K. Ueno, BSC, Monitoring of Double-Stud Wall Moisture Conditions in the Northeast," March 2015.
        - L. Arena and P. Mantha, CARB, "Moisture Research—Optimizing Wall Assemblies," May 2013.
        - K. Brozyna, G. Davis, and A. Rapport, IBACOS, "Measure Guideline: Transitioning From Three-Coat Stucco to One-Coat Stucco With EPS," April 2012.
        - Grin and J. Lstiburek, BSC, "Measure Guideline: Guidance on Taped Insulating Sheathing Drainage Planes," September 2014.
        - J. Lstiburek and P. Baker, BSC, "Measure Guideline: Incorporating Thick Layers of Exterior Rigid Insulation on Walls," April 2015.

        - Ojczyk et al., NorthernSTAR, "Project Overcoat—An Exploration of Exterior Insulation Strategies for 1½-Story Roof Applications in Cold Climates," April 2013.
        - Ojczyk, T. Murry, and G. Mosiman, NorthernSTAR, "Airtightness Results of Roof-Only Air Sealing Strategies on 1 1/2-Story Homes in Cold Climates," July 2014.
        - Ojczyk, NorthernSTAR, "Cost Analysis of Roof-Only Air Sealing & Insulation Strategies on 1 1/2-Story Homes in Cold Climates," December 2014.
        - J. Dentz and D. Podorson, Advanced Residential Integrated Energy Solutions Collaborative, "Evaluating an Exterior Insulation and Finish System for Deep Energy Retrofits," January 2014.
        - R. Lepage and J. Lstiburek, BSC, "Moisture Durability with Vapor-Permeable Insulating Sheathing," September 2013.
        - K. Neuhauser, BSC, "Measure Guideline: Three High Performance Mineral Fiber Insulation Board Retrofit Solutions," January 2015.
        - PHI, "Expanding the Market for Wall Upgrades Using Retrofit Nailbase Panels," Forthcoming.
    - *Walls for manufactured homes*
        - Levy, M. Mullens, E. Tompos, B. Kessler, and P. Rath, ARIES, "Expert Meeting Report: Advanced Envelope Research for Factory Built Housing," April 2012.
        - Levy, M. Mullens, and P. Rath, ARIES, "Advanced Envelope Research for Factory Built Housing Phase 3—Whole-House Prototyping," April 2014.
        - E. Levy, M. Mullens, and P. Rath, ARIES, "Advanced Envelope Research for Factory Built Housing, Phase 3—Design Development and Prototyping," April 2014
    - *Other*
        - Herk, R. Baker, and D. Prahl, IBACOS, "Spray Foam Exterior Insulation with Stand-Off Furring," March 2014.
        - M. Hoeschele, D. Springer, B. Dakin, and A. German, ARBI, "High Performance Walls in Hot-Dry Climates," January 2015.
        - S. Musunuru and B. Pettit, BSC, "Measure Guideline: Deep Energy Enclosure Retrofit for Interior Insulation of Masonry Walls," April 2015.
        - C.J. Schumacher and M.J. Fox, Building Science Laboratories; and J. Lstiburek, BSC, "Airflow Resistance of Loose-Fill Mineral Fiber Insulations in Retrofit Applications," February 2015.
        - J.F. Straube, K. Ueno, and C.J. Schumacher, BSC, "Measure Guideline: Internal Insulation of Masonry Walls," July 2012.

- Natarajan, S. Klocke, and S. Puttagunta, CARB, "Measure Guideline: Installing Rigid Foam Insulation on the Interior of Existing Brick Walls," June 2012.
- Jan Kosny, Ali Fallahi, and Nitin Shukla, Fraunhofer CSE, "Cold Climate Building Enclosure Solutions," January 2013.

B.1.3 Foundation Insulation Improvements

Heat loss through uninsulated basements, crawl spaces, and foundations is a significant energy and comfort issue in heating climates. Because foundations are typically surrounded by soil and have exposure to both above- and below-grade conditions, hygrothermal durability is a key concern when adding insulation and air sealing. Due to the difficulty of measuring performance and lack of validated simulations, significant gaps remain in the knowledge of the hygrothermal performance of foundations.

It is generally accepted that adding insulation to the exterior of a foundation wall provides the best hygrothermal performance, but interior insulation upgrades are more common in existing homes because of cost and accessibility issues. A challenge is to provide minimally invasive exterior insulation strategies and moisture-durable interior insulation strategies.

Progress and Results

Building America research explored innovative ways to transform damp, cold basements into more comfortable, habitable spaces and reduce 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 the foundation and install rigid insulation and liquid expanding foam. This method provides superior moisture and thermal performance to interior insulation solutions.

Background Research

NorthernSTAR has led most of the foundation-related Building America research during the past 5 years. The team held an expert meeting in November 2011, and the following issues were identified as priority topics for Building America to pursue:

- Role of moisture transport through foundation and insulation materials and its potential impact on building durability

- Role of foundation type in the process of selecting an insulation system for energy performance and building durability

- Risks associated with insulation processes for cost-benefit analysis

- Improved performance modeling capabilities that address variations in foundation types and soil conditions.

- NorthernSTAR conducted a simulation study to assess the cost-benefit trade-offs of slab-on-grade (SOG) foundation insulation. The actual slab heat flow reductions possible in retrofit homes resulted in modest site energy savings of 5% or less, which are not cost-effective. Simple paybacks are mostly longer than 40 years, except in Zone 4, which has paybacks longer than 17 years (Zone 4 was evaluated with a different retrofit strategy because the strategy appropriate for Zones 5-7 would not be appropriate). Optimized slab-on-grade foundation insulation does offer additional benefits that result from the increase in the slab surface temperatures. These benefits include increased occupant comfort from reduced radiant heat exchange with the slab and a potential decrease in slab-surface condensation, particularly around the slab perimeter.

- Below-grade basements are increasingly used for habitable space, and cold foundation walls pose challenges for moisture contribution, energy use, and occupant comfort. Building America field experience shows that insulating and air sealing at the floor/basement ceiling plane is likely to result in poor overall airtightness, so including the basement within the conditioned space is generally recommended, providing insulation at the foundation walls and possibly the floor slab. BSC found that the use of ccSPF as a method of damp foundation repair provides basement insulation and bulk water control, acting as a "hybrid" assembly. This method is an effective and mature technology with a solid track record. Many design variations can be chosen based on existing conditions (foundation wall, degree of bulk water problems), budget, desired finished appearance, use of the basement space, and risk tolerance.

- NorthernSTAR conducted a simulation study to assess the efficacy of a new approach to foundation insulation retrofits. The method consists of filling open concrete block cores with an insulating material and adding R-10 exterior insulation that extends 1 ft. below grade at a cost of approximately half that of a full-depth exterior insulation retrofit. Open-core concrete block foundation walls are very common in Minnesota and Wisconsin (NorthernSTAR territory), and simulation results showed that the proposed approach can improve the performance of these foundations in multiple ways. Combining shallow exterior insulation with an insulating core fill can reduce basement zone heat loss and increase basement interior surface temperatures substantially, making occupied basements cheaper to condition and more comfortable to inhabit. Moisture load reductions and safety improvements are also expected but could not be verified in this project; field-testing could help address this question.

- NorthernSTAR initially field-tested a minimally invasive foundation insulation upgrade technique on an existing home. The approach consisted of using hydrovac excavation technology to excavate a 4"-wide perimeter, combined with a liquid insulating foam. The combination pressure-washer and vacuum-extraction technology also enabled the elimination of large trenches and soil stockpiles normally produced by backhoe excavation and accommodated obstructions to remain in place or be minimally modified. The resulting trench was filled with liquid insulating foam, which also served as a water-control layer of the assembly. Cost savings compared to the traditional excavation process ranged from 23%–50%. Savings could be even greater because replacing building structures, exterior features, utility meters, and landscaping would be minimal or nonexistent in an excavationless process.

- NorthernSTAR collaborated with NREL and Oak Ridge National Laboratory to collect 1.5 years of test house data to better understand long-term hygrothermal transport in foundation walls. The joint project has generated specific guidance on how to install durable-basement-wall insulation systems in cold climates. Interior full-wall and exterior partial-wall insulation retrofits were tested. No advantage was found for the partial-wall exterior insulation system compared to interior full-wall insulation unless the insulation extends at least to the top of the rim joist, in which case the interior rim board surface relative humidity (RH) was lowered substantially over the uninsulated case.

- CARB published a measure guideline describing good practices for insulating basements in new and existing homes covering several insulation systems that work well, comply with current codes, and can be practically implemented by builders and contractors. The measure guideline included the following key points according to Building America research-based knowledge:
    - Always address site moisture concerns, pest issues, structural integrity, and combustion safety first.
    - If possible, insulate basement walls rather than the basement ceiling.
    - Most basements wall systems are drier when insulation is on the exterior of the foundation wall.
    - The top portion of a basement wall has the highest potential for heat loss; insulating only below-grade portions of a wall is not acceptable.
    - Insulation should be directly in contact with the foundation wall; there should be no channel for air to move between the insulation and foundation.
    - The system should be airtight so that no air can move through the insulation to the foundation.
    - Basement wall systems are dryer (overall) when there is some vapor permeability in an interior insulation system. Systems with a Class I vapor retarder can result in very wet conditions at the foundation wall. If vapor-impermeable systems are used, air sealing is even more critical.
    - Foam is recommended in many basement insulation systems, but most foam cannot be left exposed; it must be covered with a suitable thermal barrier for fire safety.

Future Research Areas

For below-grade basements, there are durability concerns associated with the use of spray foam at the sill beam/rim joist. Given that damage is often seen in sill beams in pre-retrofit conditions, further study is recommended to better understand the relative contributions of various risk factors and the effectiveness of mitigation techniques. Field-monitoring of insulated sill beams could be a worthwhile exercise in this research.

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

Projects/Timeline

FY11

- NorthernSTAR held an expert meeting to identify foundation research needs.
- A comparison was conducted of available simulation tools to determine capacity to provide accurate performance predictions of existing foundation systems.

FY12

- BSC published a measure guideline on hybrid foundation insulation retrofits.
- NorthernSTAR conducted a laboratory-grade performance data collection of hygrothermal properties for interior and exterior foundation retrofit wall insulation systems to test moisture durability and validate simulation code.
- CARB published a measure guideline on basement insulation basics.

FY13

- NorthernSTAR field-tested the excavationless basement exterior insulation method.

FY14

- NorthernSTAR performed a simulation study of concrete masonry foundation insulation.
- NorthernSTAR performed a simulation study of slab-on-grade foundation insulation retrofits.

Publications

- Top Innovations
  - 2010: Unvented, Conditioned Crawlspaces
  - 2011: Basement Insulation Systems.
- Code Compliance Briefs
  - Floors: Above Unconditioned Basement, Vented Crawlspace, Cantilevered Floors, and Floors above Garage
  - Slab-on-Grade Insulation
  - Sealing and Insulating Existing Crawl Space Walls, May 2016
  - Sealing and Insulating Existing Floors above Unconditioned Spaces, May 2016.
- Technical reports
  - K. Ueno and J. Lstiburek, BSC, "Measure Guideline: Hybrid Foundation Insulation Retrofits," May 2012.
  - R. Aldrich, P. Mantha, and S. Puttagunta, CARB, "Measure Guideline: Basement Insulation Basics," October 2012.
  - G. Mosiman, R. Wagner, and T. Schirber, NorthernSTAR, "Excavationless Exterior Foundation Insulation Exploratory Study," February 2013.
  - L. Goldberg and B. Steigauf, NorthernSTAR, "Cold Climate Foundation Retrofit Energy Savings: The Simulated Energy and Experimental Hygrothermal Performance of Cold Climate Foundation Wall Insulation Retrofit Measures—Phase I, Energy Simulation," April 2013.

- C. Ojczyk, P. Huelman, and J. Carmody, NorthernSTAR, "Expert Meeting Report: Foundations Research Results," May 2013.
- ORNL Foundation Design Handbook, 2014.
- T. Schirber, G. Mosiman, and C. Ojczyk, NorthernSTAR, "Excavationless Exterior Foundation Insulation Field Study," September 2014.
- L. Goldberg and A. Harmon, NorthernSTAR, "Cold Climate Foundation Retrofit Experimental Hygrothermal Performance: Cloquet Residential Research Facility Laboratory Results," April 2015.
- P. Huelman, L. Goldberg, and R. Jacobson, NorthernSTAR, "Innovative Retrofit Insulation Strategies for Concrete Masonry Foundations," May 2015.
- L. Goldberg and G. Mosiman, NorthernSTAR, "High-Performance Slab-on-Grade Foundation Insulation Retrofits," September 2015.

B.2 Space Conditioning

B.2.1 Simplified Space Conditioning

Building America research targets have led to many high-efficiency houses. The advent of new, efficient homes that boast maximum space-heating and space-cooling loads of less than 10 BTU/hr-ft^2, has motivated new research on how best to condition these so-called "low-load" homes.

There is a school of thought that heating and cooling energy in low-load houses can be distributed sufficiently throughout the house via convective currents through open doors or transfer grilles, buoyancy, and conduction through interior partition walls.

Building America has ongoing research to investigate the efficacy of these "simplified" alternatives to conventional central ducted systems, such as distributed fan coils with minimized ducts, terminal fan coil units, or point-source units with buoyant force or ventilation-driven distribution.

Progress and Results

For years, Building America research has contributed to the advancement of heating and cooling system efficiency as well as spurred equipment manufacturers to tighten the air leakage from residential heating, ventilating, and air-conditioning (HVAC) system cabinets.

During the past 5 years, simplified space conditioning for low-load homes has been a focus of IBACOS's research for Building America. Stakeholder feedback, simulations, prototypes, and field research have been the basis for the following findings and recommendations.

In 2011, IBACOS held an expert meeting to exchange ideas on thermal comfort and energy characteristics of installed simplified space-conditioning systems in both new and retrofit applications. There was general consensus that simplified systems have been successfully implemented in many cases.

A simulation study shows that simplified comfort systems can provide comfortable conditions in low-load homes with less energy use compared to typical forced-air systems. Actual implementation of point-source strategies has been more challenging. One key factor is that low-load homes have differing load densities from one room to another and highly variable load densities throughout the day and year based on solar gains and internal gains. For all but the most simple house geometries, it may be necessary to supply conditioned air to each thermal zone of the house.

