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# Evaluation of Building America and Selected Building Energy Codes Program Activities

Final Report | February 21, 2018


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## ACKNOWLEDGEMENTS

The authors wish to thank the program managers, building science experts, builders, analysts, and other individuals who contributed their time and expertise to this evaluation. Jack Mayernik, Mark Friedrichs, and Yaw Agyeman provided project management and oversight. Eric Werling and David Cohan provided useful program information about Building America (BA) and the Building Energy Codes Program (BECP). Ed Pollock provided a historical overview of BA. Rosemarie Bartlett and program analysts at the Pacific Northwest National Laboratory (PNNL) provided valuable input for the analysis of energy code changes and code compliance. Lawrence Berkeley National Laboratory (LBNL) and PNNL provided information about BA publications for the publication citation analysis. Jeff Dowd provided review of the evaluation project. Cheryl Oros, Ed Vine, Paula Gruendling, and Greg Tassey served as external peer reviewers for the Evaluation Plan. Lori Lewis, Alan O'Connor, and Maryann Feldman were the peer reviewers for the Evaluation Report.

Industrial Economics, Incorporated (IEc) was the lead contractor for this project. Angela Vitulli and Daniel Kaufman, Principals at IEc, managed the contractor team. They were assisted by Jason Price, Nora Scherer, Dan Leistra-Jones, Sahil Gulati, Rachel Mak, Jacob Lehr, Michelle Predi, and Megan Willis-Jackson. Rosalie Ruegg (TIA Consulting) provided input on the evaluation design, and reviewed internal drafts of the Evaluation Plan and Final Report. Peter Yost (BuildingGreen) assisted with the selection of building energy practices for portfolio analysis. Robert Hendron (Eigen Energy) conducted the building energy modeling analysis. Ross Strategic conducted scoping interviews with program managers and staff.

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# EXECUTIVE SUMMARY

## OVERVIEW

This evaluation focuses on the research and development, demonstration, and market transformation activities conducted by the U.S. Department of Energy's (DOE) Building America (BA) program, and, to a lesser extent, model code development activities conducted by DOE's Building Energy Codes Program (BECP). The study centers on a retrospective cost-benefit analysis of selected BA program activities in the new residential construction market. It estimates the economic rate of return by comparing the economic benefits attributable to a subset of key practices advanced by BA to DOE's total investment in the BA program from its inception in 1994 through 2015.

BA is located in the Building Technologies Office's (BTO) Residential Buildings Integration program in DOE's Office of Energy Efficiency and Renewable Energy (EERE). BA supports research, development, and demonstration projects that aim to advance cost-effective energy efficiency technologies and practices in the new home and retrofit sectors. BA is based on a comprehensive "whole-house" approach to advancing residential energy efficiency while maintaining housing comfort and affordability. BA brings together building science experts, builders, developers, designers, manufacturers, and other segments of the housing industry to test and demonstrate housing solutions in real-world settings. These efforts aim to encourage the market's adoption of proven, energy-saving technologies and practices.

BA's applied research and demonstration projects are a key element of the program. They aim to facilitate market adoption by influencing energy efficiency provisions of voluntary above-code programs (e.g., Energy Star for Homes (ES Homes), Home Performance with Energy Star, and Zero Energy Ready Homes) and other early adopters. As early adopters validate the technical and economic feasibility of energy efficiency practices, it is expected that market acceptance of the practices will increase. Over time, the BA program aims for these practices to become standard practice, and to be adopted into model building energy codes – e.g., the International Energy Conservation Code (IECC).

In 2015, BTO initiated an independent program evaluation to study the impacts of BA and other selected investments in **new** residential efficiency. The evaluation estimates the benefits and costs of DOE's support for selected new home construction practices demonstrated by the BA program, as well as contributions to the knowledge base and energy security impacts. The evaluation also includes a separate, targeted analysis of BECP's support for the development of model energy codes.

## METHOD

This evaluation uses a combination of qualitative and quantitative methods, including: interviews with 49 individuals including building scientists, homebuilders, energy code officials, and other experts; building energy modeling; health benefits analysis; publication citation analysis; and economic analysis. Table ES-1 provides a summary of the evaluation methods used in this study. The text following the table explains each method in more detail.

TABLE ES-1. SUMMARY OF EVALUATION METHODS

| METHOD/PURPOSE | DESCRIPTION |
|---|---|
| **Scoping interviews to focus the study** | Interviewed 17 building science experts (including 8 BA team members, and 9 non-BA members from the public and private sectors) to help scope the evaluation, identify the practices to include in the evaluation, and provide input for the logic model. |
| **Building energy modeling to quantify energy savings** | Estimated energy savings from the selected practices that are the focus of this evaluation, across states and over time, using DOE's Building Optimization Model. |
| **Delphi panel to determine attribution of energy savings to BA** | Reviewed the modeled energy savings and considered the role of the BA program versus rival factors in advancing market acceptance of the four practices. The Delphi Panel included five experts with substantial BA involvement, three with negligible or indirect involvement, and one with no involvement with the program. |
| **Health benefits analysis to quantify and monetize environmental health impacts** | Used the attribution-adjusted energy impacts (estimated through energy modeling and adjusted by the Delphi Panel) to estimate changes in incidences of mortality and morbidity, and the monetary value of avoided adverse health events, resulting from reduced air emissions due to avoided electricity generation. |
| **Energy security analysis to determine displaced oil imports** | Energy security impacts were estimated for attribution-adjusted fuel oil reduction and the proportion of that consumption that would have been imported. |
| **Publication citation analysis to assess knowledge benefits** | Conducted a publication citation analysis focusing on 15 trade journals that are key information sources for homebuilders to identify the spread of ideas and practices demonstrated by BA, and to assess knowledge spillovers to the retrofit sector. |
| **Interviews with homebuilders to test and extend the study findings** | Interviewed BA-participating and non-participating homebuilders in different geographic areas to obtain anecdotal insights on various evaluation topics, including knowledge benefits. |
| **Calculation of economic performance measures** | Compared the monetized benefits of the selected practices to DOE's BA program costs to calculate the social rate of return on DOE's investment. |
| **Interviews with code officials to understand BECP influence on model code development** | Conducted interviews with 9 energy code experts to help assess BECP's contribution toward moving specific energy code practices into model energy codes. Interviewees included individuals knowledgeable about the code development process with representation from the public sector, private sector, and advocacy/interest groups. |

### Portfolio Approach

The evaluation methodology uses a portfolio approach to analyze the benefits of the BA program. This approach provides an efficient way to determine if a portfolio of investments with highly variable returns on individual projects has been economically worthwhile based on a lower-bound estimate of benefits. The portfolio for this evaluation is the full set of projects and activities funded by the BA program from its inception in 1994 through 2015. Through 2015, DOE invested $162 million in the BA program.[1]

From this portfolio, four energy efficient building practices were selected for detailed evaluation. The practices were selected based on discussions with program staff, review of program documents, and interviews with building science experts. Selection criteria for the practices included: (1) a clear relationship between the practices and the activities conducted by BA; (2) uptake in the market (in ES Homes and/or IECC); and (3) direct energy savings to homeowners. The four selected practices include:

[1] Discounted at 7%. Program costs total $253 million discounted at 3% and $369 million undiscounted (constant 2015$).

- **Air Tightness:** From 2006 to 2012, the IECC gradually reduced the air leakage rate allowed in new homes from about 11-14 air changes per hour at 50 Pascals (ACH50) to three ACH50 through stricter prescriptive requirements for air sealing. In addition, beginning in 2012, IECC required blower door testing to verify compliance with the air tightness requirements. ES Homes began implementing the Thermal Bypass Checklist in 2006, mandating even tighter building envelopes.
- **Duct Tightness:** IECC began mandating duct leakage testing for ducts outside conditioned spaces in 2009, and tightened the leakage requirement in 2012. ES Homes has maintained strict duct leakage testing requirements since 2006.
- **Envelope Insulation:** IECC has gradually increased the level of insulation required for the building envelope, including attics, walls, and foundations. Only small changes were made in a few climate zones in IECC 2006, but substantial increases in R-value were made in IECC 2009 and 2012. These changes carried over to ES Homes, which does not have additional requirements for envelope insulation beyond existing code. Changes to window performance were not included in this study because the evaluation was not able to establish clear attribution to BA.
- **Thermal Bridging:** In 2012, IECC began to require a layer of continuous insulating sheathing in colder climates to reduce thermal bridging through wall framing. In addition, advanced framing techniques developed by BA reduced the average framing factor significantly, shifting from 2x4 16" on-center to 2x6 24" on-center framing.

### Approach Used to Determine BA Program Impacts

For the four selected practices, the evaluation estimates energy savings, environmental health benefits, knowledge benefits, and energy security benefits. The monetized benefits of the selected practices are compared to DOE's total BA program costs to estimate the social rate of return on DOE's investment.

#### Approach Used to Determine Energy Impacts

The evaluation's approach for estimating energy impacts of the BA program was to model the impacts of the four selected building practices using DOE's Building Optimization Model (BEopt). Although originally developed for BA projects, BEopt was made public in 2010, and is now used by architects and engineering firms, utilities, state and local governments, and academic and nonprofit organizations unaffiliated with the program. BEopt uses state-of-the-art building energy simulation engines (DOE-2 or EnergyPlus) and accounts for interactive effects between practices. The modeling also accounts for differences across states/climate zones and progressions in market penetration over time. It should be noted that California was excluded from the analysis of benefits because the role of BA in influencing policy and market uptake in California is ambiguous, given California's older and more stringent building energy code regulation (Title 24).

The energy modeling was conducted using a range of housing attributes in several locations throughout the U.S., with adjustment factors applied to the results to accurately extrapolate them over the broad range of housing characteristics and weather conditions present in different parts of the country. The results were rolled up nationwide using state-level weighting factors and data for actual housing starts and actual ES Homes built over the period 2006-2015.

The IEc team modeled "intervention" homes with the four practices integrated, compared to "counterfactual" homes that would have existed at that point in time without those practices integrated. Specifically, each intervention home was defined as a home that meets the applicable statewide code or ES Homes requirements during a specific timeframe, including any of the four practices that have been adopted. To measure the incremental impact provided by the studied practices, the IEc team defined the corresponding counterfactual home as a code minimum or ES home that would have existed during that same timeframe in a counterfactual world wherein these practices had not gained enough market acceptance to be included in ES Homes and/or code. For code minimum homes, the counterfactual input was simply the value required by the IECC in the cycle preceding the introduction of the studied practice. For building attributes other than those associated with the four studied practices, the same requirements of the code or ES Homes were used for both the counterfactual and intervention cases.

Because the studied practices came online at different points in time, a temporal analysis was necessary to assess their impact. In addition, states adopt energy codes on their own cycles, which necessitated some state-by-state analysis to determine impacts at the state level. Post modeling, the IEc team used home construction statistics to estimate state-level total site energy savings, and nationwide savings, for each year, sorted by fuel type and practice. This resulted in an estimate of total (gross) energy savings from the four studied practices from 2006 through 2015.

An important aspect of the evaluation was to estimate net benefits – i.e., the portion of total energy savings that can be defensibly attributed to the BA program as opposed to alternative (or rival) factors, such as other public policies and market forces. The evaluation uses a tiered approach to attribution, including: review of project data, scoping interviews with building science experts, a publication citation analysis, and a Delphi panel. In particular, the Delphi panel (a type of expert elicitation process) asked nine experts to review the energy modeling results, consider external drivers (outside of BA) that may have contributed to the results, and downward adjust the results to reflect the external drivers. Delphi panelists were asked to consider BA's influence on the *timing* and *scale* of market acceptance for each of the four practices when developing their attribution estimates. Hence, BA's role in accelerating the market acceptance of the four selected practices in embedded in the Delphi panel's estimates. The Delphi panel's estimates were applied to the gross energy savings from BEopt to derive net energy savings.

The study uses these net energy savings to estimate energy cost savings. The IEc team developed a financial model to calculate economic benefits over time, using state-level energy price data from the Energy Information Administration (EIA). Reported figures were adjusted to constant 2015 dollars. Financial benefits were derived from energy savings by multiplying the appropriate savings figure by its corresponding energy price, and summing the results within each category as appropriate.

#### Approach Used to Determine Environmental Health Impacts

As electricity generation from power plants falls in response to the reduction in residential electricity demand, power plant emissions of carbon dioxide ($CO_2$), sulfur dioxide ($SO_2$), oxides of nitrogen ($NO_x$), and fine particulate matter ($PM_{2.5}$) also decline. A reduction in the emissions of these pollutants leads to significant public health improvements, namely reduced incidences of premature mortality and various morbidity impacts. The evaluation uses the attribution-adjusted energy impacts (i.e., the modeled energy savings adjusted downward based on the Delphi panel results) to estimate environmental health benefits that result from reduced air emissions due to avoided electricity generation. Health benefits are reported two ways: in terms of incident rates and in terms of the dollar value of avoided adverse health events.

These estimates reflect the full suite of health impacts that the U.S. Environmental Protection Agency (EPA) considers in its regulatory impact analyses of air pollution policy. However, these values do not account for health improvements that may result from improved indoor air quality in homes.

#### Approach Used to Determine Energy Security Impacts

Reductions in oil imports have energy security benefits. The study treats energy security impacts quantitatively, but does not monetize them. Carrying forward the attribution-adjusted energy savings calculated above, the study estimates displaced petroleum consumption in terms of barrels of imported oil. For this evaluation, most of the energy security impacts result from a reduction in heating oil, primarily in the northeastern United States.

#### Approach Used to Determine Knowledge Impacts

Unlike previous analyses of EERE programs that have been centered in R&D and the generation of intellectual property, and, consequently, have focused on patent analysis as a preferred measure of knowledge benefits, this study focuses on publication citation analysis as the most feasible measure of knowledge impacts. BA program managers, building science experts, and production builders interviewed for this evaluation explained that BA's research has historically been disseminated through professional networks, conferences, and trade journals. The analysis focuses on 15 trade journals that building science experts identified as key information sources for homebuilders. The citation analysis identifies the spread of ideas and practices demonstrated by the BA program; it also helps assess spillovers from the new residential sector to the retrofit sector. Results are presented quantitatively, but not in monetary terms.

#### Approach Used to Determine Economic Performance

The evaluation compares the monetized benefits of the four studied practices to DOE's portfolio investment costs. The return on DOE's investment is calculated using the internal rate of return, supplemented by other measures of economic performance. The analysis compares energy cost savings and the economic value of avoided adverse health events against total portfolio investment costs. The resulting measures of economic performance result in conservative, lower-bound estimates of the return on EERE's investment, because they include the full portfolio costs but only a subset of benefits.[2]

#### Approach Used for Targeted Analysis of the Building Energy Codes Program

While BA is the study's primary focus, the evaluation also includes a separate, targeted analysis of the BECP. Specifically, the analysis focuses on BECP's role and influence in the development of the residential chapter of the IECC in 2009 and 2012.

PNNL has conducted extensive analyses of the energy impacts, emissions reductions, and economic benefits resulting from energy savings in the IECC. The current evaluation does not duplicate PNNL's previous efforts, but instead focuses on BECP's contribution to energy-saving code proposals that were incorporated into the 2009 and 2012 IECC residential chapter.

IEc conducted the analysis in two steps: (1) identified energy-reducing code changes to the IECC in the 2009 and 2012 code cycles, and categorized code change proponents, based on available documentation; and (2) conducted interviews with nine individuals knowledgeable about the code development process to obtain qualitative insights about BECP's role and influence in the 2009 and 2012 IECC cycles.

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[2] There is no known evidence of any of the investments in the portfolio yielding large negative returns that would offset the benefits.

## RESULTS

### Energy Impacts

Table ES-2 provides estimated total, cumulative nationwide site energy savings for all four studied practices combined. The energy modeling analysis for the four selected practices found an estimated cumulative site energy savings of 250 trillion Btu, or approximately 6% of site energy use for houses built in the U.S. between 2006 and 2015 (excluding the state of California).

TABLE ES-2. GROSS TOTAL NATIONWIDE SITE ENERGY SAVINGS BASED ON MODELING STUDY

| | TOTAL SAVINGS (2006-2015) |
|---|---|
| Total Site Electricity Savings (GWh) | 17,808 |
| Total Site Natural Gas Savings (Million Therms) | 1,826 |
| Total Site Fuel Oil Savings (Million Gallons) | 47 |
| **Total Site Energy Savings - All Fuels (Trillion Btu)** | **250** |

The Delphi panel used in this study resulted in the following adjustments presented in Table ES-3 below. Net energy savings – the portion of savings that can be fairly attributed to the BA program – were estimated at approximately 140 trillion BTU. As noted above, Delphi panelists were asked to consider BA's influence on the timing and scale of market adoption of the four practices. Overall, panel members mostly agreed that the selected practices would have been adopted at a later point in time, and at a smaller scale, without the BA program. The attribution estimates in Table ES-3 reflect the Delphi panel's assessment of BA's role in accelerating the timing and increasing the scale of market adoption of the four practices.

TABLE ES-3. ATTRIBUTION ADJUSTEMENTS FROM DELPHI PANEL

| PRACTICE | GROSS ENERGY SAVED (2006 - 2015) (TRILLION BTU) | ATTRIBUTION TO BA | NET ENERGY SAVED (2006-2015) (TRILLION BTU) |
|---|---|---|---|
| Air Tightness | 183 | 57% | 104 |
| Duct Tightness | 26 | 64% | 16 |
| Insulation | 39 | 45% | 17 |
| Thermal Bridging | 3 | 66% | 2 |
| **Total** | **250** | | **140** |

Table ES-4 summarizes the net energy savings, overall and by fuel source, and the associated energy cost savings attributable to the BA program for the four practices. In keeping with DOE's evaluation guidance, this study uses the 7% real discount rate set by the Office of Management and Budget (OMB) as the primary discount rate. At the 7% real discount rate, energy cost savings through 2015 are estimated at

$689 million. The evaluators also conducted a sensitivity analysis of the estimated financial savings due to attributed energy savings. The sensitivity analysis uses the maximum and minimum attribution percentages from the Delphi panel to calculate upper- and lower-bound figures. The upper-bound estimate yields energy savings of over $1 billion. The lower-bound estimate yields $271 million in energy savings, which exceeds the program cost of $162 million.

#### TABLE ES-4. ENERGY AND ENERGY COST SAVINGS (2006-2015)

| METRIC | UNIT OF MEASURE | BASE CASE | LOW-END ESTIMATE | HIGH-END ESTIMATE |
|---|---|---|---|---|
| Total energy savings – all fuels | Million MMBtu | 139.8 | 55.3 | 205.5 |
| Electricity savings | Million kWh | 9,992 | 3,889 | 14,544 |
| Natural gas savings | Million therms | 1,021 | 406 | 1,504 |
| Fuel oil savings | Million gallons | 26 | 10 | 39 |
| Monetary value of energy savings @ 7% real discount rate | Million, 2015$ | $689 | $271 | $1,010 |
| Monetary value of energy savings @ 3% real discount rate | Million, 2015$ | $1,416 | $557 | $2,074 |
| Monetary value of energy savings undiscounted | Million, 2015$ | $2,492 | $980 | $3,650 |

### Environmental Health Impacts

The residential electricity savings associated with the BA program result in air quality benefits from avoided electricity generation, in addition to financial savings to homeowners. As shown in Table ES-5, the monetary value of avoided adverse health events due to reduced air emissions is $185 million (at a 7% real discount rate).

#### TABLE ES-5. ENVIRONMENTAL AND HUMAN HEALTH IMPACTS

| METRIC | UNIT OF MEASURE | BENEFITS (2006-2015) |
|---|---|---|
| Avoided carbon dioxide emissions ($CO_2$) | Tons | 6,184,797 |
| Avoided particulate matter emissions ($PM_{2.5}$) | Tons | 486 |
| Avoided sulfur dioxide emissions ($SO_2$) | Tons | 10,525 |
| Avoided nitrogen oxides (NOx) | Tons | 5,188 |
| Mean monetary value of avoided adverse health events due to reduced air emissions @ 7% real discount rate | Million, 2015$ | $185 |
| Mean monetary value of avoided adverse health events due to reduced air emissions @ 3% real discount rate | Million, 2015$ | $416 |
| Mean monetary value of avoided adverse health events due to reduced air emissions undiscounted | Million, 2015$ | $688 |

### Energy Security Impacts

Carrying forward the attribution-adjusted energy savings calculated above, the study estimates a reduction of 0.23 million barrels of imported oil through 2015. This is a relatively small benefits area for the BA program because only a small fraction of U.S. homes use heating oil. These impacts are not factored into the benefit-cost calculations, in keeping with DOE's evaluation guidance.

### Knowledge Impacts

The citation analysis focused on 306 articles in 15 trade journals that mention BA, alone or in combination with one or more technologies or practices that BA worked on. The number of articles mentioning BA was relatively flat from the program's inception in 1994 through 2000. It spiked in 2003, which coincides with an IECC code update. We also observe spikes in 2009 and 2011, which coincide with the 2009 and 2012 updates to the IECC. Air sealing, air barriers, and insulation were the most common topics, which further reinforces this evaluation's focus on the energy efficiency results of these practices. At least 21 of the 306 articles (6.9%) were cited a total of 174 times (8.3 times on average). Just over half were cited five times or less, while 11% were cited more than 20 times. The highest number of citations was for articles that addressed insulation (134 citations) and air leakage (84 citations).

The analysis also looked at who is citing the original articles. There appears to be some degree of cross-citing by the 15 journals, and by DOE, NREL, and BA teams. Citing entities also include several trade journals with an energy and/or engineering focus, as well as several international journals. Citations were also found in professional conference proceedings, which aligns with interview findings about conferences as an important method for disseminating BA's research. Educational institutions, and a number of master's theses and doctoral dissertations, also cite the original articles.

Finally, the citation analysis examined evidence of knowledge spillovers from the new residential market to the retrofit market. Journals that cater to the retrofit market mention practices that BA worked on, sometimes in direct reference to the BA program, and some article titles refer directly to remodeling. This provides anecdotal evidence that knowledge spillovers have occurred, consistent with findings from the homebuilder interviews.

## RETROSPECTIVE ECONOMIC IMPACT ASSESSMENT

The evaluation determines that the rate of return on EERE's investment is 30.2%, as shown in Table ES-6. The net benefits of the four energy efficiency practices total over $713 million in reduced energy costs and reduced mortality and morbidity from avoided electricity generation over the last ten years. The benefit-cost ratio is 5.4. Based on the economic findings, DOE's investment in BA has been worthwhile.

**The benefits presented in Table ES-6 are lower-bound estimates** because the evaluation compares the total cost of the BA program from 1994-2015, $162 million,[3] to the benefits of only these four practices, which started to accrue in 2006. The evaluation also does not include BA's work on construction practices that manage moisture, which protect indoor air quality and provide occupant comfort. Although these are important benefit areas for BA, they were not able to be quantified for this project. This evaluation also does not include energy savings and associated benefits that accrued to the home renovation market due to knowledge spillover.

[3] Discounted at 7%. Program costs total $253 million discounted at 3% and $369 million undiscounted (constant 2015$).

### TABLE ES-6. ECONOMIC PERFORMANCE METRICS

| METRIC | UNIT OF MEASURE | ECONOMIC PERFORMANCE (2006-2015*) |
|---|---|---|
| Social return on EERE investment (internal rate of return, IRR) | Percent | 30.2% |
| Net present value @ 7% real discount rate | Million, 2015$ | $713 |
| Net present value @ 3% real discount rate** | Million, 2015$ | $1,579 |
| Net present value undiscounted | Million, 2015$ | $2,811 |
| Benefit-to-cost ratio (BCR) @ 7% real discount rate | Ratio | 5.4 |
| Benefit-to-cost ratio (BCR) @ 3% real discount rate** | Ratio | 7.2 |

Notes:
* While benefits for the four selected practices began to accrue in 2006, the program costs and activities associated with bringing the four practices to market go back to the program's inception in 1994.
** The 3% discount rate is presented for informational purposes only; the 7% rate is the primary discount rate for this evaluation.

### IMPACTS INCLUSIVE OF REMAINING USEFUL LIFE CONSIDERATIONS

The evaluation has a primarily retrospective focus; however, because energy savings in affected homes persist over time, the study also analyzed the energy savings that will continue to accrue beyond 2015 from homes built during the study period. The evaluators calculated remaining useful life benefits based on conservative assumptions about the number of years between the construction of a new house and the first major renovation of that house, when new energy code provisions take effect, which industry experts estimated at 25 years on average. Thus, the last year of the analysis of remaining effective useful life benefits is 2039. In accordance with DOE evaluation guidance, the evaluation reports separately for retrospective benefits and effective useful life benefits for homes built during the study period.

Including the effective useful life benefits for homes built during the study period increases the energy, environmental health, and energy security benefits as follows:

- **Energy impacts:** At the 7% real discount rate, energy cost savings through 2015 were estimated at $689 million. Including effective useful life savings in the calculation brings the total to almost $2.2 billion.
- **Environmental health impacts:** Through 2015, the monetary value of avoided adverse health events due to reduced air emissions was $185 million at a 7% real discount rate. Including effective useful life benefits increases the total from $185 million to $356 million.
- **Energy security impacts:** The study estimated a reduction of 0.23 million barrels from displaced imports through 2015. Through 2039, the study estimates 0.70 million barrels of displaced oil imports.

Including remaining effective useful life benefits from homes built through 2015 has the following impacts on the economic performance metrics:

- **Social return on EERE investment:** increases from 30.2% to 32.4%

- **Net present value at 7% real discount rate**: increases from $713 million to over $2.3 billion
- **Net present value at 3% real discount rate**: increases from over $1.5 billion to over $7.3 billion
- **Benefit-to-cost ratio at 7% real discount rate:** increases from 5.4 to 15.6.
- **Benefit-to-cost ratio at 3% real discount rate:** increases from 7.2 to 30.1.

#### BUILDING ENERGY CODES PROGRAM ANALYSIS

All of the code experts interviewed for this study stated that the 2009 and 2012 IECC would have been weaker (less energy efficient) – and the improvements would have happened later – without BECP. The 2009 IECC provided the first major energy code improvement in 20 years. Two energy efficiency improving proposals that BECP submitted for the residential chapter were approved in the 2009 IECC: (1) BECP's proposal to decrease the maximum U-factor requirement for basement walls in climate zone 3 contributed to improving the building envelope; and (2) BECP's proposal to verify duct sealing through testing increased energy efficiency by requiring verifiable energy savings. BECP also supported (e.g., testified at code change hearings) complementary code change proposals submitted by other proponents.

BECP played a major role in advancing the energy efficiency improvements in the residential chapter of the 2012 IECC. BECP's proposals resulted in 11 out of the 23 energy-reducing code changes. One code change (EC-13) contained energy efficiency improvements for the building envelope, air leakage, hot water piping systems, and lighting. According to the interview findings, EC-13 would on its own have resulted in the 2012 IECC being 25% more efficient than 2006. Additional proposals backed by BECP increased the energy efficiency gains from 25% to 30%. Interviewees stated that BECP played a major role in supporting the "30% solution."

In addition to BECP's direct role in submitting code proposals and testifying at code hearings, the program conducts complementary activities that facilitate energy code development. Many interviewees indicated that they view BECP as an "honest broker" in the codes development process, and interviewees reported that BECP's credibility was important to advancing the code changes in 2009 and 2012. Additionally, BECP's technical analysis, tools, and models were also helpful for advancing energy-reducing code changes. BECP also facilitates stakeholder interactions around proposed code changes, which fosters understanding about proposed changes heading into the code cycle. The meetings also provide an opportunity for efficiency proponents and skeptics to debate proposed changes before the official vote.

Interviewees also identified two additional ways in which BECP influenced the code, although they are more closely related to code adoption/enforcement than to code development. First, BECP submits proposals that clarify prior code requirements. While such proposals do not directly impact energy consumption, they can increase energy savings through improved compliance by minimizing erroneous interpretations of the code, which are common. Second, BECP develops tools and modeling software such as REScheck that helps designers and homebuilders determine whether the proposed design of new homes or alterations to existing homes meet the requirement of the IECC. Several interviewees noted the importance of these tools.

## SOURCES OF UNCERTAINTY AND STUDY LIMITATIONS

Throughout the analysis, the evaluators made every attempt to use conservative assumptions, so that we know that the evaluation provides a conservative, lower-bound estimate of the value of the BA program. Table ES-7 summarizes the sources of uncertainty in our analysis, how the uncertainty affects the analysis, and how it was addressed. Overall, the study's treatment of uncertainty provides a conservative, lower-bound estimate of the BA program's impacts.

### TABLE ES-7. SOURCES OF UNCERTAINTY, DIRECTIONALITY, AND APPROACH FOR ADDRESSING

| SOURCE OF UNCERTAINTY | DIRECTIONALITY | APPROACH FOR ADDRESSING |
|---|---|---|
| **Code compliance rates** | Unclear | The energy modeling exercise assumes full compliance with code, as there is no defensible way to adjust for non-compliance in the context of this study's modeling approach. A PNNL field study suggests that compliance may average 100% because of over-compliance – i.e., builders who comply with code frequently exceed the energy use reduction targets in code. |
| **Exclusion of California from energy modeling analysis** | Understates program benefits | The study excluded California from the estimate of energy savings because of the inability to clearly attribute aspects of CA Title 24 (California's state energy code) to BA. However, qualitative evidence suggests that BA helped builders comply with CA Title 24 in a cost-effective manner. |
| **Selection of BA activities to evaluate** | Understates program benefits | The study only quantified the benefits of four practices, and there are many more the study did not quantify that may have produced additional energy savings. Also, many building science experts interviewed stated there are benefits associated with BA moisture management, but the study was not able to quantify moisture management benefits. The study was also not able to quantify the benefits of "enablers," such as climate maps, that facilitate but do not directly produce energy savings. |
| **Timeframe for effective useful life benefits: from home construction to first major renovation** | Understates program benefits | The study limits remaining effective useful life benefits to the average time until major renovation (25 years). This is because *some* renovations trigger the need to update to the current code. However, the effective useful life of the affected components in three of the four studied building practices (e.g., walls) is much longer than 25 years. |
| **Building energy modeling assumptions** | Understates program benefits | The study takes a conservative approach to modeling energy savings, such as: 1) excluding California from the energy modeling analysis (see above); excluding energy savings prior to Energy Star version 2.0 (due to the timeline of BA activities and when practices were adopted into ES), which greatly reduces reported savings from duct leakage; and 3) groups six states that have no mandatory energy code with "laggard" states (late adopters of code), as opposed to assuming these states use no energy code. |

While every effort was made to conduct a rigorous study, the evaluation has some limitations:

- **Inability to use experimental or quasi-experimental design:** We were not able to apply an experimental or quasi-experimental design to attribute benefits to the BA program. Given the inability to use experimental design, the evaluation contemplated a quasi-experimental comparison of BA program participants to non-participants. However, given the inability to obtain an ICR, we were not able to interview a sufficient number of individuals to conduct a statistically valid comparison. As such, we relied primarily on a Delphi panel of experts to assess attribution. Beyond the Delphi panel, the evaluation relies on counterfactual analysis.