More specifically, single-story homes with centralized open layouts can be adequately conditioned with a single thermostat in all the simulated climate zones. Two-story homes with a high window-to-wall ratio on the southern and western exposures need multiple thermostats to provide adequate comfort. In these cases, because continuous fan operation does not significantly improve comfort, a discretely zoned approach is necessary to prevent undercooling of some zones.

Another option is a home-run, manifold, small-diameter duct system that can provide space-conditioning air to individual thermal zones in a low-load home.

Low-load homes are susceptible to thermal excursions when careful design of house geometry, system type, and control strategy is not considered. Further, homebuilders should be aware of their climate and should choose a space-conditioning strategy accordingly.

The state-of-the-art space comfort systems for low-load houses are still evolving, with promising solutions in the areas of heat pumps, ductless mini-split systems, combined heating and hot water systems, point-source strategies, and supplemental dehumidification.

Future Research Areas

Multiple Building America teams and laboratories researched the technical effectiveness of a variety of high-SEER strategies (e.g., point-source or limited distribution systems, variable refrigerant flow systems, small diameter ducts, compact (short-run) 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.

More research is needed to characterize the interactions between defined air spaces in the house to enable these simplified systems to meet the demands of a mass-market audience.

Future work should include a better understanding of the limitations that low-load homes impose in terms of how quickly space-conditioning systems are able to recover from episodes of high or low temperature or RH and what can be done to mitigate discomfort during these events. Strategies worth investigating may include changes in occupant operation of homes in addition to innovations in equipment design and performance.

Projects/Timeline

FY11

- IBACOS, Simplified Space Conditioning Expert Meeting. Discussion identified outstanding gaps and barriers to justify research needs.

FY12

- IBACOS, Advanced Efficiency Measures and Thermal Comfort in Unoccupied Test Houses. Set up and initiate investigation in two lab homes on how well innovative space-conditioning distribution strategies not commonly used by production builders meet ACCA and ASHRAE guidelines for room-to-room temperature uniformity and stability compared to typical ducted forced-air systems.

FY13

- IBACOS, Evaluation of High-Velocity Space-Conditioning Systems

FY14

- IBACOS, Risk Assessment of Heating, Ventilation, and Air-Conditioning Strategies in Low-Load Homes. Simulation study of the ability of innovative space-conditioning systems to provide comfort in low-load/Zero Energy Ready Homes compared to traditional forced-air systems.
- IBACOS, Performance Analysis of a Modular Small-Diameter Air Distribution System. Lab study of prototype home-run, manifold, small-diameter duct system

FY15 FOA Selected Projects

- IBACOS, investigate a Simplified "Plug-n-Play" Air-Delivery System for Residential HVAC Systems
- Florida Solar Energy Center, High-Efficiency, Variable-Capacity, Ducted, and Ductless Space-Conditioning Systems
- The Levy Partnership, Highly Insulated Envelopes and Simplified High-Efficiency HVAC Systems

FY16 FOA Selected Project

- Steven Winter Associates, Ventilation-Integrated High-Efficiency Heat Pump System

Publications

- Top Innovation
  - 2012: Integration of HVAC System Design with Simplified Duct Distribution (IBACOS).
- Code Compliance Brief
  - Ductless Mini-Split Heat Pumps.
- Technical Reports
  - D. Stecher, IBACOS, "Final Expert Meeting Report: Simplified Space Conditioning Strategies for Energy Efficient Houses," July 2011.
  - D. Stecher and C. Imm, IBACOS, "Commissioning of the Fresno, California, Retrofit Unoccupied Test House," June 2013.

- D. Stecher and A. Poerschke, IBACOS, "Simplified Space Conditioning in Low-Load Homes: Results from the Fresno, California, Retrofit Unoccupied Test House," February 2014.
- A. Poerschke and D. Stecher, IBACOS, "Simplified Space Conditioning in Low-Load Homes: Results from Pittsburgh, Pennsylvania, New Construction Unoccupied Test House," June 2014.
- A. Poerschke, IBACOS, "Risk Assessment of Heating, Ventilation, and Air Conditioning Strategies in Low-Load Homes," February 2016.
- A. Poerschke, IBACOS; and Armin Rudd, ABT Systems, LLC, "Performance Analysis of a Modular Small-Diameter Air Distribution System," March 2016.

B.2.2 Forced-Air Distribution Systems

As space-conditioning equipment efficiencies improve and heating/cooling loads decrease due to improved envelope designs, poor duct design and installation can result in more pronounced thermal losses. Although building scientists are in agreement that ducts should be installed in conditioned space, this is not implemented in many regions due to cost and builder resistance to changes in standard practice. Building America continues to investigate low-cost solutions to bring ductwork inside the thermal boundary as well as document and educate the community on the impacts of duct losses in low-load homes.

For retrofits, improvements in upgraded envelope and comfort system equipment performance may not be fully realized if appropriate attention is not provided to existing ducted air distribution systems. According to the U.S. Environmental Protection Agency's ENERGY STAR® program, the typical home has 20% duct leakage. In older homes, it is not uncommon for duct leakage to reach 30%–50%[2] of the total system airflow. Forced-air system duct leakage is a significant problem in existing homes, contributing to energy waste, poor comfort, IAQ issues, and moisture problems.

Equipment is often oversized because it was either oversized at initial installation or it became oversized as a result of building envelope improvements. If updated load calculations support downsizing heating and cooling equipment, it may be helpful to downsize systems at the time the equipment wears out.

Progress and Results

Ductwork in unconditioned attics can cause a large amount of heat loss and gain. Building America research has developed several effective solutions to address this problem. Several approaches bring the ducts inside the conditioned space by moving the insulation to the roof deck, sealing the holes, and conditioning the attic. Duct system improvements (either by moving them into conditioned space or by tightening and insulating them) alone can result in 5%–20% of total energy savings or more.

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[2] R. Aldrich and S. Puttagunta, Consortium for Advanced Residential Buildings, "Measure Guideline: Sealing and Insulating Ducts in Existing Homes," December 2011.

The development of a new duct-sealing method that allows sealing inaccessible ducts from the inside using an aerosol sealant injected into the airstream has made it simpler to seal existing ducts. Tight ducts reduce unbalanced pressures that can create IAQ and moisture issues caused by unintentional air movement through leaks in the ductwork.

Building America has demonstrated practical, cost-efficient solutions to sealing ducts or installing ducts within the conditioned space. New construction techniques were demonstrated to bring ducts into the conditioned space in a raised ceiling chase or with a method of building a fur-down or dropped ceiling chase (which can be fast and inexpensive). 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 will provide excellent results without condensation concerns. In humid and mixed climates, the ducts should be air sealed and encapsulated in ccSPF insulation before being covered with loose-fill insulation. The 2018 International Code Council has approved a package for ducts buried within the ceiling insulation and with a deeply buried effective R-value.

Background Research

Manual duct sealing can reduce leakage to outside by 60%. Duct sealing with combined manual and injected spray-sealant duct sealing can reduce leakage to the outside by 90%, resulting in up to 20% energy savings.

Register-modification methods provide solutions for reusing existing ductwork with new, higher performance, low-flow equipment. Reducing the register-net free area will increase the air throw and spread, increasing mixing within the space, and ultimately increasing comfort.

Hygrothermal analysis and field-test observations show high condensation potential for buried ducts without ccSPF encapsulation in hot-humid climates. The analysis does not predict condensation issues when buried and encapsulated ducts are specified. Buried and encapsulated duct improvements result in 5%–20% total energy savings and a post-retrofit distribution system efficiency greater that 95%.

Future Research Areas

Building America continues to investigate system design and smart systems for optimal comfort in low-load homes. Forced-air distribution is one approach to deliver space conditioning, and more work can be done to develop better and more cost-effective air-distribution methods.

System interaction occurs when space-heating and space-cooling equipment and air-distribution systems are installed in attics, and the optimal comfort and IAQ solutions must consider the roof and attic assembly performance.

Projects/Timeline

FY11

- Established and documented existing knowledge measure guidelines

FY12

- CARB developed a measure guideline for sealing and insulating ducts in existing homes based on industry best-practice knowledge.

FY13–FY15

- Condensation potential in hot-humid climates and successful mitigation strategies (encapsulation) was validated.

FY16

- A change was proposed to the 2018 IECC for buried ducts as an equivalency path to ducts in conditioned space; this was approved by committee action hearing, and it is pending a final hearing.
- Code compliance brief published.

FY15 FOA Selected Project

- IBACOS, investigate a Simplified "Plug-n-Play" Air-Delivery System for Residential HVAC Systems

Publications

- Top Innovations
  - 2012: Integration of HVAC System Design with Simplified Duct Distribution
  - 2012: Ducts in Conditioned Space
  - 2013: Buried and Encapsulated Ducts
  - 2014: HVAC Cabinet Air Leakage Test Method
  - 2014: California Energy Standards Recognize the Importance of Filter Selection.
- Code Compliance Brief
  - Buried Ducts in Vented Attics in Hot-humid and Mixed-humid Climate Zones, May 2016.
- Technical Reports
  - D. Beal, J. McIlvaine, K. Fonorow, and E. Martin, BA-PIRC, "Measure Guideline: Summary of Interior Ducts in New Construction, Including an Efficient, Affordable Method to Install Fur-Down Interior Ducts," November 2011.
  - R. Aldrich and S. Puttagunta, CARB, "Measure Guideline: Sealing and Insulating Ducts in Existing Homes," December 2011.
  - C. Shapiro, A. Magee, and W. Zoeller, CARB, "Reducing Thermal Losses and Gains With Buried and Encapsulated Ducts in Hot-Humid Climates," February 2013
  - D. Chasar and C. Withers, BA-PIRC, "Measured Cooling Performance and Potential for Buried Duct Condensation in a 1991 Central Florida Retrofit Home," February 2013.
  - C. Shapiro, W. Zoeller, and P. Mantha, CARB, "Measure Guideline: Buried and/or Encapsulated Ducts," August 2013.

- J. Dentz et al., ARIES Collaborative "Air Distribution Retrofit Strategies for Affordable Housing," March 2014.
- Burdick, IBACOS, "Distribution and Room Air Mixing Risks to Retrofitted Homes," December 2014.
- Herk and A. Poerschke, IBACOS, "Exterior Insulation Implications for Heating and Cooling Systems in Cold Climates," April 2015.
- D. Mallay, HIRL, "Compact Buried Ducts in a Hot-Humid Climate House," January 2016.
- ARBI, "Evaluation of Techniques to Construct Air Distribution Systems with Negligible Heat Loss/Gain and High-R Enclosures in Hot Climates," Forthcoming.

B.2.3 Existing Building Heating and Cooling Performance Upgrades

Heating and cooling energy use represents approximate 54% of all energy consumed in residential buildings so when considering retrofit options for existing buildings, improvements in HVAC are an obvious target. Building America research during the years has repeatedly pointed out that many systems suffer efficiency degradations due to lack of quality installation and proper maintenance and that addressing these aspects can reduce equipment energy use—for some air-conditioning systems by as much as 50%. Naturally, therefore, conversations around equipment upgrades have centered around fault detection and retro-commissioning the installed system rather than simply upgrading the equipment itself.

For air conditioners, there is a dearth of simple diagnostics that detect and discriminate among multiple faults, such as inadequate airflow, incorrect charge, liquid line restrictions, evaporator and condenser coil fouling, and the presence of non-condensable refrigerant contaminants. Although some progress has been made with the development of computer diagnostic tools, particularly for use in utility programs, a systematic method is needed to detect and identify major system faults by field technicians who do not have access to these tools.

More than 65% of residential systems have been identified as being improperly installed by having either improper refrigerant charge[3,4] or low airflow rates across the indoor coil, consuming significantly more energy than necessary, and resolving residential HVAC system installation problems would make a significant step toward achieving Building America program goals.

Significant opportunities for improvements in gas furnace operation abound. In 2010, natural gas provided 54% of total residential space-heating energy in the United States. Natural gas burned in furnaces accounted for 92% of that total, and boilers and other equipment made up the

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[3] Downey, T., and J. Proctor. 2002. "What Can 13,000 Air Conditioners Tell Us?" *Proceedings of the 2002 ACEEE Summer Study on Energy Efficiency in Buildings*.
[4] Lstiburek, J., and B. Pettit. 2010. *Final Report on the Expert Meeting for Diagnostic and Performance Feedback for Residential Space Conditioning System Equipment* (DE-FC26-08NT00601). Westford, MA: Building Science Corporation.

remainder. A better understanding of installed furnace performance is key to energy savings for this significant energy use.

Progress and Results

Building America field studies show that more than half of installed air-conditioning systems are operating with significant defects, and proper 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.

Background Research

- CARB worked with Clark County, Nevada, to help develop procedures to optimize cooling systems. The project showed that in hot, dry climates, sensible cooling efficiencies can be improved by increasing the flow rate across the air handling unit and increasing the size of the indoor coil. Duct replacements were needed to accommodate the increased airflow, but in most cases they were due for replacement for unrelated reasons anyway, and the cost associated with increasing flow rates across the air handling unit was minimal. The resulting utility bill savings of this measure, although small, were cost-effective. The annualized rate of return of this measure was 6%–32%.

- IBACOS produced strategy guidelines on proper HVAC sizing and calculations of heating and cooling loads.

- The Partnership for Advanced Residential Retrofit (PARR) conducted a field study of 48 homes that showed that tune-ups to existing furnace and ducts resulted in a 23% increase in system efficiency. A similar study shows that existing furnaces perform within 6.4% of steady-state efficiency in the field as when retested in a laboratory to ASHRAE Standard 103 and manufacture recommended conditions. When installed properly, existing near-end-of-life furnaces can perform per original manufacture rated efficiencies. Installing a furnace correctly in the lab or in the field is a key driver in this finding: increase the blower speed to provide the correct airflow to match the manufacturer's recommended temperature rise without exceeding the manufacturer's design static pressure. If the fan speed cannot be adjusted properly, changes to the duct system will need to be made. A measure guideline was developed on high-efficiency gas furnaces.

- CARB evaluated Concept 3 replacement motors for residential furnaces. These brushless permanent magnet (BPM) motors can use much less electricity than their permanent split capacitor predecessors and are designed primarily for use in cooling-dominated climates. Results indicated that BPM replacement motors are most cost-effective in homes with correctly sized HVAC equipment (with longer run times) and proper ductwork (i.e., low static pressures). Additionally, more dramatic savings can be realized if the occupants use fan-only operation to circulate air when there is no thermal load. This is only a good solution if the motor needs to be replaced in the first place, and it is suitable as a regular upgrade.