- **Limited interview coverage.** While interviews play an important role in this evaluation, the Paperwork Reduction Act limits systematic data collection from non-federal entities to nine people/organizations without obtaining an ICR, which was not able to be obtained for this evaluation. As such, the interviews and Delphi panel were limited to nine non-federal respondents per type of interview.

  We selected Delphi panelists based on their professional reputation and experience, and their ability to provide informed responses to our specific questions. However, the small number of respondents may not be representative of their peer groups. It should be noted, however, that guidance on Delphi panel construction indicates that panels with as few as 10 individuals are recommended where qualifications for panelists are homogeneous, as they were for this panel.[4] Furthermore, some guidance indicates that "researchers should use the minimally sufficient number of subjects for the task at hand."[5]

  The evaluation used multiple methods to address uncertainties related to small sample sizes. First, a tiered approach to attribution was used, so that different interview groups provided input on the selection of the practices and the attribution of energy savings to BA. Additionally, a sensitivity analysis was conducted with the Delphi panel estimates, using the highest and the lowest attribution estimates for each practice; as noted above, the four selected practices exceed the cost of the BA program even if we use the lowest estimates. Finally, the builder interviews and citation analysis provide anecdotal support for the Delphi panel's estimates. These confirmatory methods provide greater confidence in the estimates even with the low sample sizes.

- **Threats to validity:**[6] We acknowledge threats to internal validity including:
  - Confounding: Several variables contribute to market acceptance of energy efficiency practices that BA championed.
  - Selection bias: It is possible that we have some degree of potential selection bias in our interview samples. In particular, the response rates for builder interviews were low. Recruiting builders to participate in the interviews was difficult, particularly for builders that did not participate in the BA program.

  Other potential threats to internal validity do not play a significant role in this study.[7] Regarding external validity, the original builder survey approach developed by the IEc team would

[4] Okoli and Pawlowski, "The Delpi method as a research tool: an example, design considerations and applications," *Journal of Information Systems and Management,* 42 (2004), p. 15-29 and Hsu and Sanford, "The Delphi Technique: Making Sense of Consensus," *Practical Assessment, Research and Evaluation*, Volume 12, No. 10, 2007.

[5] Hsu and Sanford, "The Delphi Technique: Making Sense of Consensus," *Practical Assessment, Research and Evaluation*, Volume 12, No. 10, 2007.

[6] The potential threats to validity are included in DOE/EERE evaluation guidance, as follows: **Internal Validity Threats**: 1) Temporal antecedence; 2) confounding; 3) selection bias; 4) maturation; 5) history; 6) selection-maturation interaction; 7) selection-history interaction; 8) regression to the mean; 9) differential attrition; 10) experimenter bias; 11) testing; 12) instrumentation; 13) contamination; 14) resentful demoralization; and 15) "John Henry effect." **External Validity Threats**: 1) Interaction effect of testing / pre-test effect; 2) interaction of selection and treatment; 3) reactive effects of experimental arrangements; and 4) multiple treatment interference.

potentially have allowed the results of these interviews to be extrapolated to the entire population of builders. However, the revised approach (given the inability to obtain an ICR) does not provide statistical power, and as such, we make no extrapolation claims of the builder interviews. We also are not attempting to extrapolate from the four selected practices to the broader universe of BA activities.

- **Limited technology coverage:** This evaluation focuses primarily on four practices that result in significant energy savings and in which BA played a direct role. However, BA has worked on many additional technologies and practices that the evaluation was not able to address.
- **Inability to monetize some impact categories:** The evaluation did not monetize knowledge benefits or energy security impacts because the valuation methods are not settled in the literature. This is a standard constraint in evaluations of EERE's programs. In addition, we understand that one of BA's most significant achievements was to use value engineering to drive down energy use cost-effectively in order to mainstream the value engineering approach, but the evaluation was not able to measure that directly. We also were not able to monetize health impacts from improved indoor air quality resulting from improved moisture control and reduced mold in homes, although BA conducted work in this area.

### IMPLICATIONS FOR BTO STRATEGIES AND PROGRAMS

Based on the evaluation findings, IEc sees the following implications for future BTO strategies and programs.

- **The evaluation findings lend support for continuing BA's hands-on, team-based field demonstration project approach.** The combination of this evaluation's quantified energy reduction results, in conjunction with the qualitative feedback that we collected from building science experts, underscores that BA forms a key link in the market diffusion chain, as the program bridges applied R&D and market acceptance for building-level energy efficiency. The team model, which facilitates communication between the building science community and production builders, is critical for reaching this audience. Production builders confirmed during our interviews that many of them tend to get their information from their network, whether at conferences or directly from other builders. They also prefer more hands-on methods of learning new building and energy-saving techniques. The BA approach of making building scientists central to teams is an effective strategy of transferring energy efficiency knowledge, and testing and refining energy efficient construction practices until they are both effective and cost-effective.
- **The evaluation findings also provide support for complementary avenues of influence.** The builder interviews found that reaching trade allies who work directly with builders is also an effective strategy for reaching builders and influencing their preferred construction techniques. For example, many builders rely on their HVAC contractors and energy raters for information about new energy efficiency practices and how to comply with energy code.
- **Builders and building science experts provided support for BA's moisture management work; additional study of benefits is warranted.** Several experts interviewed for this evaluation

[7] Note that regression to the mean as a validity threat should not be confused with the deliberate consensus-building approach of the Delphi panel method.

indicated that the key and original impetus for production builders to work with BA was to learn how to cost-effectively address moisture management and mold problems. Similarly, three BA builders interviewed responded that a key benefit of participation in the program was to learn how to better manage moisture in homes, and that what they learned from BA projects led to improved comfort for homeowners. This provides support for ongoing BA work in this area, and additional study of the benefits of this work is warranted. The most definitive study design that links BA to reduced mold to better health is likely cost-prohibitive. However, DOE could explore the feasibility of a narrower study that 1) takes as a given that the practices promoted by BA reduce the likelihood of mold, which a diverse set of experts agree on, and 2) examines the benefits of residential mold prevention in sensitive populations such as adults or children with asthma and/or respiratory allergies, using change in sick days or school absences before and after mold abatement, or house move, as the key metric.

- **The BA strategy of moving energy efficiency practices through market adoption and into code is critical for realizing widespread energy savings.** One of the largest differences we observed between BA and non-BA builders was in their stated willingness to implement these practices regardless of code requirements. Non-BA builders would be less likely to implement these practices if they were not required by code. Non-BA builders cited cost as a reason for not implementing these practices unless required by code. This finding also suggests a need for additional outreach (and how-to guidance) around the cost issue to non-BA builders. Natural information spillover has not bridged the divide between BA builders and other builders on this issue. Given what we know about how builders prefer to receive information, outreach from other builders or trade allies may be more effective than outreach directly from BA.
- **Analysis of the BECP indicates that it has played a key role in strengthening model code.** All of the experts interviewed stated that the 2009 and 2012 IECC would have been weaker (less energy efficient) – and the improvements would have happened later – without BECP involvement. The 2009 IECC provided the first major energy code improvement in 20 years. BECP played a major role in advancing the energy efficiency improvements in the residential chapter of the 2012 IECC. BECP's proposals resulted in 11 out of 23 energy-reducing code changes in 2012.

# I. INTRODUCTION

## PURPOSE AND OVERVIEW

DOE's Building Technologies Office (BTO) invests in advancing building energy performance through the development and promotion of energy efficient technologies, systems, and practices. BTO commissioned an independent program evaluation of Building America (BA) and a targeted analysis of the Building Energy Codes Program's (BECP's) work on residential energy codes. Both programs are key BTO investments designed to reduce energy consumption by improving the energy efficiency performance of new homes.

This evaluation focuses primarily on the research and development, systems integration and demonstration, and market transformation activities conducted by the BA program. Located within BTO's Residential Buildings Integration program area, the BA program supports research, development, and demonstration projects to advance cost-effective energy efficiency technologies and practices in the new home and retrofit sectors. The program uses a systems-engineering, whole-house approach to advance residential energy efficiency without compromising housing comfort, durability, and affordability. BA brings together building science experts, builders, developers, designers, manufacturers, and other segments of the housing industry to test and demonstrate housing solutions in real-world settings. These projects are intended to encourage the market's adoption of proven, energy-saving technologies and practices.

This evaluation quantifies the estimated benefits and costs of DOE's support for selected **new** home construction practices demonstrated by the BA program. It assesses the economic, energy, environmental, and knowledge impacts of selected activities. The study also examines knowledge spillovers from the new residential construction market to the housing retrofit market. The evaluation is designed both to measure how the program has performed to date and to assist BTO in communicating program impact and in strengthening program design and execution moving forward.

The evaluation includes a separate, targeted analysis of BECP's support for the development of new codes. BECP supports building energy code development, adoption, implementation, and enforcement processes to achieve cost-effective improvements in the energy efficiency of buildings. The Pacific Northwest National Laboratory (PNNL) conducted an extensive analysis of energy impacts from new codes.[8] IEc's analysis examines BECP's role in advancing code proposals that have contributed to the energy savings reported by PNNL.

[8] Livingston, OV, DB Elliott, PC Cole, and R Bartlett, *Building Energy Codes Program: National Benefits Assessment, 1992-2040*. Pacific Northwest National Laboratory. March 2014.

### DESCRIPTION OF THE BA PROGRAM

The BA program aims to "help the U.S. building industry promote and construct homes that are better for business, homeowners, and the nation."[9] Through the BA program, DOE partners with homebuilders, building science experts, product manufacturers, and other industry stakeholders to conduct applied research, development, and demonstration projects in homes, and bring to market innovations in residential building energy performance. The program targets 60% energy savings for new homes and 40% for existing homes by 2020 (from 2010 levels), while maintaining housing durability, quality, comfort, and affordability. After early years of working with custom home builders, BA focused intently on working with production builders, which lead the new housing market, to take advantage of economies of scale and the opportunity to more readily and directly change standard industry practices.

The BA program centers on cross-cutting industry teams. The teams play an important coordination role by bringing together diverse stakeholders in an otherwise highly fragmented industry. By coordinating across different segments of the industry, BA teams can evaluate all aspects of a project and make decisions quickly. Each team is led by a building science expert from the private sector or a university who recruits home builders and other team members. BA teams propose which activities and climate zones they will focus on to improve the energy efficiency of homes. Teams conduct projects in new and existing homes to advance technical solutions, address technical and business risks, and reduce barriers to market adoption.

BA's applied research and demonstration projects aim to facilitate market adoption by influencing voluntary above-code programs (e.g., Energy Star for Homes, Home Performance with Energy Star, and Zero Energy Ready Homes) and other early adopters. As early adopters use and confirm the technical and economic feasibility of BA innovations, market acceptance and market penetration are expected to increase. Over time, the BA program aims for its innovations to become standard practice. This can include the adoption of BA practices in building codes and industry standards, or "direct to market" diffusion of BA advances.

In support of promoting market awareness and acceptance of advanced building practices, the BA program has an important knowledge dissemination component. Through its Best Practice Guides, technical reports, and other content available from the Building America Solutions Center, the program collects and disseminates best practices and lessons learned to the building industry. These resources provide information and technical knowledge to promote and enable the industry's adoption of advanced building technologies and practices.

#### BA and the Broader Policy Context

The BA program launched about 20 years ago, in 1994. Since that time, concerns including climate change and energy security have elevated scrutiny of building energy consumption, as policymakers, civil service advocates, building scientists, and other stakeholders realized that investing in building-level energy efficiency is one of the most cost-effective approaches to reducing energy use and carbon emissions.[10] Several public policy efforts on the federal and state levels have targeted building energy use

[9] "Building America: Bringing Building Innovations to Market." http://energy.gov/eere/buildings/building-america-bringing-building-innovations-market. Accessed on February 18, 2016.

[10] McKinsey and Company, *Pathways to a Low Carbon Economy, Version 2.0 of the Global Greenhouse Gas Abatement Cost Curve*, 2009, available at:http://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/sustainability/cost%20curve%20pdfs/pathways_lowcarbon_economy_version2.ashx

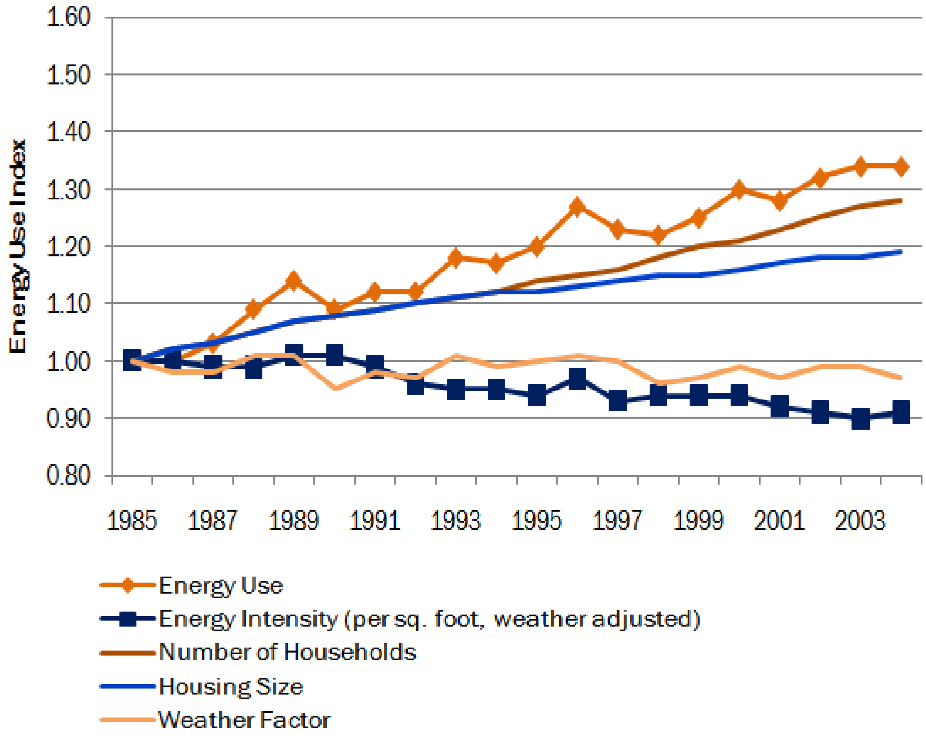
and residential energy use in particular. At the same time, trends including increased size of new homes, increased number of one-person households, spread of air conditioning as a standard feature in new homes, and increased plug loads have challenged efforts to increase residential efficiency. Nevertheless, energy use intensity (EUI) in new homes decreased over the last 20 years.