Future Research Areas

Future tasks could include supporting RESNET in adopting installation quality into the Home Energy Rating System (HERS), assessing current smart verification systems to develop best-practice guidance on their use, or working with ASHRAE to develop a standard test method to ensure that smart verification systems accurately assess performance.

Further research is also need to evaluate the potential energy savings, comfort improvement, and increased equipment lifespan associated with commissioning and retro-commissioning.

Projects/Timeline

FY11

- PARR conducted expert meetings (via webinar) on the topic of the impact of installation practices on the efficiency and long-term durability of the furnace.
- CARB began a retrofit field project with Clark County, Nevada.

FY13

- CARB evaluated replacement BPM motors in cooling-dominated climates.

Publications

- Technical reports
    - A. Burdick, IBACOS, "Strategy Guideline: Accurate Heating and Cooling Load Calculations," June 2011.
    - A. Burdick, IBACOS, "Strategy Guideline: HVAC Equipment Sizing," February 2012.
    - A. German, B. Dakin, and M. Hoeschele, ARBI, "Measure Guideline: Evaporative Condensers," March 2012.
    - L. Brand, PARR, "Expert Meeting Report: Achieving the Best Installed Performance from High-Efficiency Residential Gas Furnaces," March 2012.
    - C. Shapiro, R. Aldrich, and L. Arena, CARB, "Retrofitting Air Conditioning and Duct Systems in Hot, Dry Climates," July 2012.
    - L. Brand and W. Rose, PARR, "Measure Guideline: High Efficiency Natural Gas Furnaces," October 2012.
    - D. Springer and B. Dakin, ARBI, "Measure Guideline: Air Conditioner Diagnostics, Maintenance, and Replacement," March 2013.
    - S. Yee, J. Baker, L. Brand, and J. Wells, PARR, "Energy Savings From System Efficiency Improvements in Iowa's HVAC SAVE Program," August 2013.
    - R. Aldrich and J. Williamson, CARB, "Evaluation of Retrofit Variable-Speed Furnace Fan Motors," January 2014.
    - L. Brand, S. Yee, and J. Baker, PARR, "Improving Gas Furnace Performance: A Field and Laboratory Study at End of Life," February 2015.

B.2.4 Humidity Control

Cooling systems in tight, energy-efficient homes have longer off times due to lowered sensible heat gain. Although this can lead to significant net energy and cost savings, it creates a new challenge. While the sensible cooling load is lower in high-performance homes, the latent (moisture) load remains nearly unchanged due to ventilation requirements and internal moisture generation by occupants and their activities. Therefore, at times when there is no need to lower the space air temperature, lower infiltration combined with internal latent loads can lead to excessive humidity and potential condensation. Through field studies and modeling, Building America has been investigating the effects of mechanical ventilation and of supplemental dehumidification on indoor RH in both low-load (new construction) and retrofit homes in humid climates.

Progress and Results

- BA-PIRC conducted a series of long-term monitoring experiments comparing side-by-side leaky and tight homes in Central Florida during both the heating and cooling seasons. In cooler weather, they found that tight construction in humid climates can result in window condensation and high interior humidity levels without mechanical ventilation. Condensation potential may be reduced by selecting low U-value windows, introducing mechanical ventilation to reduce indoor humidity in the winter, and opening windows during mild periods with no space conditioning. The comparative summer testing showed that under natural infiltration, moisture content differed only modestly between the leaky and tight homes. Mechanical supply ventilation elevated moisture levels more significantly when added to the tight home.

- BSC and NREL conducted a field study in New Orleans comparing HVAC energy use and RH levels of homes with and without supplemental dehumidification. Humidity control varied significantly among individual houses, and an analysis of the equipment operation did not show a clear correlation between energy use and humidity levels. Occupancy and homeowner behavior greatly influence the interior humidity levels, and results of this project suggest that maintaining acceptable RH may require a more nuanced approach than simply adding supplemental dehumidification. Notably, occupants in the homes without dehumidifiers did not complain of comfort issues during periods of elevated RH. It is, however, important to keep in mind that people have a larger RH comfort zone that buildings, so the fact that people are not complaining is not necessarily indication that there is no moisture damage occurring.

- Simulation studies by BA-PIRC showed that although supplemental dehumidification may be required to maintain RH below 60% in mechanically ventilated homes, elevated RH is a strong function of climate, and thus the hours of “extreme” RH (more than 65%) remain about the same between homes with and without mechanical ventilation.

Future Research Areas

- Existing models of humidity-control systems in building simulation tools are limited to stand-alone dehumidifiers. Air conditioners with variable speed blowers, multi-stage 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 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.

- Occupants are a key driver of humidity loads in homes, and the humidity loads from occupants and their activities (e.g., showering, thermostat set point) 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 and among the occupants of the homes.

- Further work is needed to examine likely interactions with duct system leakage as well as the potential of enthalpy-recovery ventilation systems, which may help address moisture issues while providing more comparable energy performance.

- Another key gap and area of ongoing research is the cost-effective application of ASHRAE Standard 62.2-2013 with systems and approaches that reduce energy consumption, improve humidity control, and improve IAQ.

Projects/Timeline

FY11

- BA-PIRC/FSEC, tested side-by-side houses comparing a leaky (naturally infiltrated) home to a tight home with no ventilation

FY12

- FSEC, tested side-by-side houses comparing a leaky (naturally infiltrated) home to a tight home that alternated between mechanical ventilation (per ASHRAE 62.2) on and off every 2 weeks

FY13

- BSC expert meeting: recommended approaches to humidity control in high-performance homes and addressed modeling issues for dehumidification
- BSC field test: compared five homes in New Orleans with supplemental dehumidification to five homes without supplemental dehumidification

FY14

- BA-PIRC, performed simulation study on energy and indoor humidity impacts of ventilation in 12 cities in five climate zones.

Publications

- Technical reports
    - J. Dentz, ARIES, "Building America Expert Meeting Report: Hydronic Heating in Multifamily Buildings," October 2011.
    - Jordan Dentz and Hugh Henderson, ARIES, "Hydronic Heating Retrofits for Low-Rise Multifamily Buildings Phase 1: Boiler Control Replacement and Monitoring," April 2012.
    - L. Arena, CARB, "Expert Meeting: Optimized Hydronic Heating Systems Using Condensing Boilers and Baseboard Convectors," January 2013.
    - L. Arena and O. Faakye, CARB, "Optimizing Hydronic System Performance in Residential Applications," October 2013.

- J. Dentz, Hugh Henderson, and Kapil Varshney, ARIES, "Hydronic Heating Retrofits for Low-Rise Multifamily Buildings: Boiler Control Replacement and Monitoring," October 2013.
- L. Arena, CARB, "Measure Guideline: Condensing Boilers—Optimizing Efficiency and Response Time During Setback Operation," February 2014.
- P. Glanville, P. Rowley, D. Schroeder, and L. Brand, PARR, "Field Test of Boiler Primary Loop Temperature Controller," September 2014.
- J. Dentz, Hugh Henderson, and Kapil Varshney, "Hydronic Heating Retrofits for Low-Rise Multifamily Buildings: Boiler Control Replacement and Monitoring," September 2014.
- R. Ruch, Peter Ludwig, and Tessa Maurer, PARR, "Balancing Hydronic Systems in Multifamily Buildings," July 2014.
- J. Dentz and Eric Ansanelli, ARIES, "Thermostatic Radiator Valve Evaluation," January 2015.

B.2.5 Multifamily Hydronic Systems

Improving the performance of hydronic systems is of particular interest for multifamily buildings wherein 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 apartments 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.

With annual fuel utilization efficiencies around 95%, condensing boilers promise significant energy savings by recovering the latent energy of flue gas water vapor. Condensing boilers paired with low-temperature baseboard heating systems are one of the most cost-effective methods for heating high-performance multifamily buildings. One practical problem with condensing boilers as typically installed is that they do not achieve consistent flue gas condensation. To ensure condensation, the return temperature to the boiler must be below the flue gas saturation temperature, which is generally 54°C (130°F) for natural gas equipment.

Progress and Results

Distribution issues in hydronic systems may be caused by undersized piping, improperly adjusted balancing valves, inefficient water temperature and flow levels, and owner/occupant interaction with the boilers, distribution, and controls. Temperature imbalance leads to tenant discomfort, higher energy use intensity, inefficient building operation, and decreased equipment longevity. PARR conducted case studies on two Chicago-area buildings with known balancing issues to quantify the extent of this imbalance problem and to identify possible solutions. This study found that the spread of unit air temperatures in a multifamily hydronic building can be as wide as 56°F–104°F. The team found that different types of retrofits are necessary for different types of hydronic buildings. Increasing flow to an under-heated zone via a booster pump was found to be one effective method of improving an extreme imbalance issue.

Outdoor reset control, where the amount of heat delivered to the building is adjusted in proportion to the outdoor temperature, is a popular multifamily boiler control strategy with variants for both steam and hot water heating. In mild weather, proportionally lower water temperatures and less steam run time allow heating systems with outdoor reset control to limit overheating and reduce fuel consumption. Lower water temperatures also reduce distribution losses. Lowering the water temperature can be problematic for older boilers that are not designed to accept return water temperatures lower than 120°F–130°F for extended periods of time. Condensing boilers are well suited to accept low return water temperatures and therefore take maximum advantage of outdoor reset control. Field-monitoring by ARIES of outdoor reset control retrofits in three Cambridge, Massachusetts, apartment buildings demonstrated a heating gas use reduction of 10%–15% with a simple payback of less than 3 years.

To better characterize the optimal operating parameters of different condensing boiler systems, CARB monitored the performance of condensing boiler systems in six existing and three new homes and then held an expert meeting to discuss their findings and prioritize research needs. Based on further field-testing and modeling, several combinations of components were investigated and recommendations were made for cost-effective, responsive, energy-efficient packages. CARB also published a measure guideline with details on selecting the proper control settings to maximize system performance and improve response time when using a thermostat setback.

Future Research Areas

Validate new control technologies as they become available, including field studies of retrofit systems.

Projects/Timeline

FY11

- CARB led expert meeting to discuss research needs around optimizing performance of condensing boilers/hot water baseboard systems.
- ARIES led expert meeting on multifamily hydronic heating retrofits. Key research questions were identified.
- ARIES began 3-year field test of boiler retrofits in a 3-building, 42-unit housing development in Cambridge, Massachusetts.

FY14

- CARB published a measure guideline on effective control settings for thermostat setback in condensing boilers.
- PARR field-tested the boiler primary loop temperature controller.

FY15

- ARIES evaluated the thermostatic radiator valve evaluation. No significant energy savings were detected.

Publications

- Technical reports
    - J. Dentz, ARIES, "Building America Expert Meeting Report: Hydronic Heating in Multifamily Buildings," October 2011.

- Jordan Dentz and Hugh Henderson, ARIES, "Hydronic Heating Retrofits for Low-Rise Multifamily Buildings Phase 1: Boiler Control Replacement and Monitoring," April 2012.
- L. Arena, CARB, "Expert Meeting: Optimized Hydronic Heating Systems Using Condensing Boilers and Baseboard Convectors," January 2013.
- L. Arena and O. Faakye, CARB, "Optimizing Hydronic System Performance in Residential Applications," October 2013.
- J. Dentz, Hugh Henderson, and Kapil Varshney, ARIES, "Hydronic Heating Retrofits for Low-Rise Multifamily Buildings: Boiler Control Replacement and Monitoring," October 2013.
- L. Arena, CARB, "Measure Guideline: Condensing Boilers—Optimizing Efficiency and Response Time During Setback Operation," February 2014.
- P. Glanville, P. Rowley, D. Schroeder, and L. Brand, PARR, "Field Test of Boiler Primary Loop Temperature Controller," September 2014.
- J. Dentz, Hugh Henderson, and Kapil Varshney, "Hydronic Heating Retrofits for Low-Rise Multifamily Buildings: Boiler Control Replacement and Monitoring," September 2014.
- R. Ruch, Peter Ludwig, and Tessa Maurer, PARR, "Balancing Hydronic Systems in Multifamily Buildings," July 2014.
- J. Dentz and Eric Ansanelli, ARIES, "Thermostatic Radiator Valve Evaluation," January 2015.

B.3 Indoor Air Quality

B.3.1 Ventilation

Because airtightness is a key feature of energy-efficient homes, proper ventilation is a crucial component of a healthy indoor air environment. Numerous ongoing efforts in Building America characterize the complex interactions among different mechanical ventilation system types, indoor and outdoor temperature and humidity conditions, and indoor and outdoor pollutants in an effort to achieve the right balance among energy consumption, space-conditioning comfort, and healthy IAQ levels.

Progress and Results

During a 4-year time frame, three Building America teams have addressed various ventilation issues. Ventilation system performance has been studied with increased understanding of the complex system interactions for optimizing low pollutant levels, comfort including RH, and energy efficiency.

The key findings included the following:

- There is no direct correlation between pollutant levels and ventilation rates.
- There are no straight forward solutions; for example, exhaust-only ventilation has been proven not to be ideal.
- Optimal solutions for IAQ along with RH control and comfort depend on climate and system interactions.

The detailed research and conclusions can be found in the nine Building America technical reports listed below.

Background Research

Three Building America research teams conducted research projects on ventilation: BA-PIRC, BSC, and CARB led by Steven Winter Associates, Inc.

BSC conducted a field study comparing ventilation systems and sources of outdoor air in both a vented attic and a sealed cathedralized attic. Results from this study indicate that exhaust ventilation results in a lower uniformity of the outdoor air exchange rate among living-space zones and higher concentrations of particulates, formaldehyde, and other Top 20 volatile organic compounds when compared to supply and balanced ventilation systems.

Work was also done to develop recommendations for effective methods to minimize the flow of contaminated air from garages to living spaces. BSC conducted field research on a production-built home to evaluate the air transfer between garage and living space and provided measurement support to revise the U.S. Environmental Protection Agency Indoor airPLUS program requirements, which is part of the U.S. Department of Energy's Zero Energy Ready Home program.

BA-PIRC has been investigating the relationship between ventilation rate and energy required to maintain comfort. This work indicated a 10% reduction in total space-conditioning operating cost for a U.S. Department of Energy Zero Energy Ready Home controlled to <60% RH with 75% of the ASHRAE Standard 62.2-2013 requirement for mechanical ventilation compared to 100% of the requirement This suggests that judicious choices regarding when to ventilate and when not to (based on a variety of indoor and outdoor environmental factors) could deliver substantial energy savings.