This section places BA's efforts within the context of other residential energy efficiency initiatives and discusses BA's role in contributing to this positive trend. The IEc team collected the information presented in this section from interviews with program staff, scoping interviews with building science experts familiar with BA, and a review of key literature.

### EUI Trends

Figure 1-1 presents energy use and EUI from 1985 to 2004, for all homes including new construction and existing homes. The exhibit shows that total energy use increased over this time as the number of households and the average house size increased. However, EUI decreased during the same period as homes became more efficient.[11] Unfortunately, EUI data specific to new residential construction are not available nationally after 2004.

**FIGURE 1-1. RESIDENTIAL ENERGY USE INTENSITY AND CONTRIBUTING FACTORS, 1985-2004**




Source: DOE, Energy Efficiency and Renewable Energy (EERE), "Trend Data: Residential Buildings Sector," updated 14 May 2008. Note: The indicators on this chart are based on an Energy Use Index that is calibrated to 1985 levels.

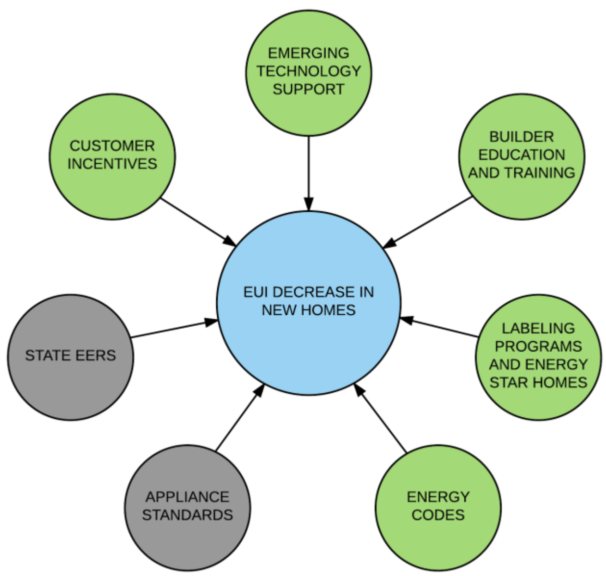
[11] US DOE, Energy Efficiency Trends in Residential Buildings, 2008, p. 15.

More recent national data on the energy trend within new home construction are available for Home Energy Rating System (HERS)-rated homes. For context, the average HERS Index Score for a home built in the 1970s was 130. The HERS Index Score for homes built to the 2006 IECC is 100. In 2013 and 2014, the average HERS score for a rated home was 63, and it dropped to 62 in 2015. HERS-rated homes comprised 25 percent of the market for newly constructed residences in 2015: 190,000 HERS-rated homes out of a total of 768,000 homes built in the same year. [12]

### Public Policy Influences on Residential EUI

Several public policies influenced the direction of EUI in new homes over the past 20 years, and BA directly or indirectly supported many of them. Figure 1-2 below presents these public policy influences.[13] According to literature reviewed, staff interviews, and scoping interviews with building science experts, BA plays a role in influencing the five public policy areas shaded in green.

**FIGURE 1-2. PUBLIC POLICY INFLUENCES ON EUI IN NEW HOMES**




- **Emerging Technology Support:** BA plays a central role in demonstrating the feasibility and cost-effectiveness of building energy efficiency technologies and practices in real-world conditions. BA is part of a continuum of public policy support for energy efficiency R&D (supported by DOE national labs as well as select state energy agencies), demonstration, and deployment programs (supported by state energy agencies, utilities, and advocacy organizations).
- **Builder Education and Training:** BA teams work directly with builders and tradespeople to teach them how to properly apply and install energy efficient technologies and practices. In addition, BA publications and publications of BA team members further diffuse this knowledge to the wider residential building community. BA training and education complements other sources

[12] Personal correspondence with Steve Baden, RESNET, February 2016.

[13] Public policy categories adapted from those presented in: *Alliance Commission on National Energy Efficiency Policy, Residential and Commercial Buildings*, January 2013: https://www.ase.org/sites/ase.org/files/ee_commission_building_report_2-1-13.pdf.

of training and education for builders and tradespeople, including most notably energy code training offered by states.

- **Labeling Programs, including ES Homes:** Several practices demonstrated by BA were ultimately adopted by EPA's ES Homes program. In addition, BA builders were early adopters of ES Homes, with 45 percent of all ES Homes built in 2005 built by BA teams.[14] This is because technical support from BA teams made it much easier for builders to obtain certification in the early years of ES Homes, and assistance with ES Homes certification was a key selling point for recruiting builders to BA. In addition to those adopted by ES Homes, practices demonstrated by BA were also integrated into private guarantee programs, the largest one being Masco's Environments for Living,[15] as well as the U.S. Green Building Council's LEED for Homes.

  Finally, ES Homes required a verification scheme and standard rating system to function properly, which did not exist when ES Homes was launched. ES Homes used HERS, and the Residential Energy Services Network (RESNET) developed a training and certification program for HERS raters.[16] Ultimately, some builders started to use the HERS rating system as independent from ES Homes, for example in seeking Builders Challenge certification. Thus, in influencing ES Homes practices, BA also indirectly supported the growth of the HERS index as a stand-alone label, as well as the labor market for third-party raters.[17]

- **Energy Codes:** Energy codes have been ratcheted up in stringency over the last 20 years, as shown in Figure 1-3 below. Several energy efficiency practices and technologies demonstrated by BA ultimately were adopted into the IECC and the International Residential Code (IRC) after being demonstrated in BA homes, and then demonstrated on a very large scale through ES Homes and private guarantee programs, and in some cases, after adoption by the California energy code (Title 24). This diffusion of practices essentially negated long-standing building industry arguments that increased efficiency could not be accomplished in a cost-effective manner, and led to a political climate wherein code stringency could be increased.

[14] M. Heany et al NREL, Draft Building America Impact Assessment Framework, p. 12.

[15] The Environments for Living program provides builders with requirements, tools, and assistance to construct and market homes that offer energy efficiency and other benefits, based on the principles of building science. Environments for Living homes receive limited guarantees on comfort and heating and cooling energy use. More information about the program is available at www.environmentsforliving.com.

[16] More information about RESNET and the HERS Index can be found online at www.resnet.us.

[17] It should be noted that the Home Energy Score line item in the BTO budget is unrelated to RESNET or the HERS index. The Home Energy Score line item was for DOE to develop and maintain a software program aimed at existing homes and homeowners; it provides calculations and tips on energy efficiency investments to homeowners.

FIGURE 1-3. RESIDENTIAL ENERGY CODE STRINGENCY TREND, 1975-2012


- **Customer Incentives:** The federal and state governments, often in conjunction with utilities, have offered homeowners various tax credits, rebates, and low-cost financing to incentivize energy efficient investments including more efficient furnaces, windows, doors, and appliances, and to offset costs of higher R-value insulation. Many of these incentives are aimed at existing homes, but buyers of new homes have been able to take advantage of some of them. Most notably for new construction, the Energy Policy Act of 2005 (2005 Energy Bill) included a tax credit for builders of new homes that use 50 percent less energy for heating and cooling than IECC 2006. Twenty percent of the savings had to come from improvements in the envelope, and BA demonstrated and gained acceptance of many of these advances. This credit has been renewed every year since 2005.

Looking now at the two remaining public policy areas, gray-shaded in Figure 1-2, in which BA is considered not to play a role, we find appliance standards and state EERS.

- **Appliance Standards:** Appliances are a major source of energy use in homes; refrigeration, cooking, and wet cleaning alone comprise approximately 18 percent of home energy use.[18] Separate from BA, DOE has an appliance standards program that sets mandatory efficiency standards for several types of appliances. Some states also have programs that contribute to DOE's efforts to set mandatory standards. Moreover, EPA's Energy Star program[19] also conducts research and sets above-minimum standards for Energy Star appliances. Although BA has funded research and demonstration projects on advanced mechanical systems, including HVAC systems and water heating systems, which can be considered part of the overall appliance realm, BA-funded advances in the mechanical area have not enjoyed the market uptake of BA building enclosure advances. In addition, according to ES Homes staff and building science experts interviewed, Energy Star conducts its own appliance research, and does not credit BA with informing its work on above-code appliance standards.

[18] DOE, Energy Efficiency Trends in Residential and Commercial Buildings, August 2010, Figure 18 on p. 16.

[19] EPA's Energy Star program encompasses ES Homes as well as appliances, lighting, office equipment, electronics, and other product categories. More information about the program can be found online at www.Energy Star.gov.

- **State EERS:** Twenty-four states have minimum energy efficient resource standards (EERS) in place for electricity, and 15 states have EERS for natural gas as well. EERS requires utilities to implement demand response and energy efficiency programs to reduce the need to develop new generating capacity (i.e., build new power plants). EERS policies started around 1999 and gained traction in the mid-2000s; they have been found to reduce electricity use by one percent overall (compared to non-EERS states).[20] EERS programs are not related to BA.

### BA Program Logic Model

Figure 1-4 presents a logic model for the BA program.[21] A logic model is a graphical representation of how a program is designed to achieve its goals. The logic model shows the key elements of the program and how these elements fit together.

- **Inputs:** Staff, funds, and technical inputs dedicated to the program. Inputs include DOE/NREL staff, research from DOE's national labs and Emerging Technologies program, manufacturers who use the research, building industry stakeholders (building science experts, contractors, etc.), funding from DOE as well as partners' cost share, and other private sector investment.
- **Activities:** what the program does to achieve its goals. DOE engages key industry stakeholders, and selects and funds cross-industry BA teams. The teams study problems and barriers and identify housing solutions, which they research, build, test, and demonstrate in real-world settings. Building science experts and the national labs provide technical guidance, measure results, document best practices, and disseminate results. In addition, DOE provides training and educates building professionals based on BA's research.
- **Outputs:** immediate results from the activities. Outputs include strategies and roadmaps, houses that integrate BA innovations, and technology and practice solutions. Additional outputs include guidance, reports, and scientific advances disseminated through the BA Solution Center; other tools, websites, and publications; and training sessions and conference presentations that disseminate knowledge developed by BA.
- **Audiences/partners:** individuals and groups targeted by the activities and outputs, who the program aims to influence. Audiences and partners for the BA program include: home builders and other building professionals; voluntary above-code programs (e.g., ES Homes); other market and industry stakeholders (e.g., RESNET, private-sector guarantee programs); building scientists and academics; home energy raters; code officials; and the Federal Energy Management Program. On the remodeling side audiences include: Home Performance with Energy Star, Weatherization Assistance Program, utility rebate programs, and state and local energy retrofit programs.
- **Short-term outcomes:** changes in knowledge, awareness, attitudes, understanding, and skills resulting from program outputs, including: reduced risk and increased builder acceptance of energy-efficient technologies; validated solutions for integrating energy-efficient technologies and practices into homes; greater awareness and understanding in the industry of how to

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[20] ACEEE, *State Energy Efficiency Resource Standards Policy Brief*, April 2015: http://aceee.org/sites/default/files/eers-04072015.pdf

[21] The IEc team developed the logic model based on: draft logic models for BA developed by program staff; feedback from program staff and building science experts on the IEc team's draft logic model; and BA's *Research-to-Market Plan*. In addition, the logic model draws on Rogers' Diffusion of Innovations Model as described in DOE/EERE's *Impact Evaluation Framework for Technology Deployment Programs*, July 2007.

assemble/install advanced technologies and how to integrate best practices; access to resources on cost-effective solutions; and adoption of BA innovations by early adopters and in voluntary above-code programs (e.g., ES Homes).

- **Medium-term outcomes:** changes in market acceptance and behavior resulting from changes in knowledge and attitude. Medium-term outcomes include: leading building professionals improve or construct cost-effective, high-performance homes; EneryStar Homes completed by BA builders and other building partners; market performance and customer feedback validate new approaches; and private guarantee programs (e.g., Masco's Environments for Living program) adopt BA innovations. Other important medium-term outcomes include: code proposals that reflect BA innovations, and the adoption of BA innovations in code and building industry standards.
- **Long-term outcomes:** overarching goals of the program. Long-term outcomes for BA include: mainstream builders and the remodeling industry improve their current practices based on sound building science developed and demonstrated by BA; high-performance home technologies and best practices become standard practice; and improvements in codes and building industry standards make the use of energy-efficient technologies and practices the market standard for new and remodeled homes. This in turn leads to: energy and other resource savings, improved occupant health and comfort, improved housing quality and industry profitability, environmental health effects, additions to the knowledge base, and social returns on EERE's investment.