Data from a 10-home, multiyear study in a hot-humid climate show that select IAQ contaminant levels were variable and did not follow the commonly held belief that the concentration of IAQ contaminants exhibit an inverse relationship with ventilation rate. The study suggests that other factors in addition to ventilation rate, such as ventilation system design (i.e., balanced compared to supply-only and exhaust-only; distributed compared to non-distributed), may be important in determining the efficacy of a ventilation system in achieving the desired dilution effect.

Adding or improving mechanical ventilation in existing homes is particularly challenging, and often there is no single solution that is best for all cases. Performance, efficiency, cost, required maintenance, and other factors must be considered when choosing a ventilation system. CARB published a measure guideline that discusses the pros, cons, and approximate costs of retrofit ventilation systems.

CARB also found that the majority of high-performance, new-construction, multifamily housing in the northeastern United States use some type of exhaust-only ventilation. For all ventilation systems, but particularly for exhaust-only systems—such as those with no ducted supply or with passive inlet vents—controlling where fresh makeup air originates is difficult. Without the ability to control where makeup air comes in, it is possible to draw in contaminated air from other sources (e.g., exhaust from adjacent garage, short-circuiting home's own indoor pollutants that were exhausted, etc.)

Future Research Areas

Building America continues investigating smart ventilation systems that will use advanced controls to provide variable ventilation rates customized to conditions of the home. The desired outcome is to provide appropriate IAQ and comfort while using less energy. There is a clear need for an IAQ baseline datasets to inform us on the IAQ levels with current ventilation practices.

Further exploration of the efficacy of different ventilation systems and disaggregating the impact of ventilation rate and system type is necessary to understand how to apply these findings in the field to achieve optimum IAQ and homeowner comfort in new homes for the least cost and lowest energy impacts.

Projects/Timeline

FY12

- BSC field tested implementing retrofit exhaust ventilation systems in mid-rise multifamily homes, resulting in substantial heating energy and cost savings.

FY13

- CARB conducted a retrofit ventilation project in Las Vegas, Nevada. An energy-recovery ventilator was implemented after comparing the modeling results of different strategies.

FY14

- BA-PIRC performed a simulation study on energy and humidity impacts of different ventilation systems in 12 cities in five climate zones.
- BSC evaluated air transfer between the garage and living space in a single-family detached home.
- BSC performed a field study comparing various ventilation systems and sources of outdoor air in a vented attic and sealed cathedralized attic.
- CARB published a measure guideline on selecting ventilation systems for existing homes.
- CARB studied optimal ventilation strategies for new construction multifamily homes.

FY15

- BA-PIRC/Pacific Northwest National Laboratory concluded a multiyear study on the correlations among ventilation system design, ventilation rates, and various IAQ contaminant concentrations in hot-humid climates.

FY15 FOA Selected Projects

- Gas Technology Institute, develop a systems approach for managing air sealing, ventilation, and air distribution.
- FSEC, test a new smart ventilation system.

FY16 FOA Selected Projects

- Newport Partners, develop a quiet smart range hood.
- Steven Winter Associates, demonstrate a ventilation-integrated, high-efficiency heat pump system
- Southface Energy Institute, establish an IAQ scoring system.

Publications

- Top Innovations
  - 2012: Outside Air Ventilation Controller
  - 2012: Low-Cost Ventilation in Production Housing
  - 2014: ASHRAE Standard 62.2. Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings.
- Technical Reports
  - *Single-family*
    - E. Martin, BA-PIRC, "Impact of Residential Mechanical Ventilation on Energy Cost and Humidity Control," January 2014.
    - R. Aldrich and L. Arena, CARB, "Evaluating Ventilation Systems for Existing Homes," February 2013.
    - Rudd and D. Bergey, BSC, "Ventilation System Effectiveness and Tested Indoor Air Quality Impacts," February 2014.
    - R. Aldrich, CARB, "Measure Guideline: Selecting Ventilation Systems for Existing Homes," February 2014.
    - Rudd, BSC, "Air Leakage and Air Transfer Between Garage and Living Space," September 2014.
    - W. Zoeller, J. Williamson, and S. Puttagunta, CARB, "Sealed Crawl Spaces with Integrated Whole-House Ventilation in a Cold Climate," July 2015.
    - BA-PIRC, "Comparative Performance of Two Ventilation Strategies in a Hot Humid Climate," Forthcoming.
  - *Multifamily*
    - K. Ueno, J. Lstiburek, and D. Bergey, BSC, "Multifamily Ventilation Retrofit Strategies," December 2012.
    - S. Maxwell, D. Berger, and M. Zuluaga, CARB, "Evaluation of Ventilation Strategies in New Construction Multifamily Buildings," July 2014.

B.3.2 Combustion Safety Simplified Test Protocol

Home performance professionals, weatherization teams, and building inspectors perform combustion safety testing on natural gas appliances before they upgrade homes for energy-efficiency improvements. Homes that fail the combustion safety tests must have expensive remediation measures performed before energy efficiency upgrades are pursued. The current test procedures are standardized in the National Fuel Gas Code, Building Performance Institute standards, and Residential Energy Services Network standards, which are undergoing revision. The U.S. Department of Energy's Building America research teams PARR and NorthernSTAR, in collaboration with Lawrence Berkeley National Laboratory and with assistance from the American Gas Association, have developed and validated a simplified testing protocol (STP) for combustion safety that has fewer steps, requires less time, and more accurately identifies unsafe appliance installations that require remediation than approaches currently used in the field.

Progress and Results
Since the project began in 2011, industry test standards have been significantly aligned as a direct result of project team member contributions. Many of the recommendations in the STP are included in the Building Performance Institute Standard Practice for Basic Analysis of Buildings (BPI-1200-S-2015) (effective January 1, 2016).

Based on sequential application of the tests in the field, the STP identifies problem houses as effectively as the worst-case procedures that are currently in use.

Field trials have revealed little evidence that combustion safety failures due to spillage from non-dryer exhaust are common and that only a very small number of homes are subject to the failures. Most failures are caused by incorrectly sized vents that lead to back-drafting.

Future Research Areas
The STP still overpredicts combustion safety risks, and data suggest that vent system inspection offers an adequate appraisal of the tendency toward excessive spillage. Additional work could continue to refine the STP to increase its accuracy or even eliminate spillage testing completely. More comprehensive documentation of the actual occurrence of combustion safety events in houses nationally and a better understanding of the causes and effects of backdrafts are also needed.

Projects/Timeline
FY11

- PARR, Combustion Safety Expert Meeting – The discussion identified outstanding gaps and barriers to justify research needs. The meeting resulted in a harmonization activity among the Building Performance Institute, National Fuel Gas Code, and other organizations to develop a single approach to field inspections and code coverage.

FY12

- PARR/NorthernSTAR, Combustion Safety Measure Guidelines – Two measure guidelines were developed on combustion safety solutions for the two most common cases. The guidelines include an STP checklist.

FY13

- PARR/NorthernSTAR, Combustion Safety Simplified Testing Method Development – A test plan and instrumentation package were developed to collect field data to validate the STP checklist.

FY14

- PARR/NorthernSTAR, Combustion Safety Simplified Test Protocol Pilot Study – A field study was conducted on 300 homes in cold-climate zones.

FY15

- PARR/NorthernSTAR, Combustion Safety Simplified Test Protocol Pilot Study—Expanded Scope – The study was expanded to 1,000 homes among 17 states.

FY15 FOA Selected Project

- Gas Technology Institute for air sealing, ventilation, and air distribution during weatherization.

Publications

- Technical Reports
  - L. Brand, PARR, Building America Expert Meeting: Combustion Safety," March 2013.
  - J. Fitzgerald and D. Bohac, NorthernSTAR, "Measure Guideline: Combustion Safety for Natural Draft Appliances Through Appliance Zone Isolation," April 2014.
  - L. Brand, PARR, "Measure Guideline: Combustion Safety for Natural Draft Appliances Using Indoor Air," April 2014.
  - PARR, "Case Study: Combustion Safety for Appliances Using Indoor Air," May 2014.
  - L. Brand, D. Cautley, D. Bohac, P. Francisco, L. Shen, and S. Gloss, PARR and NorthernSTAR, "Combustion Safety Simplified Test Protocol," November 2015.
  - PARR and NorthernSTAR, "Case Study: Combustion Safety Simplified Test Protocol Chicago, Illinois, and Minneapolis, Minnesota," December 2015.

B.3.3 Multifamily Compartmentalization

Multifamily building developers are challenged with constructing to significantly tighter levels, addressing compartmentalization issues among units, and adopting test procedures to prove compliance. The 2012 IECC mandates 3 ACH50 measured air leakage requirements for all units within multifamily buildings. The Leadership in Energy and Environmental Design (LEED) certification program, ASHRAE Standard 189, and ASHRAE Standard 62.2 have comparable compartmentalization requirements. Fire-resistance rated wall assemblies (or area separation walls) have been identified as the major source of difficulty in air sealing/compartmentalization.

Progress and Results

The development of guidance and details to aid builders to comply with 2012 IECC air leakage requirements is based on field-test results. Even with best-practice guidance, field tests show that achieving the target of 3 ACH50 (used for both single-family and multifamily buildings) can be challenging for builders to meet. Achieving the 0.30 CFM50/ft^2 airtightness target was possible and may be a better metric for the smaller volumes found in apartments. The relationship between a house's exterior enclosure area (which is exposed to ambient conditions) and its volume is not constant and depends on the footprint geometry. Energy loss occurs at the exterior enclosure, and the difference between defining an air leakage requirement based on dwelling area and on volume is more pronounced for attached than detached homes. For this reason there is a school of thought that a CFM per square foot metric may better account for the nuances of multifamily construction.

Research on innovative new approaches to apartment compartmentalization air sealing using aerosol-based sealing processes showed air leakage reductions of 60%–85%. The study was focused on multifamily applications but the aerosol-based sealing approach could work for single-family homes as well.

CARB examined a limited amount of test data to develop an empirical model to estimate outside air leakage based on a measurement of total leakage and a few key characteristics of the multifamily unit. Their analysis indicated that prediction accuracy of 20% could be achieved by considering only six variables in addition to total leakage: climate zone, ductwork location, door area, shared surface area, envelope perimeter, and age. These results are based on limited datasets, but they show promise that the air leakage to the outside can be estimated using a simple blower door test (rather than a more expensive guarded blower door test.)

Future Research Areas

Building America has provided technical solutions for the air sealing and insulation of multifamily common walls. This Building America success is ready to transfer to industry engagement activities for code definition of party walls. Further research of the use of aerosol air sealing technologies in new construction is ongoing in an effort to increase airtightness at reduced cost, and it should include UL listing.

Projects/Timeline

FY16 FOA Selected Project

- Center for Energy and Environment, evaluate the optimal integration of an envelope air sealing method that uses aerosol sealant in production building.

Publications

- Code Compliance Brief
  - Air Sealing and Insulating Common Walls (Party Walls) in Multi-Family Buildings, May 2016.
- Technical Reports
  - C. Harrington and M. Modera, Building Industry Research Alliance (BIRA), "Laboratory Testing of Aerosol for Enclosure Air Sealing," May 2012.
  - J. Dentz, F. Conlin, and D. Podorson, ARIES, "Case Study of Envelope Sealing in Existing Multiunit Structures," October 2012.
  - S. Klocke, O. Faakye, and S. Puttagunta, CARB, "Challenges of Achieving 2012 IECC Air Sealing Requirements in Multifamily Dwellings," October 2014.
  - K. Ueno and J. Lstiburek, BSC, "Field Testing of Compartmentalization Methods for Multifamily Construction," March 2015.
  - S. Maxwell, D. Berger, and C. Harrington, CARB, "Apartment Compartmentalization With an Aerosol-Based Sealing Process," March 2015.

- O. Faakye and D. Griffiths, CARB, "Multifamily Envelope Leakage Model," May 2015.
- C. Harrington and D. Springer, CARB, "Field Trial of an Aerosol-Based Enclosure Sealing Technology," September 2015.

B.4 Hot Water

B.4.1 Heat Pump Water Heater

Heat pump water heaters (HPWHs) have demonstrated efficiencies of two to three times those of standard electric resistance water heaters. Approximately 40% of homes in the United States are served by electric water heaters, and for many of them converting to a HPWH (at end-of-life or anytime) is a cost-effective measure. Depending on the climate and the relative costs of natural gas and electricity, in some locations converting from a gas water heater to a HPWH may also be economically attractive.

Progress and Results

Field, laboratory, and simulation studies by Building America have shown that the performance of HPWHs can vary greatly depending on a number of factors. The efficiency of the heat pump is affected by ambient air temperature, humidity, and tank water temperature. Additionally, the use of the backup (and low-efficiency) resistance-heating elements can vary significantly depending on climate (both due to inlet water and evaporator inlet air), set points, and load patterns. Both high daily loads and short bursts of high-intensity loads can challenge the heat pump's recovery capacity, triggering backup electric-resistance elements to turn on. Load-reduction measures to reduce hot water use at showerheads, fixtures, and appliances should improve HPWH efficiency. Because performance is strongly dependent on end user choices and usage patterns (in addition to installation and commissioning), educating both plumbers and consumers is a critical step in achieving optimal performance. To this end, CARB published a measure guideline on installing HPWHs in both existing and new homes.

Although a lot of recent research has been conducted on single-family HPWH performance, considerably less research has been done on larger, central HPWH systems. In part, this is because there are few central HPWH installations and even fewer product options for central installation. ARBI conducted a field study to evaluate the efficiency of a central HPWH system in student apartments in Davis, California. The system operated in resistance-heat mode much of the time, resulting in measured energy consumption that far exceeded the original performance estimates. This study highlighted the importance of proper commissioning, underscoring a further need to educate plumbers and consumers.

Future Research Areas

In addition to the occupant factors noted above, incorporating ducting strategies to leverage the cooling effect of the heat pump on the surrounding air should be investigated. A field evaluation of optimal ducting strategies could lead to further improvements in the cost-benefit calculus of HPWH.

Projects/Timeline

FY12

- CARB published measure guideline on HPWHs in new and existing homes.
- ARBI published a water heater selection guide.
- ARBI field tested a centralized HPWH system in an apartment building in West Village, California.