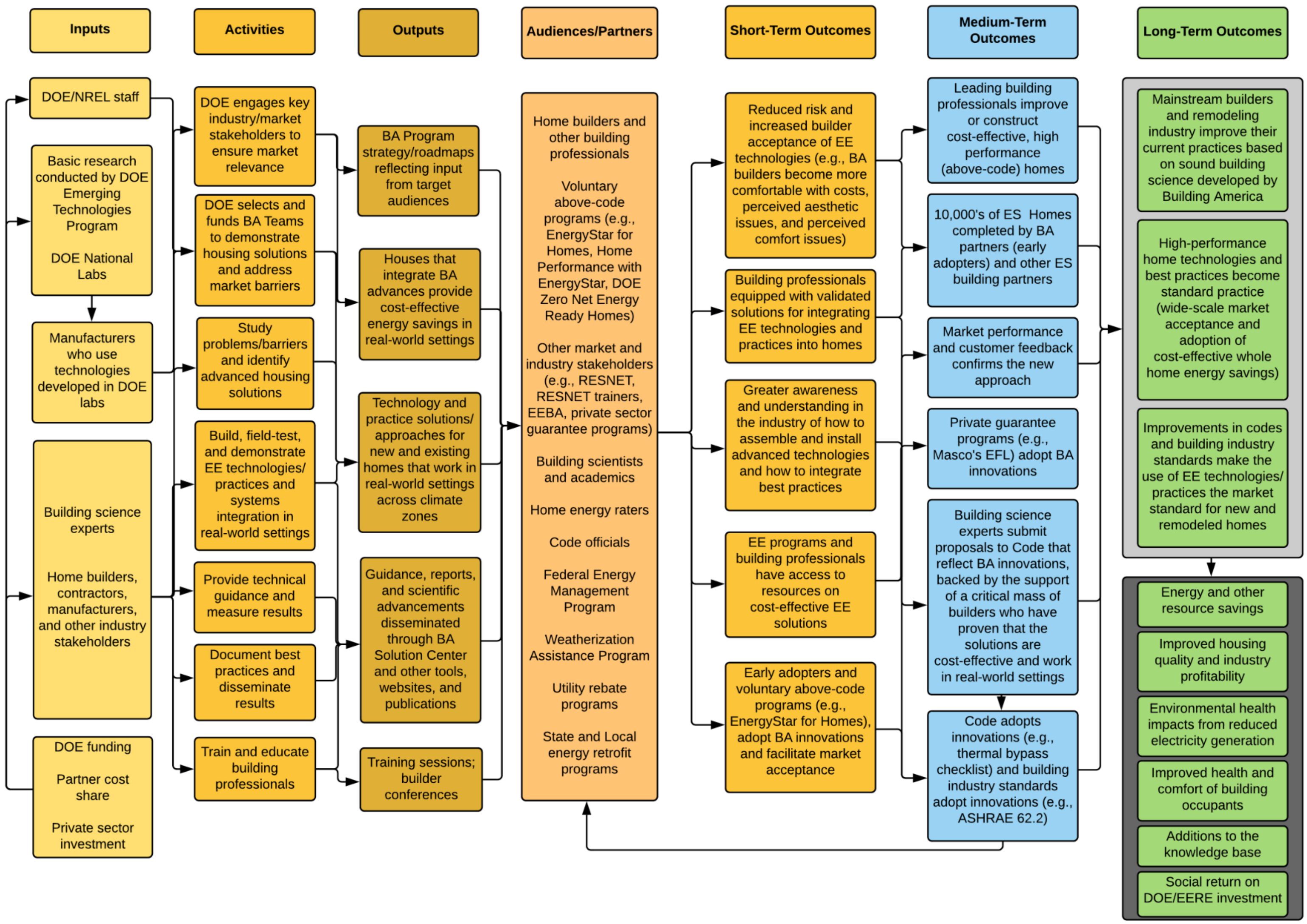
As discussed earlier in this chapter, the BA program operates within a broader technology and market context. Contextual factors include the following:[22] significant changes in building materials, equipment, and construction practices over the last century; a fragmented and risk-averse housing industry that under-invests in research and is slow to adopt innovations; reduction in thermal loads resulting in changed research priorities, including more focus on indoor air quality and ventilation; the need for advances in knowledge, technology, and standard practices to ensure that high-performance homes do not incur additional risk of failure; changing consumer expectations about comfort; modern building envelope assemblies that are more sensitive to design flaws; and tax credits for high performance homes.

In addition, the logic model reflects key assumptions underlying the program's design; assumptions include: building professionals re-evaluate and change their attitudes/beliefs about advanced building technologies and practices based on new information; and building professionals act on their new attitudes/beliefs by adopting advanced technologies and practices.

In the following chapter, we discuss the specific energy efficiency practices selected for in-depth study in this evaluation. In Chapter 3, we discuss the metrics, data sources, and methods used in this evaluation to study the logic model outcomes for the selected practices.

[22] The contextual factors shown in the logic model were identified in: BA program documents, discussions with program managers, and scoping interviews with external building science experts.

## FIGURE 1-4. BUILDING AMERICA PROGRAM LOGIC MODEL




**Context:** Significant changes in building materials, equipment, and construction practices over the last century. Fragmented and risk-averse housing industry under-invests in research and is slow to adapt innovations. Reduction in thermal loads resulted in changed research priorities, including more focus on indoor air quality and ventilation. Advances in knowledge, technology, and standard practices are required to ensure high-performance homes do not incur additional risk of failure. Changing consumer expectations about comfort. Modern building envelope assemblies more sensitive to design flaws. Tax credits for high performance homes.
**Assumptions:** New/better information and real-world demonstrations cause building professionals to re-evaluate and change their attitudes and beliefs about advanced building technologies and practices. Building professionals act on their new attitudes and beliefs by deciding (and following through on their decision) to adopt advanced building technologies and practices.

# II. ENERGY EFFICIENCY PRACTICES FEATURED IN THE EVALUATION

## PRACTICES SELECTED FOR DETAILED STUDY

The energy savings calculations for this evaluation focus on selected energy efficiency practices and their adoption in the market. The evaluators chose a subset of practices that BA demonstrated that were particularly successful in diffusing throughout the market for new residential construction. These practices were selected through discussions with program staff, review of program documents, and scoping interviews with building science experts. Criteria for inclusion were: a clear connection to BA program activities, uptake in the market (in Energy Star Homes or building codes), and direct energy savings. These practices are described below. Though the study attempted to break out individual practices, they are inherently interrelated. As discussed in Chapter 3, the impacts of the practices were estimated using energy modeling to account for interactive effects.

### Air Leakage and Infiltration Requirements

Air leakage and infiltration are well-known issues for home energy performance, and energy codes have included air sealing requirements for many years. However, traditional requirements only address critical areas of potential air leakage, requiring that these be sealed with a durable material such as caulking, gasketing, or weather stripping. BA research focused on increasing the stringency of air sealing and air barrier requirements, in particular to reduce thermal bypass issues.[23] Thermal bypass is the movement of heat around or through insulation, which occurs when air barriers are missing or when there are gaps between the air barrier and insulation, for example between the garage and living space.[24] Air leakage and infiltration requirements may include requiring a specific performance level (e.g., seven air changes per hour) and whole-building pressurization testing (i.e., blower door testing), or may require prescriptive measures such as specific requirements for air sealing and/or thermal bypass air barriers.

Air leakage and infiltration requirements are included in ES Homes and in energy codes. Infiltration requirements were included in the first version of ES Homes, but these were not influenced by BA as both programs started around the same time. The second version of ES Homes incorporated a "Thermal Bypass Checklist" that was strongly influenced by BA, as well as an infiltration performance requirement. The third version of ES Homes expanded the Thermal Bypass Checklist and reduced the infiltration performance requirement. Energy Star requirements for Version 2 (V2) and Version 3 (V3) also specify a performance path that requires blower door testing, or a prescriptive path that does not require testing. The 2009 IECC adopted a substantial amount of the Thermal Bypass Checklist and required either inspection against the checklist or a whole-building pressurization test (with a performance requirement),

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[23] U.S. Department of Energy. Building America Top Innovations Hall of Fame Profile: Thermal Bypass Air Barriers in the 2009 International Energy Conservation Code. January 2013. http://energy.gov/sites/prod/files/2014/01/f6/4_3d_ba_innov_thermalbypassairbarriers_011713.pdf

[24] Energy Star Qualified Homes. Thermal Bypass Checklist Guide. June 2008. http://www.EnergyStar.gov/ia/partners/bldrs_lenders_raters/downloads/TBC_Guide_062507.pdf

and the 2012 IECC made both the checklist and the whole-building pressurization test (with an increased performance requirement) mandatory.

### Duct Leakage Requirements

Ducts are often located in vented (unconditioned) attics and crawlspaces, which results in significant energy losses due to the loss of conditioned air through leaks, as well as energy losses and potential air quality issues from pulling in unconditioned air through leaks and for uninsulated ducts, the direct heat loss/gain through the duct wall to the unconditioned space. There are two main strategies to reduce duct leakage: move ducts to a conditioned space or insulate and air-seal the ducts. Moving ducts to a conditioned space can result in 8% to 15% cost savings for air conditioning.[25] BA has worked on three approaches for moving ducts to a conditioned space: installing ducts in a dropped ceiling or chase for single-story homes; installing ducts between floors in multi-story homes; and installing ducts in conditioned attics or crawlspaces in both single- and multi-story homes. Requirements for reducing duct leakage may include requiring a specific performance level of duct leakage (e.g., less than four cubic feet per minute per 100 square feet), requiring duct pressure testing, requiring that ducts be moved to a conditioned space, or requiring that ducts have a certain level of insulation (e.g., R-6).

Duct leakage requirements are included in ES Homes and in energy codes. Duct leakage requirements were included in the first version of ES Homes, but these were not influenced by BA as both programs started around the same time. ES Homes version 2.0 included a performance requirement for both the performance and prescriptive path, and required insulation on ducts in unconditioned spaces for the prescriptive path. ES Homes version 3.0 included a more stringent performance requirement and increased the insulation requirement in unconditioned attics in the prescriptive path, while version 3.1 (for states that have adopted the most recent energy code) requires all ducts and air handlers in the conditioned space for the prescriptive path. The 2009 IECC added a requirement for duct pressure testing as well as changed the simulated performance path rules to require that all ducts not in conditioned space have a certain level of insulation. The 2012 IECC decreased the duct leakage performance requirement.

### Insulation Requirements

Insulation is used to prevent heat flow through the building envelope, and is an important factor for a building's overall energy use. Insulation in the building envelope includes ceiling, wood frame wall, mass wall, floor, basement wall, slab, and crawl space insulation. Insulation is rated by an R-value; a higher R-value indicates greater insulating effectiveness. There are many types of insulation that can be used, including fiberglass, cellulose, and natural fibers.[26] Requirements for insulation typically include required R-values, but do not specify the type of material to be used.

All building codes and above-code programs include requirements for insulation. ES Homes refers to building codes for insulation requirements. According to building science experts that IEc interviewed during the evaluation scoping phase, BA can claim credit for the increased insulation requirements in the 2006, 2009 and 2012 IECC. Changes to insulation requirements in the 2006 IECC include:[27,28]

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25 U.S. Department of Energy. Building America Top Innovations Hall of Fame Profile: Ducts in Conditioned Space. January 2013. http://energy.gov/sites/prod/files/2014/01/f6/1_1g_ba_innov_ductsconditionedspace_011713.pdf

26 http://energy.gov/energysaver/insulation

27 Unpublished document from BTO's chief architect, checked against 2003 IECC and 2006 IECC.

- Ceiling R-value increased in climate zones 1 and 2;
- Wall R-value (exterior wall in 2003, wood frame wall in 2006) increased in climate zones 1, 2, 4 marine, and 5;
- Floor R-value increased in climate zones 1 and 2, and changed from R-21 to R-30 or insulation sufficient to fill the framing cavity at R-19 minimum in climate zones 4 marine, 5, 6, 7, and 8;
- Basement wall R-value changed from a single R-value ranging from R-8 to R-19 to either R-10 continuous insulation or R-13 cavity insulation in climate zones 4, 5, 6, 7, and 8;
- Slab perimeter R-value increased in climate zones 4 and 5; and
- Crawl space wall R-value changed from a single R-value ranging from R-6 to R-20 to either R-5 continuous insulation or R-13 cavity insulation in climate zone 3 and to either R-10 continuous insulation or R-13 cavity insulation in climate zones 4, 5, 6, 7, and 8.

Changes to insulation requirements in the 2009 IECC include:[29]

- Wood frame wall R-value increased in climate zones 5 and 6;
- Mass wall R-value increased in climate zones 4, 5, and 6;
- Floor R-value increased in climate zones 7 and 8; and
- Basement wall R-value increased in climate zones 3, 6, 7, and 8.

Changes to insulation requirements in the 2012 IECC include:[30]

- Ceiling R-value increased in climate zones 2, 3, 4, and 5;
- Wood frame R-value increased in climate zones 3, 4, 6, 7, and 8;
- Mass wall R-value increased in climate zones 3, 4, 5, and 6;
- Basement wall R-value increased in climate zone 5; and
- Crawl space R-value increased in climate zones 5, 6, 7, and 8.

### Thermal Bridging Requirements

Thermal bridging occurs when a more conductive material allows heat flow across a thermal barrier.[31] A more conductive material is also a poor insulating material, such as wall studs. Wall studs between insulation allow heat flow through walls almost four times faster than insulation,[32] which reduces the

[28] The 2003 and 2006 IECC insulation requirements do not line up directly for two reasons: the climate zones changed for the 2006 IECC and the 2003 IECC separated requirements based on window to wall ratios, and this separation was eliminated in the 2006 IECC. Therefore, IEc summarized the changes between these codes to the best of our ability.

[29] U.S. Department of Energy. Cost-Effectiveness Analysis of the 2009 and 2012 IECC Residential Provisions – Technical Support Document. April 2013. https://www.energycodes.gov/sites/default/files/documents/State_CostEffectiveness_TSD_Final.pdf

[30] Ibid.

[31] http://www.greenbuildingadvisor.com/blogs/dept/guest-blogs/what-thermal-bridging

[32] U.S. Department of Energy. Building America Top Innovations Hall of Fame Profile: Advanced Framing Systems and Packages. January 2013. http://energy.gov/sites/prod/files/2014/01/f6/1_1b_ba_innov_advancedframing_011713.pdf

effective R-value of the wall system. There are multiple solutions to reduce thermal bridging, and the ones that BA has worked on include advanced framing and using continuous insulation. Continuous insulation refers to rigid insulation applied to the exterior of the structural assembly. Continuous insulation incudes structural insulated panels (SIPs), which combine structural framing, insulation, and sheathing into one product and can be used for roofs, walls, or floors.[33] Continuous insulation has multiple benefits: reduced thermal bridging; better air tightness (if the rigid insulation used is taped or sealed); it warms the structural cavity to the interior, reducing condensation problems in any heating climate, and allowing for reduced vapor retarders, which promotes drying to the interior in any climate. It is a systems integrated building improvement. Advanced framing involves techniques that reduce the amount of framing used for structural support, as builders often use more framing than needed. Reducing framing reduces thermal bridging and increases the amount of space available for insulation, which can lead to 13% energy savings.[34] Requirements for thermal bridging may include requiring specific placement of insulation, requiring advanced framing, or requiring continuous insulation.

Requirements for reducing thermal bridging have been incorporated into ES Homes and the IECC. The third version of ES Homes includes detailed requirements for reducing thermal bridging, including using advanced framing and continuous insulation. The 2012 IECC requires continuous insulation for climate zones 6, 7, and 8.

Table 2-1 below summarizes the uptake of each of the selected energy efficiency practices in ES Homes and building energy codes.

#### TABLE 2-1. MARKET UPTAKE OF ENERGY EFFICIENCY PRACTICES

| PRACTICE | ES HOMES | IECC |
|---|---|---|
| Air leakage and infiltration requirements | 2006 (v2)<br>2012 (v3) | 2009 IECC<br>2012 IECC |
| Duct leakage requirements | 2006 (v2)<br>2012 (v3) | 2009 IECC<br>2012 IECC |
| Insulation requirements | | 2006 IECC<br>2009 IECC<br>2012 IECC |
| Thermal bridging requirements | 2012 (v3) | 2012 IECC (only certain climate zones) |

The IEc team confirmed that BA worked on these practices before they were taken up by the market by reviewing historical program documents and confirming during the scoping interviews with experts in the building industry that BA had a significant impact for the uptake of the chosen practices in the market. Additional information on attribution is provided the section Counterfactual Approach and Attribution.

### Role of the Four Selected Practices in California

The State of California does not use IECC model codes as the basis for regulating energy use in buildings. Instead, California has its own building energy statute called Title 24 that is generally more stringent than

[33] http://www.greenbuildingadvisor.com/green-basics/structural-insulated-panels

[34] Ibid.