Publications

- Code Compliance Brief
  - Heat Pump Water Heaters.
- Technical Reports
  - C. Shapiro, S. Puttagunta, and D. Owens, CARB, "Measure Guideline: Heat Pump Water Heaters in New and Existing Homes," February 2012.
  - B. Dakin, C. Backman, M. Hoeschele, and A. German, ARBI, "West Village Community: Quality Management Processes and Preliminary Heat Pump Water Heater Performance," November 2012.
  - M. Hoeschele, D. Springer, A. German, J. Staller, and Y. Zhang, ARBI, "Strategy Guideline: Proper Water Heater Selection," April 2015.

B.4.2 Tankless Hot Water

Tankless water heaters are compact gas or electric units that heat water as needed, without storing it in a reservoir as traditional water heaters do. These units can provide "endless" hot water, up to a maximum flow rate (defined by heating capacity, set point, and inlet water temperature). Tankless heaters offer several attractive advantages: there are no standby losses; equipment life expectancy is higher; and they can deliver more hot water per hour, a key benefit for intensive users such as large families. Potential disadvantages include high initial cost as well as a time delay in delivering hot water, especially if the heat exchanger has fully cooled off since the previous water draw event. In addition, the on-demand nature of water heating can allow occupants to take longer showers, increasing overall hot water use simply by making it more readily available. In utility districts with demand charges, tankless heaters may exceed demand limits triggering higher utility costs. Building America has studied the pros and cons of tankless systems to gauge under what circumstances they are most suitable and economical.

Progress and Results

Tankless water heaters may save 5%–40% (depending on fuel type and efficiencies of the specific model) in annual cost to operate compared to a tank-type water heater using the same fuel type. The University of Florida's Building Energy-Efficient Housing for America team sought to quantify real-world energy impacts of tankless retrofits in 110 public housing units in Florida through simulation and utility-bill analysis. Their study sample did not demonstrate a significant change in hot water use between the pre- and post-retrofit periods, and utility bills indicated energy savings ranging from 25%– 40% on average, with households with the lowest hot water consumption least likely to benefit from a tankless retrofit.

Building America research has shown that a number of factors are important when determining whether a tankless water heater is a cost-effective measure. Some of these factors are specific to the home, such as the location of the unit and overall configuration of the distribution system including length and geometry, as well as interactions with other building systems that may affect their cost and performance. Additional maintenance issues should be considered, such as an increased risk of scaling from hard water. IBACOS published a measure guideline that steps through the key considerations when transitioning to a tankless system.

Future Research Areas

User behavior and adaptability to delivery characteristics heavily impact whether occupants will be satisfied with this measure. Some occupants may allow the performance changes to negatively influence their perception of the technology. Hybrid gas technologies that combine on-demand heating with a small storage volume exist; this option may offer a good compromise between conventional delivery characteristics and energy efficiency.

This tankless water-heating technology has matured such that market engagement activities are the next appropriate steps to increase adoption.

Projects/Timeline

FY11

- The University of Florida's Building Energy-Efficient Housing for America performed a simulation and field study of energy impacts of tankless water heater retrofits in 110 public housing units.

FY12

- IBACOS published a measure guideline for transitioning to tankless domestic hot water.

Publications

- Top Innovations
    - 2010: Tankless Gas Water Heater Performance.
- Technical Reports
    - K. Brozyna and A. Rapport, IBACOS, "Measure Guideline: Transitioning to a Tankless Water Heater," September 2012.
    - R. Ries, R. Walters, and D. Dwiantoro, BEEHA, "Assessing the Energy Savings of Tankless Water Heater Retrofits in Public Housing," January 2013.
    - M. Hoeschele, D. Springer, A. German, J. Staller, and Y. Zhang, ARBI, "Strategy Guideline: Proper Water Heater Selection," April 2015.

B.4.3 Hot Water Distribution

Distribution system characteristics are significant drivers of energy consumption because of the large house sizes and number of fixtures in modern homes. Inefficient distribution systems waste heat and water and cause long wait times for hot water delivery. Although water heater performance has been well characterized, there is a dearth of detailed studies on the impacts of distribution systems. By some estimates, distribution losses may range from 10%–40% of annual domestic hot water energy consumption. Factors that significantly impact the magnitude of these losses include plumbing layout and hot water usage patterns, both highly variable among different homes.

Progress and Results

Through model development and field-validation efforts, Building America research has helped to improve the accuracy of distribution system modeling in whole-house energy simulations.

Models in ARBI's Hot Water Simulation Program and Thermal Energy Systems Specialists' Transient System Simulation Program have been developed to analyze distribution system performance. These high-fidelity pipe models have been validated using both laboratory and field data. A full distribution system developed in TRNSYS has been validated using field-monitoring data and then exercised in a number of climates to understand climate impact on distribution performance.

Using these models, ARBI characterized distribution efficiencies for a variety of systems. Results indicate that insulated trunk and branch systems with a centrally located water heater provide the most site energy savings. Demand recirculation systems are not likely to save energy (and in some cases may increase energy use), although they do save water. Compact plumbing practices and insulation levels have the most impact on energy consumption (energy savings of 2%–6% for insulation and 3%–4% per 10 gal of enclosed volume reduced).

Future Research Areas

Compact distribution systems have been studied and validated 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.

Specifically, future analysis to quantify the sensitivity of simulation results to model input assumptions would help determine whether developing a methodology to simplify the integration of the detailed TRNSYS model into mainstream simulation applications would be worthwhile.

Projects/Timeline

FY13

- ARBI enhanced its Hot Water Simulation Program to improve pipe heat transfer model and validates it with laboratory results.

FY14

- ARBI performed a model-based evaluation of domestic hot water distribution system options.

Publications

- Technical Reports
    - M. Hoeschele and E. Weitzel, ARBI, "Hot Water Distribution System Model Enhancements," November 2012.

- C. Backman and M. Hoeschele, ARBI, "Validation of a Hot Water Distribution Model Using Laboratory and Field Data," July 2013.
- E. Weitzel and M. Hoeschele, ARBI, "Evaluating Domestic Hot Water Distribution System Options With Validated Analysis Models," September 2014.

Appendix C: FY14–FY16 Progress toward STC Goals

During the past several years, the Building America Program has focused on solving the following core technical challenges to enable 50% energy savings in residential buildings and accelerate market transformation in the housing sector by 2030.

This section provides an overview of the FY14–FY16 progress toward the key milestones that were established by the Building America Standing Technical Committees (STCs) in these five technical challenge areas for existing and new homes in all U.S. climate regions. The key milestones themselves were derived from a consensus review of the detailed gap-identification process conducted by the Building America STCs. The consensus milestones are not the only developments required to meet the Building America technical challenges, but they are significant indicators of progress toward meeting these technical challenges. They also help identify gaps in existing research that need to be filled in the future. See Appendix D for a profile of each of the Building America industry teams.

Appendix C Table of Contents

C.1 High-Performance Thermal Enclosure Assemblies

High-performance thermal enclosure assemblies and systems that are affordable, easy to construct in new homes or retrofits, durable, and acceptable to production and code processes.

C.1.1 By the end of 2015, define the requirements for attaching both lightweight and heavyweight cladding over typical thicknesses of insulating sheathing (i.e., 1", 1.5", 2", and 4") for both 16" and 24" on-center framing. Lightweight cladding includes vinyl siding, fiber cement, and wood lap siding; heavyweight cladding includes brittle cladding such as hard-coat stucco and stone veneer.

Significance

Insulating sheathing is necessary to meet the Building America 50% energy-savings target. The model codes and U.S. Department of Housing and Urban Development (HUD) Manufactured Home Construction and Safety Standards do not have a prescriptive path allowing its use. If a prescriptive path is not provided in the model codes and a performance path is not provided in the HUD standards, the Building America 50% energy-savings target will not be achieved except under engineering or architectural seal—an impractical approach for market transformation.

FY14–FY16 Progress

Multiple Building America teams and laboratories researched the technical effectiveness of a variety of strategies:

- Alliance for Residential Building Innovation (ARBI) worked on high-performance walls in hot-dry climates.
- Building America Partnership for Improved Residential Construction (BA-PIRC) worked on insulating siding retrofits in cold climates.
- Building Science Corporation (BSC) worked on cladding attachments over foam insulating sheathing.
- BSC provided guidance on taped insulating sheathing drainage planes.
- BSC worked on moisture management for high-R walls.
- IBACOS worked on stand-off furring for exterior spray foam insulation retrofits.
- Oak Ridge National Laboratory (ORNL) worked on the risk assessment of energy-efficient wall assemblies.

BASC Content

- Guide
  - Drainage Plane Behind Exterior Wall Cladding.
- Code compliance brief
  - Continuous Insulation – Cladding/Furring Attachment**.**

FY14–FY16 Publications

- R. Lepage, C. Schumacher, and A. Lukachko, BSC, "Moisture Management for High R-Value Walls," November 2013.
- P. Baker, P. Eng, and R. Lepage, BSC, "Cladding Attachment Over Thick Exterior Insulating Sheathing," January 2014.
- Herk, R. Baker, and D. Prahl, IBACOS, "Spray Foam Exterior Insulation with Stand-Off Furring," March 2014.
- P. Baker, BSC, "Initial and Long-Term Movement of Cladding Installed Over Exterior Rigid Insulation," September 2014.
- M. Hoeschele, D. Springer, B. Dakin, and A. German, ARBI, "High Performance Walls in Hot-Dry Climates," January 2015.
- K. Neuhauser, BSC, "Measure Guideline: Three High Performance Mineral Fiber Retrofit Solutions," January 2015.

FY14–FY16 Webinars

- High Performance Building Enclosures: Part I, Existing Homes, May 21, 2014
- High Performance Building Enclosures: Part II, New Construction, August 13, 2014
- High-Performance Enclosure Strategies, Part 1: Unvented Roof Systems and Innovative Advanced Framing Strategies, February 12, 2015.

C.1.2 By the end of 2015, adopt code language defining the requirements for insulating the underside of wood floors using insulating sheathing.

Significance

Insulating sheathing under the floor framing is a low-cost, practical way of achieving the Building America goal of 50% energy savings in cold climates. The model codes do not have a logical prescriptive path for its use. Alternative approaches are available prescriptively in the model codes so that this is not a critical need; however, the alternatives come at a performance and cost penalty.

FY14–FY16 Progress

NorthernSTAR's work on air movement and performance of floors using physical testing led to an International Energy Conservation Code (IECC) and International Residential Code change in 2015 for floors and insulation placement.

BASC Content

- Code Compliance Brief
  - Sealing and Insulating Existing Floors above Unconditioned Spaces**.**

C.1.3 By the end of 2015, provide guidance on how to incorporate high-R-value wall assemblies using insulating sheathing over wood framing in situations where fire-rated wall assemblies are required. Typical situations where fire-rated assemblies are required are in new and existing one- and two-family homes and townhouses with a minimum fire separation distance of less than 5'0" and in new and existing multifamily homes (3-plus units) with a minimum fire separation distance of less than 10'0".

Significance

Insulating sheathing is necessary to meet the Building America target of 50% energy savings. The model codes do not have a prescriptive path allowing its use. If a prescriptive path is not provided in the model codes, the Building America 50% energy savings will not be achieved for these types of buildings.

FY14–FY16 Progress

Multiple Building America teams researched these strategies:

- IBACOS led an expert meeting on "Code Challenges with Multi-Family Area Separation Walls" on September 29, 2014.
- IBACOS addressed the technical challenges of air sealing and insulation of townhome party walls to comply with fire codes in Stapleton, Colorado.
- Consortium for Advanced Residential Buildings (CARB) worked with compartmental air sealing in multifamily buildings.
- Partnership for Home Innovation (PHI) worked on retrofit wall upgrades using structurally insulated panels.

- BSC worked with compartmentalization air-sealing methods for multifamily construction.

BASC Content

- Guide
  - Air Sealing Multifamily Party Walls.
- Code Compliance Brief
  - Air Sealing and Insulating Common Walls (Party Walls) in Multi-Family Buildings**.**

FY14–FY16 Publications

- K. Ueno and J. Lstiburek, BSC, "Field Testing of Compartmentalization Methods for Multifamily Construction," March 2015.
- J. Wiehagen and V. Kochkin, PHI, "Extended Plate and Beam Wall System: Concept Investigation and Initial Evaluation," August 2015.
- D. Mallay, J. Wiehagen and V. Kochkin, PHI, "Advanced Extended Plate and Beam Wall System in a Cold-Climate House," January 2016.
- M. Del Bianco and J. Wiehagen, PHI, "Using Retrofit Nail Base Panels to Expand the Market for Wall Upgrades," February 2016.

C.1.4 By the end of 2015, address common practices that use methods in violation of existing codes, including those routinely performed by the weatherization industry such as dense-packing unvented cathedral ceilings and low-slope roofs.

Significance

Promoting methods that violate existing codes raises legal, moral, and ethical issues.

FY14–FY16 Progress

Building America teams and labs worked on a variety of strategies, including:

- BSC worked on dense-packed roof assemblies.
- ORNL investigated hygrothermal sealed attics in mixed-humid climates.

C.1.5 By the end of 2015, develop a method of retrofitting monolithic slab-on-grade foundations.

Significance

Retrofit Building America energy targets in cold and mixed climates will not be met without slab foundation insulation.

FY14–FY16 Progress

NorthernSTAR worked on high-performance slab-on-grade insulation retrofits.

BASC Content

- Guide
  - Rigid Foam Insulation Installed over Existing Foundation Slabs.
- Code Compliance Brief
  - Slab-on-Grade Insulation**.**

FY14–FY16 Publications

- L. Goldberg and G. Mosiman, NorthernSTAR, "High-Performance Slab-on-Grade Foundation Insulation Retrofits," September 2015.
- D. Parker, J. Kono, R. Vieira, and L. Gu, BA-PIRC, "Evaluation of the Impact of Slab Foundation Heat Transfer on Heating and Cooling in Florida," 2016.

C.1.6 Develop guidance on design methods for enclosure design with a focus on above-grade walls; guidance to be provided for both new construction and retrofits in all U.S. climate zones.

Significance

Reducing and quantifying risk while instilling confidence in the industry is necessary for market transformation and adoption of technology.

FY14–FY16 Progress

Multiple Building America teams and laboratories researched the technical effectiveness of a variety of strategies:

- ARBI researched high-R-value walls to support a Codes & Standards Enhancement report that proposed a minimum composite U-value of 0.05 for the 2016 California Title 24 standards.
- ARBI developed an innovative application of aerosol-sealing technology for whole-house air sealing that was anticipated to be less costly than manual methods in production-scale applications.
- Advanced Residential Integrated Energy Solutions (ARIES) worked on envelopes for factory-built housing and deep-energy retrofits.
- BA-PIRC worked on insulating siding retrofits in cold climates.
- BSC monitored moisture in walls and roof assemblies.
- BSC led an expert meeting on "Guidance on Modeling Enclosure Design for Above-Grade Walls" on May 12, 2014.
- CARB worked on high-R-value walls without exterior rigid insulation.
- IBACOS studied moisture risk in unvented attics and double-stud walls.
- NorthernSTAR worked on air sealing and foundation insulation retrofits.
- PHI worked on extended plate and beam panelized walls.
- PHI builders prepared guide for high-performance walls.
- NREL worked on moisture properties of residential wall assemblies.

BASC Content
N/A (Design content not included in BASC).

FY14–FY16 Publications

- J. Dentz and D. Podorson, ARIES, "Evaluating an Exterior Insulation and Finish System for Deep Energy Retrofits," January 2014.
- E. Levy, B. Kessler, M. Mullens, and P. Rath, ARIES, "Advanced Envelope Research for Factory Built Housing, Phase 3—Design Development and Prototyping," January 2014.
- E. Levy, M. Mullens, and P. Rath, ARIES, "Advanced Envelope Research for Factory Built Housing, Phase 3—Whole-House Prototyping," April 2014.
- J. Woods, J. Winkler, D. Christensen, and E. Hancock, "Using Whole-House Field Tests to Empirically Derive Moisture Buffering Model Inputs," August 2014.
- D. Prahl and M. Shaffer, IBACOS, "Moisture Risk in Unvented Attics Due to Air Leakage Paths," November 2014.
- C. Ojcyzk, NorthernSTAR, "Cost Analysis of Roof-Only Air Sealing and Insulation Strategies on 1 ½-Story Homes in Cold Climates," December 2014.
- K. Ueno, BSC, "Monitoring of Double-Stud Wall Moisture Conditions in the Northeast," March 2015.
- L. Goldberg and A. Harmon, NorthernSTAR, "Cold Climate Foundation Retrofit Experimental Hygrothermal Performance: Cloquet Residential Research Facility Laboratory Results," April 2015.
- S. Musunuru and B. Pettit, BSC, "Measure Guideline: Deep Energy Enclosure Retrofit for Interior Insulation of Masonry Walls," April 2015.
- P. Huelman, L. Goldberg, and R. Jacobson, NorthernSTAR, "Innovative Retrofit Insulation Strategies for Concrete Masonry Foundations," May 2015.
- H. Loomis and B. Pettit, BSC, "Measure Guideline: Deep Energy Enclosure Retrofit for Zero Energy Ready House Flat Roofs," May 2015.
- H. Loomis and B. Pettit, BSC, "Measure Guideline: Deep Energy Enclosure Retrofit for Double-Stud Walls," June 2015.
- C. Harrington and D. Springer, ARBI, "Field Trial of an Aerosol-Based Enclosure Sealing Technology," September 2015.
- K. Ueno, BSC, "Analysis of Joist Masonry Moisture Content Monitoring," October 2015.
- J. Lstiburek, K. Ueno, and S. Musunuru, BSC, "Strategy Guideline: Modeling Enclosure Design in Above-Grade Walls," February 2016.
- L. Arena, CARB, "Construction Guidelines for High R-Value Walls without Exterior Rigid Insulation," March 2016.
- J. Lstiburek, K. Ueno, and S. Musunuru, BSC, "Modeling Enclosure Design in Above Grade Walls," March 2016.

C.2 Optimal Comfort Systems for Low-Load Houses (SC2-5)

Optimal comfort systems for low-load houses that are affordable, easy to install in new homes or retrofits, have negligible distribution losses, operate efficiently at partial load, and provide reliable control of temperature and humidity (i.e., comfort).

C.2.1 In 2015, demonstrate market-ready space-conditioning equipment that delivers 30% cooling-energy savings relative to current forced-air seasonal energy efficiency ratio (SEER) 16 systems while delivering Building America best-practice ventilation and providing adequate moisture control to ensure enclosure durability and occupant comfort in new and existing low-load homes.

Significance

Although equipment with SEER > 16 currently exists, builders and remodelers achieving 30% whole-house energy savings have found SEER 16 to represent the upper limit of cost-effectiveness. Most existing homes do not ventilate to the increased ventilation rates proposed by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 62.2, nor do they employ supplemental dehumidification—which would increase costs. To achieve 50% whole-house energy savings, more cost-effective higher efficiency equipment, systems, and integrated strategies are required. Sensible capacities < 1.5 tons and sensible heat ratios less than 75% may also be required.

FY14–FY16 Progress

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 criteria remains.

- BA-PIRC evaluated a SEER 21 heat pump.
- BA-PIRC worked on ductless heat pumps in affordable housing.
- BSC evaluated supplemental dehumidification in warm-humid and hot-humid climates.
- Multiple teams performed a field evaluation of ductless mini-split systems.
- Pacific Northwest National Laboratory hosted a low-load heating, ventilating, and air-conditioning system (HVAC) expert meeting hosted by in January 2014 (for labs and multiple teams).
- NREL worked on mini-split and variable-speed heat pump characterization.
- NREL worked on supplemental dehumidification equipment sizing and moisture modeling.

BASC Content

- Guides
  - Whole-Building Delivered Ventilation
  - Continuously Operating Ventilation and Exhaust Fans
  - Back-Draft Dampers at Shared Common Exhaust Duct
  - Ventilation Air Inlet Locations.

FY14–FY16 Publications

- Burdick, IBACOS, "Comfort and HVAC Performance for a New Construction Occupied Test House in Roseville, California," October 2013.
- P. Kerrigan, BSC, "Heating, Ventilation, and Air Conditioning Design Strategy for a Hot-Humid Production Builder," March 2014.
- D. Parker, J. Kono, R. Vieira, P. Fairey III, J. Sherwin, C. Withers Jr., D. Hoak, and D. Beal, BA-PIRC, "Flexible Residential Test Facility: Impact of Infiltration and Ventilation on Measured Cooling Season Energy and Moisture Levels," May 2014.
- P. Kerrigan and P. Norton, BSC, "Evaluation of the Performance of Houses With and Without Supplemental Dehumidification in a Hot-Humid Climate," October 2014.
- Rudd, BSC, "Measure Guideline: Supplemental Dehumidification in Warm-Humid Climates," October 2014.
- Booten, C. Christensen, and J. Winkler, "Energy Impacts of Oversized Residential Air Conditioners—Simulation Study of Retrofit Sequence Impacts," NREL-TP-5500-60801, November 2014.
- S. Puttagunta, CARB, "Low-Load Space-Conditioning Needs Assessment," May 2015.
- K. Sutherland, D. Parker, E. Martin, D. Chaser, and B. Amos, BA-PIRC, "Phased Retrofits in Existing Homes in Florida Phase II: Shallow Plus Retrofits," February 2016.

FY14–FY16 Webinars

- High Performance Space Conditioning Systems, Part I, October 23, 2014
- High Performance Space Conditioning Systems, Part II, November 18, 2014
- High Performance HVAC Systems, Part II: Low-Load HVAC Systems for Single and Multifamily Applications, November 18, 2015.

C.2.2 In 2015, document new-construction, community-scale adoption of space-conditioning distribution system solutions that ensure negligible conductive, radiant, and leakage losses in new and existing low-load homes.

Significance

Interior ducts or ductless systems (and equivalent hydronic distribution solutions) are a feature of Zero Energy Ready Homes (ZERHs) and are expected to be an integral component of a 50% whole-house energy-savings package. ZERHs are already laying the groundwork for the adoption of such solutions.

FY14 Progress

Building America teams and laboratories conducted research on distribution implications of mini-splits and other low-load distribution approaches.

- ARBI studied innovative high-performance attic duct strategy; results support the Title 24 code change proposal for 2016.
- ARBI investigated minimal distribution system configurations.

- BA-PIRC worked on designing and applying interior duct methods and repairing ducts in existing homes.
- BA-PIRC worked on foam insulation of ductwork in attics.
- CARB worked on buried and/or encapsulated ducts.
- IBACOS investigated minimal distribution system configurations.
- IBACOS provided guidance on the code-compliant use of plastic components in thermal (i.e., nonventilated) air distribution systems.
- IBACOS worked on the impact of energy-efficiency upgrades on room air distribution.
- NREL researched zoned HVAC equipment that does not require distribution.
- NREL worked on strategies for multi-zoning homes with central systems.
- PHI evaluated buried ducts in a hot-humid climate.

BASC Content

- Guides
    - Encapsulated Ducts
    - Ducts Buried in Attic Insulation
    - Ducts Buried in Attic Insulation and Encapsulated
    - HVAC Ducts Shall Not Be Run within Exterior Walls
    - Injected Spray Sealant for Existing HVAC Ducts
    - Building Cavities Not Used as Supply or Return Ducts
    - Ducts in Dropped Ceilings
    - Duct in Raised Ceiling Sections.
- Code Compliance Brief
    - Buried Ducts in Vented Attics in Hot-humid and Mixed-humid Climate Zones**.**

FY14–FY16 Publications

- R. Beach, D. Prahl, and R. Lange, IBACOS, "Computational Fluid Dynamics Analysis of Flexible Duct Junction Box Design," December 2013.
- D. Stecher and A. Poerschke, IBACOS, "Simplified Space Conditioning in Low-Load Homes: Results from Fresno, California Retrofit Unoccupied Test House," February 2014.
- J. Dentz, F. Conlin, P. Holloway, D. Podorson, and K. Varshney, ARIES, "Air Distribution Retrofit Strategies for Affordable Housing," March 2014.
- Poerschke and D. Stecher, IBACOS, "Simplified Space Conditioning in Low-Load Homes: Results from Pittsburgh, Pennsylvania, New Construction Unoccupied Test House," June 2014.
- Burdick, IBACOS, "Distribution and Room Air Mixing Risks to Retrofitted Homes," December 2014.
- M. Hoeschele, R. Chitwood, A German, and E. Weitzel, ARBI, "High-Performance Ducts in Hot-Dry Climates," July 2015.
- Poerschke and R. Beach, IBACOS, "Comfort in High-Performance Homes in a Hot-Humid Climate," January 2016.

- D. Mallay, PHI, "Compact Buried Ducts in a Hot-Humid Climate House," January 2016.
- Poerschke, IBACOS; and A. Rudd, ABT Systems, "Performance Analysis of a Modular Small-Diameter Air Distribution System," March 2016.
- Poerschke, R. Beach, and T. Beggs, IBACOS, "Comparative Cooling Season Performance of Air Distribution Systems in Multistory Townhomes," 2016.
- Withers, J. Cummings, and B. Nigusse, BA-PIRC, "Cooling and Heating Seasonal Energy and Peak Demand Impacts of Improved Duct Insulation on Fixed Capacity (SEER 13) and Variable Capacity (SEER 22) Heat Pumps," September 2016.

FY14–FY16 Webinar

- Design Strategies for Ducts in Conditioned Spaces, March 20, 2014.

C.2.3 In 2015, demonstrate market-ready space-conditioning equipment for low-load homes that delivers 10%–20% heating energy savings compared to current best practices in new homes.

Significance

Current industry guidelines for heat pump sizing and transition point temperatures often result in excessive use of auxiliary strip heat in cold climates. Stakeholders need guidance on climate appropriateness, system design, component selection, and risk avoidance for heat pumps and "combo" heating and water heating systems.

FY14–FY16 Progress

Multiple Building America teams worked with cold-climate heat pump sizing. Transition point temperature optimization for dual-fuel heat pumps was also investigated. Multiple Building America teams and laboratories researched the technical effectiveness of a variety of strategies:

- ARBI worked on air-to-water heat pumps in low-load homes.
- ARIES evaluated thermostatic radiator valves for multifamily buildings.
- ARIES studied boiler control replacements for multifamily buildings.
- BA-PIRC studied the sizing of fixed-capacity and variable-capacity heat pumps.
- BSC performed long-term monitoring of mini-split heat pumps.
- CARB worked on inverter-driven air-source heat pumps in cold climates.
- IBACOS studied the heating system sizing impact of exterior insulation retrofits.
- IBACOS evaluated cold-climate heat pumps.
- NorthernSTAR studied combined heating and hot water upgrades in existing homes.
- PARR worked on gas furnace performance.
- Multiple teams studied combined heating and hot water systems.

BASC Content

- Guides
    - ECM Air Handler Fans
    - Evaporative Cooling
    - Geothermal Heat Pumps

- Ground-Source Heat Pump Foundation Heat Exchanger (FHX)
- Mini-Split (Ductless) Heat Pumps
- Condensing Boilers
- Traditional Split Heat Pumps.

FY14–FY16 Publications

- L. Arena and O. Faakye, CARB, "Optimizing Hydronic System Performance in Residential Applications," October 2013.
- N. Mittereder and A. Poerschke, IBACOS, "Ground Source Heat Pump Sub-Slab Heat Exchange Loop Performance in a Cold Climate," November 2013.
- C. Backman, A. German, B. Dakin, and D. Springer, ARBI, "Air-To-Water Heat Pumps with Radiant Delivery in Low-Load Homes," December 2013.
- Building America Case Study, NorthernSTAR, "Retrofit Integrated Space and Water Heating: Field Assessment," May 2014.
- R. Ruch, P. Ludwig, and T. Maurer, PARR, "Balancing Hydronic Systems in Multifamily Buildings," July 2014.
- J. Dentz and E. Ansanelli, ARIES, "Thermostatic Radiator Valve Replacement," January 2015.
- L. Brand, S. Yee, and J. Baker, PARR, "Improving Gas Furnace Performance: A Field and Laboratory Study at End of Life," February 2015.
- Herk and A. Poerschke, IBACOS, "Exterior Insulation Implications for Heating and Cooling Systems in Cold Climates," April 2015.
- L. Arena, CARB, "Analyzing Design Heating Loads in Multifamily Buildings," June 2015.
- J. Cummings, C. Withers, and J. Kono, BA-PIRC, "Cooling and Heating Season Impacts of Right-Sizing of Fixed- and Variable-Capacity Heat Pumps With Attic and Indoor Ductwork," June 2015.
- K. Ueno and H. Loomis, BSC, "Long-Term Monitoring of Mini-Split Ductless Heat Pumps in the Northeast," June 2015.
- J. Williamson and R. Aldrich, CARB, "Field Performance of Inverter-Driven Heat Pumps in Cold Climates," August 2015.
- M. Lubliner, L. Howard, D. Hales, R. Kunkle, A. Gordon, and M. Spencer, BA-PIRC, "Performance and Costs of Ductless Heat Pumps in Marine Climate High-Performance Homes – Habitat for Humanity The Woods," February 2016.
- NorthernSTAR, "Combined Space and Water Heating – Measure Guideline: Installation and Optimization," 2016.