IECC model code at any given time, and Title 24 mandated the four practices at the focus of this analysis prior to IECC model codes. Several building industry experts interviewed during the scoping phase of the evaluation cautioned the IEc team against making the argument that implementation of these practices in California could be attributed to DOE, because of California's different and more advanced regulatory regime. For example, duct leakage requirements in California Title 24 cannot be attributed to BA because they had been demonstrated by LBNL and mandated in California prior to BA's national-level work on the issue.

However, BA did have teams working in California for decades, and the building industry experts suggested that BA helped builders in CA meet requirements of Title 24 and the California-specific version of Energy Star in a more cost-effective manner. Given this, although we exclude California from our building modeling approach, we asked California builders who we interviewed about BA's role in helping them comply with Title 24 and the California-specific version of Energy Star in a more cost-effective manner.

### ADDITIONAL PRACTICES REVIEWED BUT NOT SELECTED FOR DETAILED STUDY

The evaluators also considered the following technologies and practices, but decided not to focus on them for the energy savings portion of the evaluation:

- **Moisture management:** According to building science experts interviewed for this evaluation during the scoping interviews, around the time that the BA program launched in the mid-1990s, the residential building industry faced growing concerns about moisture damage and mold growth in new homes. Coverage of "black mold" and "toxic mold" by national news outlets helped to spark growing concerns among homeowners about the health effects of mold, and growing concerns among homebuilders and insurers about the liability associated with moisture in homes.[35] Homebuilders were quite concerned about moisture and mold from a liability and cost perspective, as well as from a customer satisfaction and reputation perspective. Insurers responded by tightening policy restrictions related to mold. Builders were also concerned that energy efficiency code requirements on the horizon, including requirements for tighter enclosures and reduced air leakage, would exacerbate the incidence of moisture problems and mold growth.

  Thus, several experts interviewed for this project indicated that the key and original impetus for production builders to work with BA was to learn how to cost-effectively address moisture management and mold problems. Production builders in the mid-1990s did not see growing market demand for energy efficient homes and were not particularly interested, as an industry, in energy efficiency. In fact, they were concerned that energy efficiency requirements would exacerbate moisture problems. However, the original set of participating production builders in BA were receptive to the energy efficiency advice of BA's building science experts, as long as that advice was relatively cost-effective and concurrently addressed moisture and mold. Once BA gained a good reputation among the first wave of participating production builders, it was subsequently easier for the program and the BA teams to recruit additional production builders.

[35] Examples of articles from the *New York Times* include: Andrew Jacobs, "Moldy Walls Put Tenants on Edge," July 28, 1996; Robyn Meredith, "Infants' Lung Bleeding Traced to Toxic Mold," January 24, 1997; and Lynnette Holloway, "Families Plagued by Home-Wrecking Mold," November 9, 1997.

Managing moisture properly can confer a number of benefits to builders and homeowners alike. First, managing moisture can reduce costs, and in particular the costs to builders of warranty callbacks and the costs to homeowners of mitigating mold issues.[36] Second, managing moisture properly can avoid mold issues and health concerns related to the presence of mold. However, indoor air quality (IAQ) health benefits cannot be quantitatively estimated within the scope of work of this evaluation.

In Appendix A, we discuss the moisture management practices demonstrated and diffused by BA, and the challenges inherent in quantifying IAQ benefits from these practices. Appendix A also discusses BA's work on ventilation and homes and the challenges inherent in quantifying both economic and IAQ impacts from ventilation practices.

The evaluation also examined "enabling factors" that were important for facilitating successful market adoption of energy-reducing technologies and practices, but do not by themselves directly generate energy savings. The interviews with production builders inquired about these enabling factors and other resources developed by the BA program. These include:

- **BEopt:** NREL developed the BEopt modeling tool to help BA teams identify the most cost-effective integrated-systems approaches to attaining energy savings goals, to more easily select appropriate packages of technologies and practices for residential construction projects. BEopt is based on DOE's EnergyPlus whole-building simulation engine, and provides detailed simulation-based analysis based on house specifications including size, architecture, occupancy, vintage, location, and utility rates. BEopt is able to do this because it pulls in existing data sources including weather files and utility rates. BEopt allows modelers to see the effect on energy use as well as first cost and lifecycle cost from different enclosure and mechanical equipment options. Although originally developed for BA projects, BEopt was made public in 2010, and is now used by architects and engineering firms, utilities, state and local governments, and academic and nonprofit organizations unaffiliated with the program.[37]
- **Vapor retarder classification system:** A vapor retarder is a layer of material that prevents water vapor from entering a building's walls or ceilings and prevents insulation from becoming damp. However, in climates that are cold in winter but hot enough in summer to use air conditioning, the vapor barriers intended to keep moisture out in winter can also prevent walls from drying out in the summer. Research sponsored by BA and conducted by the Building Science Corporation (BSC) proposed there should be three classes of vapor retarders based on permeability and that a vapor barrier should be defined as a Class I vapor retarder. As a result, the 2007 supplement to the 2006 IRC provided a new rating system for vapor retarders based on their permeability and permitted Class III vapor retarders like latex paint in all climate zones under certain conditions. This, in turn, has led to new homes that more effectively control moisture flow.
- **Building science-based climate maps:** Appropriate building science solutions vary by climate zone; for example, what works in hot and humid climates may not be effective in dry cold

[36] The IEc team had planned to inquire about reduced warranty callbacks through a survey with builders. Unfortunately, as discussed below, we were not able to proceed with the survey.

[37] Information largely obtained from: Eric Wilson, NREL, "Using BEopt to Optimize Home Energy Performance," Home Energy, July/August 2015, available at: http://www.nrel.gov/docs/fy15osti/63862.pdf.

climates. Prior to BA, the Model Energy Code (MEC) and IECC climate maps were by county, which complicated the efforts of large national builders to develop designs for different parts of the country. The BA climate maps enabled production builders to develop a limited number of approaches that applied to everywhere they built homes. The climate maps were adopted in the 2004 IECC Supplement and in ES Homes, Version 2. Although the climate maps do not have direct energy benefits that can be quantified on a per-house basis, they provide a consistent national framework for high-performance homes.

The IEc team determined the following technologies and practices did not have clear attribution to BA, and are not included in the evaluation:

- **Window requirements**. While BA uses high performance windows in its projects, there have been multiple drivers of change in the market for windows according to scoping interviews with building science experts and the IEc team's document review. As such, we cannot determine clear attribution to BA. Other influences include ES Homes window ratings, the Efficient Windows Collaborative, and rebate programs.
- **Mechanical system improvements.** BA has conducted extensive research and demonstration projects on mechanical system approaches including advanced HVAC systems, smaller capacity heat pumps, and combined heat and hot water systems. BA also advanced the argument that builders could reduce the size of HVAC systems when tightening a house, reducing initial HVAC system costs for the builder and homeowner. However, in general, market uptake for BA's advances in this area has been lackluster, especially relative to BA's successes in moving enclosure requirements into the marketplace. Specifically, although BA teams attempted to partner with various mechanical companies to create lower load equipment (boilers, furnaces, AC units), the program has not been able to influence the equipment that the manufacturers produce. Also, although the Air Conditioning Contractors of America (ACCA) have embraced BA's approach to trade off envelope improvements for HVAC sizing in their guidance, building science experts interviewed during the scoping phase of the study indicate that oversizing is still common practice.

This evaluation focuses primarily on determining the benefits of the four selected practices and comparing those benefits to the cost of the BA program. In the next chapter, we describe in detail the data sources and methods for assessing the benefits of the selected practices, and for calculating the social return on DOE's investment in the BA program. Chapters 4-9 present the results of those analyses.

# III. DATA SOURCES AND METHODS

## OVERVIEW OF THE METHODOLOGY

This chapter describes the data sources and methods used in this evaluation. The chapter begins with an overview of the portfolio approach used in this study. This is followed by a crosswalk of the logic model outcomes in Figure 1-4 with the metrics and methods used. A description of the data sources employed in this evaluation, including existing sources and new data collections, follows. Next, the chapter describes the definition of the counterfactual and the evaluation's approach to assess attribution. The following sections of the chapter describe the evaluation methodology for assessing the major benefit categories covered in this evaluation – energy impacts, environmental health impacts, knowledge impacts, and energy security impacts – as well as the approach used to calculate measures of economic performance. This is followed by a discussion of our approach to calculating effective useful life benefits. The chapter concludes with a discussion of sources of uncertainty and limitations of the evaluation methodology.

## PORTFOLIO APPROACH

This study uses a portfolio approach for conducting a retrospective cost-benefit analysis. The portfolio for this evaluation is the full set of projects and activities funded by the BA program from its inception in 1994 through 2015. As described in the previous chapter, the evaluators, in deliberation with program staff and independent building science experts, selected four practices from the BA portfolio for detailed evaluation. The study provides quantitative estimates of the benefits of the selected practices and compares these benefits to the total DOE investment cost for the entire portfolio. Therefore, the investment costs include both the practices that are evaluated in detail and those that are not. The portfolio approach provides an efficient way to determine if a portfolio investment has been economically worthwhile based on a lower-bound estimate.[38]

The evaluation calculates the social return on DOE's investment by comparing the monetized benefits resulting from DOE's investment in the four selected practices to DOE's investment costs for the entire BA program. To calculate social return, the public and private benefits of the selected practices are compared to DOE's cost. The social return on DOE's investment is calculated using the internal rate of return, supplemented by other measures of economic performance. The resulting measures of economic performance result in conservative, lower-bound estimates of the actual social return on EERE's investment, because they include the full portfolio cost but only a subset of benefits. Benefits are based on

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[38] For a portfolio of projects variable in their returns, focusing on a selected group of projects that seems most feasible to evaluate provides an efficient way to provide a lower-bound estimate, provided that the projects not examined do not have negative effects that may offset the benefits. For a portfolio characterized by projects with similar profiles of returns, drawing a random sample may be a preferred approach. For a small portfolio, it may be feasible to provide total coverage.

a subset of practices selected for detailed analysis; in addition, it is not possible to fully monetize the benefits even for the selected practices.[39]

Where possible, the evaluation addresses additional technologies and practices qualitatively. For example, the evaluation looks at "enabling factors" that were important for facilitating successful market adoption of energy-reducing technologies and practices, but do not by themselves directly generate energy savings (e.g., climate maps, BEopt, and the vapor retarder classification system).

### CROSSWALK OF LOGIC MODEL OUTCOMES TO METRICS AND METHODS

As shown in the program logic model in Chapter 1, Figure 1-4, the BA program has both R&D and market adoption components. On the R&D side, the program conducts applied research, tests new technologies in real-world settings, and measures and documents results. On the market adoption side, the program conducts demonstration projects and outreach activities to shift the market's awareness, acceptance, and use of BA innovations. Therefore, measuring the program's success requires looking at metrics for R&D programs plus additional metrics for market adoption programs. Ultimately both the R&D programs and the market adoption programs are geared to the same metrics of long-term performance: consumption of energy and other resources, emission of air pollutants and greenhouse gases, and resulting return on investment and other performance impact metrics.

Table 3-1 summarizes the metrics and the data sources/methods used in this evaluation to address the short-term, medium-term, and long-term outcomes depicted in the logic model. The data sources and methods shown in the last column of the table are discussed later in this chapter. The results of the analyses conducted using these data sources and methods are presented in Chapters 4-9.

[39] Although energy security and knowledge impacts are not monetized, they "reflect, in a broad sense, evidence of the larger return" on EERE's investment. *Guide for Evaluating Realized Impacts of DOE/EERE R&D Programs*, August 2014.

**TABLE 3-1. CROSSWALK OF OUTCOMES IN THE LOGIC MODEL WITH METRICS AND APPROACHES USED IN THE EVALUATION**

| LOGIC MODEL ELEMENTS | METRICS | EVALUATION SOURCES/METHODS |
|---|---|---|
| **Short-Term Outcomes** | | |
| Reduced risk and increased builder acceptance of EE technologies | • Extent to which EE technologies that BA worked on have gained increased market acceptance<br>• Nature and extent of BA's contribution to advancing the selected technologies in the market<br>• Self-reported use of BA EE innovations when not required by code | • Scoping interviews<br>• Delphi panel<br>• Homebuilder interviews |
| Building professionals equipped with validated solutions for integrating EE technologies and practices into homes | • Identification of tools and resources developed by BA to help homebuilders integrate EE practices<br>• Extent to which BA resources and tools are used by homebuilders | • Scoping interviews<br>• Homebuilder interviews |
| Greater awareness and understanding in the industry of how to assemble and install advanced technologies and how to integrate best practices | • Extent to which EE technologies that BA worked on have gained increased market acceptance<br>• Level of awareness and understanding among homebuilders | • Scoping interviews<br>• Homebuilder interviews |
| EE programs and building professionals have access to resources on cost-effective EE solutions | • Number and description of publications that cite BA research<br>• Self-reported use of BA resources (BA Solution Center, Best Practice Guides, etc.) | • Publication citation analysis<br>• Homebuilder interviews |
| Early adopters and voluntary above-code programs (e.g., ES Homes) adopt BA innovations and facilitate market acceptance | • Number and description of practices that BA worked on that were adopted in ES Homes specifications<br>• Nature and extent of BA's role in advancing the selected practices | • Scoping interviews<br>• Delphi Panel |
| **Medium-Term Outcomes** | | |
| Leading building professionals improve or construct cost-effective, high performance (above-code) homes | • Adoption of ES Homes by leading homebuilders<br>• Number of ES homes that incorporate above-code BA innovations, by year and climate zone | • Scoping interviews<br>• Review of ES Homes data |
| 10,000s of ES Homes completed by BA partners (early adopters) and other ES building partners | • Adoption of ES Homes by leading homebuilders<br>• Number of ES homes that incorporate above-code BA innovations, by year and climate zone | • Scoping interviews<br>• Review of ES Homes data |
| Market performance and customer feedback confirms the new approach | • Not directly addressed in the evaluation | • N/A |

| LOGIC MODEL ELEMENTS | METRICS | EVALUATION SOURCES/METHODS |
|---|---|---|
| Private guarantee programs (e.g., Masco's EFL) adopt BA innovations | • Not directly addressed in the evaluation | • N/A |
| Building science experts submit proposals to Code that reflect BA innovations, backed by the support of a critical mass of builders who have proven that the solutions are cost-effective and work in real-world settings | • Number and description of BA innovations submitted for IECC 2006, 2009, 2012<br>• Nature and extent of BA's contribution to energy-saving code proposals | • Review of energy code proposals<br>• Interviews with building energy code experts |
| Code adopts innovations (e.g., Thermal Bypass Checklist) and building industry standards adopt innovations (e.g., ASHRAE 62.2) | • Number and description of BA innovations submitted for IECC 2006, 2009, 2012<br>• Nature and extent of BA's contribution to energy-saving code proposals | • Review of energy code proposals<br>• Interviews with building energy code experts |
| **Long-Term Outcomes** | | |
| Mainstream builders and remodeling industry improve their current practices based on sound building science developed by BA | • Trends in homebuilding practices including use of selected practices<br>• Nature and extent of BA's role in helping to mainstream selected building practices<br>• Extent to which homebuilders use EE innovations advanced by BA when not required by code | • Scoping interviews<br>• Delphi Panel<br>• Homebuilder interviews |
| High-performance home technologies and best practices become standard practice (wide-scale market acceptance and adoption of cost-effective whole home energy savings) | • Extent to which selected practices have become standard practice and have been adopted by ES Homes and/or IECC<br>• Attribution of market changes to BA<br>• Number of new housing permits in states that have adopted codes with BA innovations<br>• Number of ES homes with above-code BA innovations<br>• Qualitative assessment by homebuilders about the degree to which selected practices have become "standard practice" | • Scoping interviews<br>• Delphi Panel<br>• Review of housing start data<br>• Review of ES Homes data<br>• Homebuilder interviews |

| LOGIC MODEL ELEMENTS | METRICS | EVALUATION SOURCES/METHODS |
|---|---|---|
| Improvements in codes and building industry standards make the use of EE technologies/ practices the market standard for new and remodeled homes | • Extent to which selected practices have become standard practice and have been adopted by ES Homes and/or IECC<br>• Attribution of market changes to BA<br>• Number of new housing permits in states that have adopted codes with BA innovations<br>• Number of ES homes with above-code innovations demonstrated by BA<br>• Qualitative assessment by homebuilders about the degree to which selected practices have become "standard practice"<br>• Nature and extent of knowledge spillovers from new residential construction to the retrofit market | • Scoping interviews<br>• Delphi Panel<br>• Review of housing start data<br>• Review of ES Homes data<br>• Homebuilder interviews<br>• Citation analysis |
| Energy savings and other resource savings | • Estimated whole-home energy savings from combinations of selected innovations, multiplied by the number of homes with those innovations<br>• Percentage of modeled energy savings that can be attributed to BA as opposed to rival factors | • Energy modeling in BEopt<br>• Review of housing start data<br>• Review of ES Homes data<br>• Delphi Panel |
| Improved health and comfort of building occupants | • Unable to measure or infer this within the parameters of this evaluation (see explanation in moisture management discussion in Chapter 2 and Appendix A) | • N/A |
| Improved housing quality and industry profitability | • Unable to measure or infer this within the parameters of this evaluation | • N/A |
| Environmental health effects from reduced electricity generation | • Reduced air pollutants ($CO_2$, $NO_X$, $SO_2$, and $PM_{2.5}$) due to reduced electricity generation (using attribution-adjusted energy savings)<br>• Avoided mortality and morbidity (incident rates and dollar value of avoided adverse health events) | • Attribution-adjusted electricity savings<br>• eGRID and Integrated Planning Model<br>• EPA damage per ton values (based upon peer-reviewed work and willingness-to-pay research) |
| Additions to the knowledge base | • Frequency with which BA and/or BA practices are cited in leading trade journals<br>• Citations of the original articles<br>• Knowledge dissemination and spillover reported by homebuilders | • Citation analysis<br>• Homebuilder interviews |
| Social return on DOE/EERE investment | • Internal rate of return<br>• Net present value<br>• Benefit-cost ratio | • Monetary value of attributed energy savings<br>• Monetary value of attributed environmental health benefits<br>• Analysis of program cost data<br>• Economic analysis |

### DATA SOURCES

This section describes the existing data sources and new data collections that the IEc team used in conducting the evaluation.

#### Existing Data Sources

The evaluation draws on several existing data sources, including program background information, portfolio cost data, project details, program publications, home energy trend data, and market data. Each source is described briefly below.

- **Background documents:** To gather general information on the BA program's activities and goals, the IEc team reviewed a number of documents, which include, but are not limited to: program logic models (unpublished); the 2015 Building America Research-to-Market Plan;[40] a prior evaluation of the program published in 2004;[41] a draft impact assessment report currently being completed by NREL; and a narrative of BA's program history written by the former program manager of BA (unpublished).
- **Portfolio costs:** A key focus of this evaluation is to compare the benefits of selected practices to overall portfolio costs. DOE provided the IEc team with budget data for the BA program in the form of a summary Word document. Separately, DOE provided all available Congressional Budget Requests from 1995 through 2015 to the IEc team. The IEc team used this information to estimate BA portfolio costs.
- **Project details:** The IEc team reviewed a variety of data sources to understand BA's accomplishments and help us identify practices for in-depth study. The first was Top Innovation profiles featured on BA's website, which highlight practices demonstrated by the program that have been particularly successful in the market. Another document that provided information on particularly successful practices was the "Building America System Research Results: Innovations for High Performance Homes" report,[42] which summarizes BA achievements from 1995 to 2006. The IEc team also received project lists from NREL, who manages contracts for the BA program. These project lists varied in the amount of data available, with older project lists containing significantly less detail than more recent lists. These data generally provided the following details: team name, year, and project description. NREL also provided a list of team members and partners, which the IEc team used in developing the universe of production builders for the BA builder interviews.
- **Program publications:** BA provides guidance to the building industry on home energy efficiency issues. The Building America Solution Center[43] provides a variety of resources, including but not limited to: checklists for energy efficiency programs, building science publications, and "climate packages" which outline practices that can be used in different climate zones to reach 30% energy

[40] U.S. Department of Energy. *Building America Research-to-Market Plan*. November 2015.

[41] Norber-Bohm, Vicki and White, Chad. *Building America Program Evaluation*. September 2004.

[42] U.S. Department of Energy. *Building America System Research Results: Innovations for High Performance Homes*. May 2006. http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/building_america_lessons_2006.pdf

[43] https://basc.pnnl.gov/

efficiency above code. Other tools and guidance that BA provides include: case studies; Best Practice Guides; Top Innovation profiles; Window Replacement, Rehabilitation, and Repair Guide; Quality Management System Guidelines; Energy and Environmental Building Alliance (EEBA) Builder's Guides; EEBA Water Management Guide; Attic Air Sealing Guidelines; National Residential Efficiency Measures Database; Building America House Simulation Protocol (HSP); Building Energy Optimization Analysis Method (BEopt); and the Domestic Hot Water Event Schedule Generator. We inquired about many of these publications during the builder interviews. We also received detailed lists of publications from PNNL and NREL.

- **Home energy trend data:** The IEc team received data on HERS Index scores over time from RESNET. Home energy ratings, such as HERS, capture the energy efficiency of homes, without the influence of plug loads. RESNET was able to provide the average score for a home built in the 1970s, the score of a home built to the 2006 IECC, and the average score for homes built in 2013 to 2015. They also provided the number of homes with HERS ratings from 2009 to 2015.
- **Market uptake data:** To determine the market uptake of the four selected practices, the IEc team reviewed changes to ES Homes, the IECC, and California's Title 24. For ES Homes, the IEc team reviewed the three versions of the program requirements, and interviewed EPA staff about which particular requirements were influenced by BA. To explore BA's influence on the IECC, the IEc team reviewed a set of unpublished documents from BTO's chief architect and code proposals. BTO's documents highlighted major changes in the IECC from 2003 to 2012 and noted which changes were influenced by BA. The IEc team reviewed the proposals associated with these changes, for the purpose of noting who proposed the change and the details of the change. For California's Title 24, the IEc team reviewed multiple versions of the code and identified if and when practices from BA were incorporated. The IEc team confirmed the involvement of BA on the chosen practices through scoping interviews with building science experts.
- **Market data:** As discussed below in the section Approach to Estimate Energy Savings, to calculate energy savings from practices advanced by BA, the IEc team multiplied the modeled energy savings of selected practices by the number of homes that have incorporated the selected practices. This analysis required data on the number of new homes by state and year and the number of new Energy Star homes by state and year. The IEc team used housing permit data from the Census Building Permits Survey for the number of new homes by state and year. EPA provided the number of ES Homes by state and year.

#### New Data Collection via Interviews

Interviews were the primary data collection method for this evaluation. The evaluators conducted interviews with approximately 50 individuals, including: scoping interviews with 17 building science experts, two rounds of interviews with 9 Delphi Panel members, interviews with 17 homebuilders in four distinct categories, and interviews with 9 energy code experts. Table 3-2 summarizes the interviews by type/purpose, number, composition, and timeframe during which the interviews were conducted. Further details about interview selection, administration, and use are provided following the table.

TABLE 3-2. SUMMARY OF INTERVIEWS CONDUCTED

| TYPE AND PURPOSE OF INTERVIEW | NO. OF INTERVIEWEES | COMPOSITION | TIMEFRAME |
|---|---|---|---|
| **Scoping interviews with building science experts:*** Help scope the evaluation and select practices to include in the evaluation; and provide input for the BA program logic model. | 17 | 8 BA team members; 9 non-BA from public and private sectors | January – February 2016 |
| **Delphi panel:*** Review the energy reduction benefits estimated by the energy modeling exercise and consider the role of the BA program versus rival factors in advancing market acceptance of the four selected energy efficiency practices. | 9 | 5 members with substantial involvement in BA; 3 members with negligible or indirect involvement with the program; and 1 member with no involvement with the program | Round 1: February-March 2017<br>Round 2: May 2017 |
| **BA builders with no California closings:** Examine the BA program's role in supporting the development and demonstration of the selected practices, and the subsequent adoption of these practices in the new residential construction market. | 5 | 5 BA builders with no CA closings | August-October 2017 |
| **BA builders with California closings:** Examine to what extent, if any, the BA program helped California builders come into compliance with Title 24, or go beyond compliance in a more cost-effective manner. | 5 | 5 BA builders with CA closings | August-October 2017 |
| **Non-BA builders with no California closings:** Examine how, if at all, non-BA builders are influenced by the diffusion of specific practices demonstrated and/or diffused by the BA program. | 4 | 4 non-BA builders with no CA closings | August-October 2017 |
| **Non-BA builders with California closings:** Explore the extent of knowledge spillovers, if any, from BA builders with closings in California to non-BA builders with closings in California. | 3 | 3 non-BA builders with CA closings | August-October 2017 |
| **Energy code experts:** Understand the contribution of BECP toward moving specific energy efficiency practices into model energy codes. | 9 | Balanced representation for public sector, private sector, and advocacy/interest groups | August-December 2016 |
| **Total** | **52 (49)*** | | |

Note (*): Three of the same individuals participated in the scoping interviews and Delphi panel. All of the other interviewees are additive and non-overlapping – i.e., 49 unique individuals were interviewed for this evaluation.

### Scoping Interviews with Building Science Experts

The IEc team conducted a round of interviews with 17 building science and other experts to help scope the evaluation and select practices to include in the evaluation. Specific topics discussed with experts included: factors influencing trends in residential energy use over the past 20 years; BA's role and influence within the housing industry; BA's relationship to ES Homes and RESNET/HERS; the impact of BA on specific energy efficiency and moisture management practices; drivers external to BA that affected uptake of energy efficiency and moisture management practices in new residential construction; feasibility of various approaches to analyzing potential moisture management benefits of practices pioneered by BA, and potential warranty callback data sources; and spillover of practices advanced by BA to the renovation market.

Appendix B includes the generic interview guides that the IEc team used to conduct the scoping interviews; we have one for experts that were BA team members and one for experts that had not worked under contract with BA. We customized the interview guides as appropriate for each individual interview, adding questions about relevant topics particular to interviewee expertise. In keeping with Paperwork Reduction Act (PRA) requirements, we did not ask the same or similar question to more than nine interviewees subject to the PRA. In addition, for experts that had worked under contract as a BA team member, we also asked for feedback on the program logic model, and made some minor updates to the logic model based on common comments from experts. The experts' comments on the logic model are integrated in the logic model diagram presented earlier in Figure 1-4.

Table 3-3 below provides a summary of scoping interviews conducted with building science experts and other industry experts. We selected the experts based on recommendations from building scientists on the IEc team as well as recommendations made by DOE. We aimed to strike a balance between experts who are knowledgeable about BA and experts who are independent from the BA program. It was difficult to identify building science experts who never worked on a BA team but felt confident providing comprehensive feedback on the impact of BA's work on specific practices. However, BA team members were highly consistent in their comments about the relative impact of BA on various energy efficiency and moisture management practices, which made the selection of practices to include in the evaluation a more straightforward task. We conducted a second round of more targeted interviews, using customized and shorter interview guides, to collect additional information on the regulation of building energy in CA, and on moisture management and builder callbacks.

**TABLE 3-3. SUMMARY OF EVALUATION SCOPING INTERVIEWS CONDUCTED**

| EXPERTS INTERVIEWED | | | EXPERTISE | | |
|---|---|---|---|---|---|
| FIRM/ORGANIZATION | PERSONS INTERVIEWED (#) | BA TEAM MEMBER? | BA EE PRACTICES | CA TITLE 24 AND CA REGS | MOISTURE ISSUES / CALLBACKS |
| BSC | 3 | Yes | X | X | X |
| IBACOS | 2 | Yes | X | | X |
| CARB | 1 | Yes | X | | X |
| BIRA/ Consol | 2 | Yes | X | X | X |
| Mason-Grant Consulting | 1 | No | X | | |
| California Energy Commission | 2 | No | | X | |
| Ann Edminster (sole proprietor) | 1 | No | | X | |
| LBNL | 1 | No | X | | X |
| RESNET | 1 | No | X | | |
| State Farm | 1 | No | | | X |
| Thrive Builders | 1 | No | | | X |
| Bushnell and Associates | 1 | No | | | X |

In addition to the comprehensive scoping interviews, the IEc team also utilized our network of contacts in the building sector to address several ad hoc questions about code applicability, segmentation of the building industry, and other background topics.

### Delphi Panel

IEc convened a Delphi panel of nine experts from the private and public sectors to review the energy reduction benefits estimated by the energy modeling exercise and consider the role of the BA program versus rival factors in advancing market acceptance of the four energy efficiency practices. The Delphi process, generally speaking, seeks to synthesize expert judgement by conducting an iterative series of interviews with experts knowledgeable in a particular subject matter. Results from individual interviews are aggregated and distributed back to the initial participants in summary form for additional consideration and revision. The process usually iterates for two to three rounds, eventually converging on an agreed upon result or narrow range of results. The Delphi Panel process for this study was conducted over two rounds.

Experts selected for this Delphi panel have broad and deep knowledge of:

- Building science and residential energy efficiency challenges;
- Public policy interventions to address residential energy use in the U.S. over the last 20 years;
- Trends in U.S. residential energy efficiency;
- BA program activities;
- The fundamentals of how energy modeling works in order to understand how it was used for this project and the results produced; and
- A willingness to spend up to a day of time reviewing background information on this evaluation necessary for providing informed input.[44]

We recruited Delphi panelists based on recommendations from building science experts and IEc's professional network. During our scoping interviews with building science experts (see above), we asked interviewees for recommendations on other experts that may fit our selection criteria. We also relied on IEc's network of contacts in the building science field and industry research to identify potential additional members. Once potential members were identified, we contacted them to ascertain their availability and eligibility to participate in the panel. We faced some challenges in the recruitment process – namely, that the field of building science experts with residential energy efficiency specialization is small. Given such a small field and the dominance of the BA program in the field, it was difficult to identify experts with no involvement with the BA program. Thus, our final panel consisted of five members with substantial involvement with the program,[45] three members with negligible or indirect involvement with the program, and one member with no involvement with the program. Due to the requirements of the Paperwork Reduction Act, the Delphi panel was limited to nine members. To encourage a candid assessment of BA's influence, we promised anonymity to the Delphi panel members.