FY14–FY16 Webinar

- New Construction Hybrid-Ductless Heat Pumps Study: Resistance is Futile, June 24, 2015.

C.2.4 In 2015, demonstrate systems and strategies that achieve 10%–15% space-conditioning energy savings by upgrading or supplementing existing heating/cooling equipment and distribution for existing homes where HVAC change-out is not cost-effective.

Significance

Achieving 50% savings in retrofit typically requires HVAC change-out with current best practice for new construction. Retrofit opportunities of 50% energy savings are limited when existing HVAC equipment is not at end of life. Diagnostic procedures and guidelines are needed to assess equipment component (fans, fan flow, coils, etc.) performance.

FY14–FY16 Progress

- ARBI worked on air-conditioner precooling strategies in homes.
- Limited work occurred among Building America teams to investigate the installation of ductless heat pumps without removing existing central systems.
- NorthernSTAR, PARR, and PHI worked on improved duct leakage testing.
- PARR performed a lab and field study on furnaces, the impacts of installation variation on efficiency, and efficiency improvement opportunity for tune-ups in the field (6.4%).

FY14–FY16 Publications

- R. Aldrich and J. Williamson, CARB, "Evaluation of Retrofit Variable-Speed Furnace Fan Motors," January 2014.
- J. Dentz, D. Podorson, and K. Varshney, ARIES, "Mini-Split Heat Pumps Multifamily Retrofit Feasibility Study," May 2014.
- J. Dentz, H. Henderson, and K. Varshney, ARIES, "Hydronic Heating Retrofits for Low-Rise Multifamily Buildings: Boiler Control Replacement and Monitoring," September 2014.
- A. German and M. Hoeschele, ARBI, "Residential Mechanical Precooling," December 2014.

FY14–FY16 Webinar

- Retrofitting Central Space Conditioning Strategies for Multifamily Buildings, July 16, 2014.

C.3 High-Performance Ventilation Systems and Indoor Air Quality Strategies (SC1)

High-performance ventilation systems and indoor air quality strategies that are affordable and easy to install in new homes or retrofits effectively control fresh outdoor air delivery and occupant exposure to pollutants of concern without adversely affecting thermal comfort or indoor relative humidity, and include automatic failure-mode diagnostics.

C.3.1 In 2015, document Building America Best Practice Guidelines for effective, reliable, and climate-specific whole-house mechanical ventilation systems for new and existing homes.

Significance

A majority of production-scale homes currently achieving 30% whole-house energy savings are not ventilated according to the current version of ASHRAE 62.2. In moving from 30% to 50% whole-house energy savings, it is important to ensure adequate ventilation rates to control odors and remove moisture from point sources such as bathrooms, laundries, and kitchens.

FY14–FY16 Progress

Lawrence Berkeley National Laboratory, NREL, and Pacific Northwest National Laboratory coordinated on developing best-practice guidelines for residential mechanical ventilation. NREL also collected and analyzed temperature and relative humidity data from multiple test houses in various climates to evaluate how ventilation affects moisture removal, enclosure drying, and occupant comfort. Multiple Building America teams and laboratories researched the technical effectiveness of a variety of strategies:

- BA-PIRC worked on ventilation management with mini-splits in hot-humid climates.
- BA-PIRC and PARR worked on temperature-based ventilation control.
- BSC provided ventilation guidance for high-performance residential new construction.
- BSC worked on air leakage between the garage and living space.
- CARB worked on best practices for ventilation in multifamily new construction.
- CARB worked on bath exhaust fan design.
- CARB worked on sealed crawlspaces with integrated whole-house ventilation (with NREL field-test support).
- NorthernSTAR and PARR worked on combustion safety of vented gas appliances.
- PARR worked on outdoor temperature-controlled ventilation.

BASC Content

- Guides
    - Whole-Building Delivered Ventilation
    - Continuously Operating Ventilation and Exhaust Fans
    - Back-Draft Dampers at Shared Common Exhaust Duct
    - Ventilation Air Inlet Locations
- Case Study
    - Development of an Outdoor Temperature Based Control Algorithm for Residential Mechanical Ventilation Control
- Code Compliance Brief
    - Bathroom Fan Ratings

FY14–FY16 Publications

- E. Martin, BA-PIRC, “Impact of Residential Mechanical Ventilation on Energy Cost and Humidity Control,” January 2014.
- R. Aldrich, CARB, “Measure Guideline: Selecting Ventilation Systems for Existing Homes,” February 2014.
- Rudd and D. Bergey, BSC, “Ventilation System Effectiveness and Tested Indoor Air Quality Impacts,” February 2014.

- L. Brand, PARR, "Measure Guideline: Combustion Safety for Natural Draft Appliances Using Indoor Air," April 2014.
- J. Fitzgerald and D. Bohac, NorthernSTAR, "Measure Guideline: Combustion Safety for Natural Draft Appliances Through Appliance Zone Isolation," April 2014.
- S. Maxwell, D. Berger, and M. Zuluaga, CARB, "Evaluation of Ventilation Strategies in New Construction Multifamily Buildings," July 2014.
- Rudd, BSC, "Air Leakage and Air Transfer Between Garage and Living Space," September 2014.
- S. Klocke, O. Faakye, and S. Puttagunta, CARB, "Challenges of Achieving 2012 IECC Air Sealing Requirements in Multifamily Dwellings," October 2014.
- Rudd and D. Prahl, IBACOS, "Duct System Flammability and Air Sealing Fire Separation Assemblies in the International Residential Code," December 2014.
- S. Puttagunta and O. Faakye, CARB, "Interaction of Unvented Attics With Living Space in Three Northeast Homes," February 2015.
- S. Maxwell, D. Berger, and C. Harrington, CARB, "Apartment Compartmentalization With an Aerosol-Based Sealing Process," March 2015.
- O. Faakye and D. Griffiths, CARB, "Multifamily Envelope Leakage Model," May 2015.
- W. Zoeller, J. Williamson, and S. Puttagunta, CARB, "Sealed Crawl Spaces with Integrated Whole-House Ventilation in a Cold Climate," July 2015.
- D. Berger and R. Neri, CARB, "Measure Guideline: Passive Vents," February 2016.
- S. Maxwell. D. Berger and M. Zuluaga, CARB, "Evaluation of Passive Vents in New Construction Multifamily Buildings," February 2016.
- BA-PIRC, "Energy Efficient Management of Mechanical Ventilation and Relative Humidity in Hot Humid Climates," 2016.
- BA-PIRC, "Flexible Residential Test Facility: Impact of Infiltration and Ventilation on Measured Cooling Season Energy and Moisture Levels," July 2016.
- BA-PIRC, "Comparative Performance of Two Ventilation Strategies in a Hot Humid Climate," Forthcoming.
- BA-PIRC, "Laboratory Evaluation of Energy Recovery Ventilators," July 2016.

FY14–FY16 Webinars

- Multifamily Ventilation Strategies and Compartmentalization Requirements, September 24, 2014
- Ventilation Strategies for High-Performance Homes, Part I: Application-Specific Ventilation Guidance, August 26, 2015.

C.4 Domestic Hot Water Systems

Domestic hot water systems that are affordable, easy to install in new homes or retrofits, and offer optimal efficiency and negligible storage and distribution losses.

C.4.1 In 2015, use data-driven analysis to provide heat pump water heater (HPWH) manufacturers with the necessary data to optimize product design from a systems integration perspective. Achieve 50% energy savings relative to electric storage water heaters in preferred applications. Deliver best-practices report with quality assurance guidelines to utility partners that provide confidence and ensure that average performance targets will be met in both new and existing homes.

Significance

HPWHs offer the technical potential to be one of the primary contributors to the 50% savings goal in homes that currently have electric storage water heaters. This activity was closely coordinated with the relevant space-conditioning research.

FY14–FY16 Progress

Multiple Building America teams and laboratories researched the technical effectiveness of a variety of strategies:

- ARBI worked on central HPWHs for student apartment buildings.
- BA-PIRC worked on comparing the in situ performance of HPWHs to other efficient water heaters under the same loads and weather conditions.
- BA-PIRC worked on ducting supply and return air to HPWHs.
- BARA and CARB jointly worked on HPWH installation and performance in Florida.
- CARB worked on HPWH field performance in the northeastern United States.
- PHI worked on ducting strategies for HPWHs in the southeastern United States.
- NREL worked with the Sacramento Municipal Utility District on HPWH and solar water heating as retrofit measures in existing homes.
- NREL and the Florida Solar Energy Center worked on photovoltaic-driven HPWHs.

BASC Content

- Guide
    - Heat Pump Water Heaters
- Case Studies
    - Technology Solutions Case Study: Heat Pump Water Heater Retrofit
    - Technology Solutions Case Study: Performance of a Heat Pump Water Heater in the Hot-Humid Climate, Windermere, Florida
    - Technology Solutions Case Study: Field Performance of Heat Pump Water Heaters in the Northeast, Massachusetts and Rhode Island.
- Code Compliance Brief
    - Heat Pump Water Heaters

FY14–FY16 Publications

- J. Williamson and S. Puttagunta, CARB, "Systems Evaluation at the Cool Energy House," October 2013.

- German, C. Bell, B. Dakin, and M. Hoeschele, ARBI, "West Village Student Housing Phase I: Apartment Monitoring and Evaluation," June 2014.
- Sparn, K. Hudon, L. Earle, C. Booten, and P.C. Tabares-Velasco, "Greenbuilt Retrofit Test House: Final Report," June 2014.
- Shapiro and S. Puttagunta, CARB, "Field Performance of Heat Pump Water Heaters in the Northeast," February 2016.
- M. Sweet, P. Francisco, and S. Roberts, Southface Energy Institute, "Heat Pump Water Heater Ducting Strategies with Encapsulated Attics in Climate Zones 2 and 4," May 2016.
- BA-PIRC, "Side-by-Side Testing of Water Heating Systems: Results from the 2013 - 2014 Evaluation," 2016.
- ARBI, "Indoor Heat Pump Water Heater Evaluation in a Hot-Dry Climate," 2016.
- BA-PIRC, "Effect of Ducted HPWH on Space Conditioning and Water Heating Energy Use – Central Florida Lab Home," 2016.

FY14–FY16 Webinar

- Central Multifamily Water Heating Systems, January 21, 2015.

C.4.2 In 2015, enable high-efficiency, closed-combustion gas water heater replacements that utilize existing home gas system infrastructure (1/2" gas line) by developing a > 0.82 energy factor (or > 90% thermal efficiency) solution with < 100 kBtu/h input capacity.

Significance

The vast majority of the approximately 8 million residential water heaters sold annually are for the replacement market. The current nature of the replacement market is such that most replacements are of an emergency nature, which for natural gas systems precludes the installation of available high-efficiency, high-capacity tankless units due to the need for larger gas lines. With demonstrated tankless gas savings of 30%–40%, the elimination of tankless water heaters as a cost-effective retrofit option limits high-efficiency options to the incremental improvements (~10%) available in storage models that have higher energy factors. The development of efficient "hybrid" technologies (which combine tankless with a small storage volume) would allow for high-efficiency, combustion-safe products to be installed more economically without gas-line modifications.

FY14–FY16 Progress

- NorthernSTAR work on hybrid gas water heaters.

BASC Content

- Guide
  - Direct Vent Equipment, March 2016

FY14–FY16 Publication

- NorthernSTAR, "Simple Retrofit High Efficiency Natural Gas Water Heater Field Test," 2016.

C.4.3 In 2015, document viable strategies for high-efficiency, single-family new home water heating systems that reduce energy use by 35%–40% for natural gas and 50%–60% for electric compared to conventional water heating system practice. Distribution system improvements will provide at least 10% reduction in water heater recovery load.

Significance

Significant opportunities exist in new homes to improve water heating system performance, beyond only installing a water heater with a higher energy factor. Savings approaching 60% are attainable for electric storage water heater base case scenarios, with slightly lower expected savings for gas systems. A holistic approach beginning with house design (layout of hot water use points and water heater location) and efficient fixture/appliance selection will contribute to reduced distribution losses, reduced energy use, and greater customer satisfaction due to improved hot water delivery.

FY14–FY16 Progress

Building America teams worked on a variety of strategies:

- ARBI worked on high-efficiency water heating systems.
- ARIES worked on residential hot water loads.
- BA-PIRC worked on the in situ performance of efficient water heaters under the same loads.

BASC Content

- Landing page
  - Water Heaters**.**

FY14–FY16 Publications

- H. Henderson and J. Wade, ARIES, "Disaggregating Hot Water Use and Predicting Hot Water Waste in Five Test Homes," April 2014.
- M. Hoeschele, D. Springer, A. German, J. Staller, and Y. Zhang, ARBI, "Strategy Guideline: Proper Water Heater Selection," April 2015.

C.4.4 In 2015, adopt climate-based Building America system design and implementation guidelines for combined heating and hot water systems relative to stand-alone water heating and space-conditioning technology options in new and existing homes. Develop combined system solutions that minimize parasitic losses, deliver 15% savings relative to conventional gas benchmark systems, and identify preferred delivery options for different loads and climates. Enable builder and retrofit partners by delivering best-practice installation guidelines.

Significance
Findings from NorthernSTAR's combined hydronic field-test project suggested 10%–15% savings compared to the base case (80% annual fuel utilization efficiency furnace, minimum efficiency gas water heater) at a cost equivalent to a conventional furnace and water heater retrofit. When components reach the same commodity status as furnaces, these systems could advance combined hydronic systems from a cost-neutral to a negative cost alternative while also contributing to the Building America energy-savings goal.

FY14–FY16 Progress
Building America teams researched a variety of strategies, including:

- NorthernSTAR worked on improving the performance of combination space and water heating systems. Control system improvements with 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.
- PARR worked on integrated space- and water heating systems.

BASC Content

- Guide
    - Integrated Heating and Hot Water with Tankless Gas or Electric Water Heating.
- Case studies
    - Technology Solutions Case Study: Advanced Controls Improve Performance of Combination Space and Water Heating Systems, Minneapolis, Minnesota**.**

FY14–FY16 Publications

- B. Schoenbauer, D. Bohac, and P. Huelman, NorthernSTAR, "Combined Space and Water Heating: Next Steps to Improved Performance," July 2016.
- NorthernSTAR, "Combined Space and Water Heating – Measure Guideline: Installation and Optimization," 2016.
- PARR, "Evaluation of Technical and Utility Programmatic Challenges with Residential Forced-air Integrated Space/Water Heat Systems," July 2016.

C.4.5 By 2015, develop and demonstrate multifamily hot water recirculation control strategies that reduce average recirculation losses by 15% compared to continuously operating recirculation systems in new and existing homes.

Significance
Most larger multifamily buildings with central water heating utilize continuous hot water recirculation, which can result in a more than 50% increase in water heating load. Advanced demand-based control systems have entered the market that can theoretically reduce recirculation losses by limiting pump operation. Limited data is available on performance, so Building America research can play a vital role in assessing the technology (and customer satisfaction) and recommending control changes to improve performance.

FY14–FY16 Progress
Building America teams researched the technical effectiveness of a variety of strategies, including:

- ARBI worked on using solar water heating to reduce recirculation losses in multifamily buildings.
- ARIES worked on control strategies for central domestic hot water systems.

FY14–FY16 Publications

- D. Springer, M. Seitzler, C. Backman, and E. Weitzel, ARBI, "Using Solar Hot Water to Address Piping Heat Losses in Multifamily Buildings," October 2015.
- J. Dentz, E. Ansanelli, H. Henderson, and K. Varshney, ARIES, "Control Strategies to Reduce the Energy Consumption of Central Domestic Hot Water Systems," June 2016.

FY14–FY16 Webinar

- Central Multifamily Water Heating Systems, January 21, 2015.

C.4.6 In 2015, evaluate the reliability and energy savings provided by low-cost solar water heating systems in new and existing homes with the goal of achieving 35%–40% energy savings vs. conventional water heating systems in partnership with the DOE emerging technology program.

Significance
Solar thermal water heating can be applied in climates that do not favor heat pump water heaters and can make a significant contribution to the 50% savings goal. Current factors limiting solar thermal growth include high first costs, excessive system complexity, low natural gas prices, and the recent emergence of HPWHs as a primary competitor for electric water heating sites.

FY14–FY16 Progress
Building America teams and laboratories researched a variety of strategies:

- ARBI worked on solar water heating (SWH) systems in multifamily buildings.
- CARB worked on SWH systems in ZERHs.
- CARB worked on SWH systems in multifamily buildings.

BASC Content

- Landing page
  - Solar Water Heating.

FY14–FY16 Publications

- J. Burch, T. Merrigan, NREL; R, Rhodes, J. Rhodes, Rhotech Solar; A. Patnode, J. Thorton, Thermal Energy System Specialists, "Advanced Low-cost Solar Water Heating R&D: Performance and Cost-Benefit Analysis of an Ultra-low-cost Solar Water Heater," September 2014 (DOE/NREL internal only).
- R. Aldrich, CARB, "Indirect Solar Water Heating in Single-Family, Zero Energy Ready Homes," February 2016.

- R. Aldrich and J. Williamson, CARB, "Role of Solar Water Heating in Multifamily Zero Energy Homes," April 2016.

C.5 Automated Home Energy Management

Automated home energy management systems with effective whole-house control strategies that are validated, reliable, affordable, and easy to install.

C.5.1 By 2015, validate effective whole-house control strategies that maximize comfort and energy savings in new and existing homes. Evaluate reliable and effective automation strategies. Develop measurement methods to collect the necessary data required to identify a control opportunity for each strategy, and establish control system requirements to effectively capture energy-saving opportunities.

Significance

This work can complement and extend work by other stakeholders by focusing on defining the requirements and incremental savings associated with the development of effective and automated whole-house energy management systems. As homes become more efficient and there are fewer easy targets for improving energy efficiency, the next step in further reducing energy use is to have the systems in the house work together cohesively. Effective control strategies, enabled by either new sensors or existing sensors, ensure that all the systems in the home are working as intended and are all working together to reduce overall energy consumption.

FY14–FY16 Progress

- CARB worked on validating the energy savings of ZERHs in cold climates.

FY14–FY16 Publication

- J. Williamson and S. Puttagunta, CARB, "Validating Savings Claims of Cold Climate Zero Energy Ready Homes," June 2015.

C.5.2 By 2015, identify and break down barriers to the market adoption of technologically sound automated home energy management (AHEM) solutions for new and existing homes. The primary Building America role here is to support the development of AHEM taxonomy to minimize market confusion and standardize stakeholder understanding of product functionality.

Significance

AHEM has been a promising field of new development for several years, with numerous companies adding products to the space; however, with the rapid pace of development, few people outside of the industry can keep up. This has meant that consumers have little to no idea what AHEM is, what sort of products are being developed, and why they should care. Creating a clear taxonomy of available products and encouraging consistent terminology within the

Building America community helps AHEM adoption within Building America, which will eventually help improve adoption in the market as a whole.

C.5.3 *In 2015, determine the opportunities to use controls to curb inadvertent energy use in homes, and quantify the energy that can be saved in new and existing homes. Compile inadvertent energy use results for HVAC, lighting, and miscellaneous electric loads. This defines the upper limit on the incremental energy-savings potential for a comprehensive AHEM system without taking into account demand-response controls. Use these results to prioritize the development of AHEM solutions. Also use the results for return-on-investment calculations for specific AHEM solutions.*

Significance

The opportunities for saving energy with AHEM are not well understood. Occupant behavior plays a big role in the potential of AHEM, but before the behavioral aspects can be taken into account, the energy-savings potential for different systems must be assessed. The three main systems where AHEM is expected to be applicable, at least initially, are HVAC, lighting, and miscellaneous electric loads. Determining the potential savings in each area defines the upper limit for the savings potential of AHEM. From there, field trials with AHEM systems and occupants help define the behavioral impact on those savings.

FY14–FY16 Progress

- NREL performed collaborative work on plug-load monitoring.
- NREL worked on advanced power strips.

FY14–FY16 Publication

- B. Auchter, D. Cautley, D. Ahl, Energy Center of Wisconsin; L. Earle, and X. Jin, NREL, "Field Trial of a Low-Cost, Distributed Plug Load Monitoring System," March 2014.

C.5.4 *In 2015, analyze control strategies for energy impact during demand-response events, and evaluate related utility cost and energy savings in new and existing homes. Use those results and results from appliance tests to determine the energy impact for utilities and for consumers. Use several sample pricing plans to determine the cost impact to consumers. Use results from field tests and modeling of precooling events to determine the energy impact on consumer and utility for typical peak-pricing schedules. Develop methodology for optimizing precooling schedule (duration, set point, start time) for maximum energy savings and peak reduction without sacrificing comfort. The precooling schedule would also need to save consumers money, so this sort of analysis would help utilities design their time-of-use schedules and defend those schedules to their public utility commissions.*

Significance

Utilities are interested in AHEM products because of their potential to advance demand-response programs. As advanced metering infrastructure (AMI) meters becomes even more ubiquitous and utilities begin to implement time-of-use pricing, demand-response capabilities and ways to reduce peak electric usage will become even more important. However, the energy-savings potential of different demand-response strategies is not well understood. Testing demand-response-enabled appliances helps define their potential. Utility bill savings from effective demand response helps offset costs of AHEM systems and other Building America advanced efficiency measures, such as the incremental cost for the demand-response appliances.

FY14–FY16 Progress

- ARBI worked on precooling strategies for homes
- NREL worked on testing demand-response-enabled appliances.
- NREL and ARBI worked on modifying the Building Energy Optimization® software to include demand response for existing California homes.

FY14–FY16 Publications

- B. Sparn, X. Jin, and L. Earle, NREL, "Laboratory Testing of Demand-Response Enabled Household Appliances," October 2013.
- C. Christensen, S. Horowitz, J, Maguire, P. Tabares-Velasco, NREL; D. Springer, P, Coates, C. Bell, Davis Energy Group; S. Price, P. Sreedharan, K. Pickrell, Energy + Environmental Economics, "BEopt-CA (Ex): A Tool for Optimal Integration of EE, DR and PV in Existing California Homes," April 2014.
- German and M. Hoeschele, ARBI, "Residential Mechanical Precooling," December 2014.

Appendix D: Building America Industry Teams

The Building America Program teams are consortia comprising building scientists, consultants, academics, engineers, builders, architects, manufacturers, and others that represent the residential industry among various stakeholder communities and regions. The following table provides the names, corresponding acronyms, web links, and brief descriptions of each team. The teams are critical to the success of Building America research, and they do much of the heavy lifting needed to successfully prove innovative solutions to a risk-averse building community.

Building America Team	Description
Advanced Residential Integrated Energy Solutions (ARIES)	The Levy Partnership, Inc. (New York, New York): Accelerates the development and commercialization of innovative and cost-effective approaches for dramatically reducing energy use of the nation's affordable housing, both existing and new. The team is broadly representative, including more than 50 organizations drawing from all stakeholders in the affordable housing community.
Alliance for Residential Building Innovation (ARBI)	Davis Energy Group (Davis, California): Evaluates and demonstrates innovative technologies and residential construction techniques and deployment strategies. ARBI combines research on specific technologies with deployment activities in both the new and existing home sectors, including research on what motivates homeowners to invest in home energy upgrades, and strategic approaches to reducing costs through efficient home evaluation and bulk purchasing
Building America Research Alliance (BARA)	Building Media, Inc. (Kent, Washington): Combines technical expertise and real-world construction experience with communications and outreach expertise to bridge the gap between research and market integration. BARA focuses exclusively on the home renovation and retrofit market, with emphasis on developing, deploying and promoting technically sound, cost-effective measures to radically improve home performance.

Building America Team	Description
Building America Partnership for Improved Residential Construction (BA-PIRC)	Florida Solar Energy Center (FSEC), University of Central Florida (Orlando, Florida): applies practical research expertise to develop real-world solutions for industry, utility partners, and housing manufacturers that achieve significant energy and cost savings in new and existing homes in hot-humid and marine climates. With access to several research facilities—the Manufactured Housing Laboratory, Hot Water Systems Laboratory, and Flexible Research Test Facility— BA-PIRC works with industry partners to design, test, and monitor energy efficiency, indoor air quality (IAQ), and building durability strategies.
Building Energy Efficient Homes for America (BEEHA)	University of Nebraska-Lincoln (Lincoln, Nebraska) and University of Florida (Gainesville, Florida): Explores and delivers systems-engineered solutions for new and existing homes using simulation and building systems research laboratories. In addition to achieving energy savings, special effort is placed on cost-effectiveness, scalable deployment, and marketability of each solution.
Building Industry Research Alliance (BIRA)	ConSol (Stockton, California): Working primarily on the West Coast, BIRA consists of more than 80 industry partners representing a wide variety of builders, architects, manufacturers, state energy offices, utilities, and representatives from all aspects of the new residential homebuilding industry. The team leader, ConSol, is recognized as a leader in energy-efficiency analysis, policy, and implementation.
Building Science Corporation (BSC)	BSC (Somerville, Massachusetts): Leading developer of energy efficient enclosure, ventilation and dehumidification systems for durable, high performance homes. BSC has worked with dozens of industry partners during the past decade and is responsible for the construction of more than 10,000 Building America houses and 100,000 ENERGY STAR houses (through its partner MASCO and the Environments for Living® program). BSC provides advanced solutions to technical challenges, code barriers and market requirements for new and existing homes.

Building America Team	Description
Consortium for Advanced Residential Buildings (CARB)	Steven Winter Associates, Inc. (Norwalk, Connecticut): focuses on improving new and existing homes (specializing in multifamily and affordable housing) by leveraging new technologies, underutilized technologies, and innovative market delivery strategies. The CARB team researches advanced building systems and whole house performance, and transfers that knowledge to the marketplace in order to elevate home performance industry-wide.
Habitat Cost Effective Energy Retrofit (CEER) Program Team	Dow Chemical Company (Midland, Michigan): Applies innovative retrofit technologies in partnership with Habitat for Humanity affiliates primarily in the cold and mixed-humid climate regions. The CEER team improves retrofit methodologies by validating cost-effective strategies through test homes and identifying technology gaps that must be addressed.
IBACOS	IBACOS (Pittsburgh, Pennsylvania): Develops and demonstrates integrated systems of design, procurement, construction, quality assurance, and marketing needed to transform residential building retrofits and new construction.
National Energy Leadership Corps (NELC)	Pennsylvania State University (State College, PA): Offers a new approach to home and homeowner energy audits and assessments that facilitate multiple levels of energy-efficiency measures for existing homes, including modest and low-cost improvements, extensive energy retrofits, occupant interactions, and the introduction of advanced energy controls and renewable energy technologies.
Partnership for Home Innovation (PHI)	Home Innovation Research Labs (HIRL) (Upper Marlboro, Maryland): Removes technological, regulatory, and cost barriers to building innovation by leveraging its access to remodelers and home builders. HIRL is an integrated, system-based technology advancement center.

Building America Team	Description
NorthernSTAR	University of Minnesota (St. Paul, Minnesota): Develops high-performance, energy-efficient solutions for new and existing homes in cold and severe-cold climates using a holistic integration of information and technologies across the building system, the construction/delivery system, and the market/user system.
Partnership for Advanced Residential Retrofit (PARR)	Gas Technology Institute (Des Plaines, Illinois): Applies strong experience in design, development, integration, and testing of advanced building energy equipment, components, and systems in laboratory and test house settings to improve performance, quality, and market acceptance of whole-house residential energy-efficiency retrofits in cold climates.
Partnership for Innovation in Sustainable Renovation	Fraunhofer Center for Sustainable Energy Systems (CSE) (Cambridge, Massachusetts): Deploys large-scale energy savings by integrating efficiency and renewable energy systems in new and existing homes. CSE has extensive experience in whole-house system integration research, from simulation through commissioning.

Appendix D References

- "DOE Announces $30 Million for Energy-Efficient Housing Partnerships," July 2010.
- Past Building America Projects web site, DOE.

APPENDIX

BUILDING AMERICA **FY 2016 ANNUAL REPORT**

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

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