[44] Panelists received honoraria for their participation.

[45] Among the five Delphi panel members who had substantial involvement with the BA program, three of them overlapped with individuals interviewed during the scoping stage.

As described above, a Delphi panel relies on an iterative process, wherein interviews are conducted with the panel members, and the results of that first round of interviews are circulated back to the panel members, to potentially adjust in a follow-up interview. Specifically, this Delphi panel was conducted in the following steps:

- **Send Delphi panel materials to panelists to review (see Appendix C):** Once the panel members were recruited, the first step was to send them materials to review. Panelists needed to review the materials to make an informed estimate of the energy savings to attribute to the BA program. These materials included: 1) an introduction to the purpose of the effort and a general introduction to the program; 2) a description of the evaluation process overall, including a detailed discussion of the energy savings methodology; 3) a discussion of the attribution approach, and the role of the Delphi panel; 4) a lengthier description of the BA program and its historical context and activities; 5) detailed descriptions of the four selected practices; and 6) an explanation of the energy modeling approach and results. We also provided the interview guide (in Appendix C).

- **Conduct Round 1 interviews:** After the panel members reviewed the materials and considered their charge, we conducted the first round of interviews. In this round, we asked panel members to identify what, if any, other drivers may have influenced the market acceptance of each practice. We also asked them to consider if the market acceptance of each practice would have occurred at the same scale or in the same timeframe without the BA program. For each practice, we asked:

  - External to BA, what, if any, *other drivers* do you think influenced the market acceptance of the practice?
  - Without BA, would the market acceptance of the practice have occurred at the same *scale*? Please explain.
  - Without BA, would the market acceptance of the practice have occurred in the same *timeframe*? Please explain.

  Finally, for each practice, we asked the panel members to estimate the percent of the modeled energy benefits of the practice they think should be attributed to the BA program vs. other drivers. As such, the Delphi panel's attribution estimates reflect their assessment of BA's role in accelerating and increasing the scale of market adoption of the four selected practices.

- **Compile Round 1 results into summary memo:** Following the first round of interviews, we compiled the responses into a summary memo, which we distributed to the panel members. Each panel member received an individualized memo that provided: 1) a summary of the panel's input on the BA program's influence in promoting market acceptance and adoption of each practice in the new residential market; 2) a summary of the external drivers identified by the panelists, and the number of panelists who identified each driver; 3) a chart with the percentage of energy savings that can be attributed to the BA program, disaggregated for each of the nine panel members (with the individual's estimate circled), and the average value assigned by the panel; and 4) a table with a brief summary of the rationale provided for each member's estimate (with the individual's estimate and rationale highlighted).[46]

[46] The summary memo anonymized the panel members.

- **Conduct Round 2 interviews:** After the panelists reviewed the summary memo from the first round of interviews, we conducted another interview with each panel member. In this second round of interviews, we asked panelists to consider how their responses compare to their peers' responses, and to revisit the same questions from the first interview, with the added benefit of input from their peers. Specifically, we asked the panelists if there were additional channels of influence of the BA program they were compelled to consider, and if there were any channels of influence identified by other panel members with which they disagree. Then, for each practice, we asked the panelists if there are additional external drivers they now think influenced the market acceptance of the practice, and if they have any additional thoughts on how the external drivers influenced the scale and timeframe of acceptance of the practice. Finally, we asked panel members if they would like to adjust the percent of the benefits of the practice they attribute to the BA program.
- **Synthesize results of Delphi panel:** Based on the results of the Round 2 interviews, we synthesized the final thoughts of the panel members on the influence of the BA program, the external drivers that influenced the market acceptance of each practice (including scale and timeframe of acceptance), and the final estimate of the percentage of the modeled energy benefits that can be attributed to the BA program.

#### Interviews with Homebuilders

The IEc team collected primary data from production builders in phone interviews. These interviews were conducted with program participants, as well as non-program participants, and focused on practice adoption and influence of the BA program on the industry.

The primary objective of these interviews was to obtain the perspective of builders for the evaluation. The interviews are used to help the IEc team understand BA's role in supporting the development and demonstration of the four selected practices, and the subsequent adoption of these practices in the new residential construction market. The results also allow the team to probe whether and how non-BA builders are influenced by the diffusion of the selected practices, to determine if there is a "spillover" effect of BA's activities. Finally, the results address the extent to which the BA program supported builders in California to come into compliance with Title 24.

The target population for this effort was the production home builders in the United States. Production builders are defined as those that build on land owned by the building firm, and use stock plans to construct a large number of buildings each year. This is in contrast to custom builders, who build unique, architect-designed custom homes.[47] We targeted production builders because BA focused on working with them for most of the program's history.

We identified the top 200 production builders in the U.S. (in terms of total closings) through Builder Online's annual "Builder 100" and "Next 100."[48] The top 200 production builders in the U.S. hold a vast majority of the production homes built each year. Next, we compiled the list of all builders participating in the BA program during the full course of the program's history. We then conducted a crosswalk of the two lists to create four distinct groups, as summarized in Table 3-4. As noted above, one of the goals of

[47] http://architecture.about.com/cs/buildyourhouse/g/production.htm

[48] "2015 Builder 100" and "Next 100." Builder Online. http://www.builderonline.com/builder-100/builder-100-list/2015/

the interviews was to determine what, if any, impact BA has had on California builders' ability to come into compliance with Title 24 in a cost-effective manner.

### TABLE 3-4. SUMMARY OF PRODUCTION BUILDERS

| | BA PARTICIPANTS | NON-BA PARTICIPANTS |
|---|---|---|
| California Builder | 17 | 14 |
| Non-California Builder | 13 | 156 |

Initially, the IEc team designed a data collection methodology that involved a statistically valid survey of BA builders and non-BA builders. The survey would have addressed similar objectives to those outlined above; however, the sampling approach was designed to produce robust results that could potentially be extrapolated to the entire population of builders.[49] Specifically, the responses of the two groups could be compared to determine whether or not there is a statistically significant difference between the responses of the BA builders and the responses of the non-BA builders. In 2016, the IEc team followed OMB guidelines for requesting information from the public, as stipulated in the Paperwork Reduction Act.[50] Following these guidelines, the IEc team worked with DOE to complete and submit an Information Collection Request (ICR) to OMB, including publishing a 60-day notice in the Federal Register. The IEc team prepared and delivered a briefing for OMB on the survey effort, and responded to multiple rounds of comments on the submissions. OMB also approved a pre-test of the interview guide and recruitment procedures. However, after 17 months of discussion with OMB, DOE decided not to continue to pursue ICR clearance, as it appeared unlikely that clearance would be obtained in time to conduct the survey during the evaluation period.

Therefore, the IEc team developed a revised approach for achieving as many of the objectives of the survey effort as possible while adhering to OMB guidelines. This approach, while not providing statistical rigor, provided a broader understanding of the topics, and allowed the team to probe for more details from builders on the topics explored. For each group, the IEc team compiled all responses to open-ended questions and created a coding scheme to organize and analyze the results. The IEc team distilled each response into the relevant takeaway point(s), and categorized these points across responses.

A total of 17 builders were interviewed for this effort, in each of the four groups:

1. BA builders with California closings: 5 builders
2. BA builders with no California closings: 5 builders
3. Non-BA builders with California closings: 3 builders

[49] In other words, the responses of the builders that we selected for the survey could be used to represent the responses of the entire population of builders.

[50] Under this Act, federal agencies are required to seek public comment on proposed collection efforts and to submit proposed collections for review and approval by OMB. This applies to any survey asking identical questions of ten or more non-federal persons within a 12-month period. "Memorandum for the Heads of Executive Departments and Agencies, and Independent Regulatory Agencies: Information Collection under the Paperwork Reduction Act." Executive Office of the President: Office of Management and Budget. April 7, 2010. https://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/PRAPrimer_04072010.pdf

4. Non-BA builders with no California closings: 4 builders

Each of these groups was interviewed separately, with separate interview guides (see Appendix D for the interview guides for each group of homebuilders).

Across the four groups, interviewees represent a range of regions across the United States. As shown in Table 3-5, the majority of builders build homes in the West, and about half of the builders build in the South and Midwest.

#### TABLE 3-5. SUMMARY OF REGIONS

| REGION* | BUILDERS (%)** |
|---|---|
| Northeast | 6 (35%) |
| West | 14 (82%) |
| South | 8 (47%) |
| Midwest | 8 (47%) |
| Pacific | 1 (6%) |
| *The regional classifications in this table are from Builder Online magazine. **Note that some builders build homes in multiple regions; therefore, the column does not total to 100%. | |

#### Interviews with Energy Code Experts

During the implementation phase of this project, the IEc team conducted interviews with nine building energy code experts. The main purpose of the interviews with energy code experts was to seek expert opinion on the contribution of BECP toward moving specific energy efficiency practices into model energy codes. As such, further details about these interviews are provided in Chapter 10 (BECP Analysis). The interview guide for energy code experts is provided in Appendix E.

### COUNTERFACTUAL APPROACH AND ATTRIBUTION

In conducting the energy modeling exercise in BEopt, the evaluators gave careful consideration to the counterfactual. For production homes, standard construction practices with energy efficiency implications are defined by energy code. In other words, for advances in energy practices that made it into code, once they are in code, the counterfactual is the same vintage of code *without* the more stringent practices. This is because prior to BA, production home builders in the U.S., as a general rule, did not build homes with better energy efficiency performance than what was required by code. For practices that were in ES Homes but did not make it into code, or were not yet in code during some of the years of our analysis, the counterfactual is specified as an ES Home that would have existed without the more stringent practices. Appendix F summarizes the counterfactual for each state and each analytical timeframe.

The many parameters of previous energy code requirements are pre-programmed into BEopt, which the IEc team used to estimate the combined energy savings of the selected practices. BEopt is specifically designed to compare innovative building energy efficiency practices to a conventional home designed only to meet energy code. Because adoption of energy code varies dramatically by state, the building modeling conducted for this study takes state adoption into consideration, and compares the energy savings of selected practices to the code requirements that would have otherwise been in effect, in each year of our analysis. The modeling approach also accounts for the fact that some homes would have been

Energy Star homes; for those homes, we look at the impact of the four practices using a counterfactual of an ES Home that would have existed without the more stringent practices adopted. Details on the modeling approach can be found in Appendix F.

In developing the methodology for this evaluation, the evaluators paid particular attention to designing an approach that allows us to attribute energy savings and other benefits with confidence to the BA program. Specifically, the study uses a tiered approach to attribution:

1. Selection of Energy Efficiency Practices
    a. Due Diligence File Review
    b. Scoping Interviews with Building Science Experts
2. Quantitative Adjustment of Energy Modeling Results: Delphi Panel
3. Qualitative Methods
    a. Homebuilder Interviews
    b. Citation Analysis

### Selection of Energy Efficiency Practices

#### Due Diligence File Review

The evaluators first looked for evidence that specific energy-saving improvements integrated into above-code programs and energy codes can be traced directly back to BA program activities, as evidenced in the project data files and BA Top Innovations.

For example, as shown in Table 3-6, the IEc team systematically searched project data to identify projects associated with practices mentioned by BA staff and ES Homes staff as demonstrated and diffused by BA. For example, IEc searched the project data for “advanced framing,” and found this term in 36 project descriptions. Where possible, IEc then determined which BA team(s) worked on the largest number of projects related to each practice. For example, CARB/DEG worked on 12 out of 36 projects (more than any other BA team) whose description included “advanced framing.”[51]

[51] Note that the table is not designed to be a comprehensive list of BA accomplishments. Rather, it presents key words in BA project files primarily for the four practices that were ultimately selected for in-depth study.

### TABLE 3-6. FREQUENCY OF BA PROJECTS FEATURING ENERGY EFFICIENCY PRACTICES EXAMINED FOR INCLUSION

| EE SEARCH TERM | EE PRACTICE | TOTAL PROJECT COUNT FOR SEARCH TERM | MOST COMMON TEAM | # OF PROJECTS FROM MOST COMMON TEAM |
|---|---|---|---|---|
| Advanced Framing | Thermal bridging | 36 | CARB/DEG | 12 |
| Air Barrier | Air leakage | 2 | FSEC | 2 |
| Air Infiltration | Air leakage | 49 | BIRA | 49 |
| Air Sealing | Air leakage | 17 | CARB/DEG | 11 |
| Attic Insulation and/or Radiant Barrier | Insulation | 35 | BIRA | 19 |
| Attic/Ceiling Interface | Insulation | 1 | unknown | NA |
| Duct Leakage | Duct leakage | 8 | BAIHP | 6 |
| Floor Insulation | Insulation | 6 | BAIHP | 4 |
| ICFs | Insulation | 9 | CARB/DEG | 5 |
| Insulation/ Thermal Alignment | Insulation | 1 | unknown | NA |
| Insulation Placement | Insulation | 1 | unknown | NA |
| SIPs | Thermal bridging | 25 | BIRA | 6 |
| Thermal Bridging | Thermal bridging | 3 | BSC | 2 |
| Thermal Bypass | Air leakage | 5 | ARBI | 1 |
| Unconditioned + Infiltration | Duct leakage | 2 | BAIHP | 2 |
| Unconditioned + Insulation | Duct leakage | 1 | FSEC | 1 |
| Unconditioned + Sealing | Duct leakage | 2 | BAIHP | 2 |
| Unvented Crawl Spaces | Duct leakage | 3 | BAIHP | 2 |
| Water Heating/ Space heating Combined Systems | Mechanical | 1 | FSEC | 1 |

Note: Project data available to the IEc team was incomplete, and therefore the project counts shown here may be low. Note that the "most common team" is based on the partial data provided to IEc; however, other teams may have been active, but not be reflected in the data. Overall, the data (though partial) shows that BA worked on the four practices that this evaluation addresses in detail.

#### Scoping Interviews with Building Science Experts

As discussed above, during the initial scoping for this evaluation, the evaluators asked building science experts to identify practices that were substantially influenced by the BA program and cross-checked their reports with other interviewees. The evaluators asked the experts directly about rival hypotheses, including research carried out by national labs but not under the BA umbrella, and research carried out by the private sector. The four energy efficiency practices selected for evaluation were consistently mentioned by the building science experts as ones that BA substantially demonstrated and diffused in the marketplace, and that would not have been adopted into ES Homes and/or energy code without BA's work to demonstrate their technical and economic feasibility.

### Quantitative Adjustment of Energy Modeling Results: Delphi Panel

Once the building energy modeling was complete and produced estimates of energy savings from the selected practices, the evaluators quantitatively adjusted the results for attribution. Specifically, we used the Delphi Panel of experts to review the energy modeling results for the four selected energy efficiency practices, consider external factors that may have contributed to the results, and potentially downward adjust the results to reflect external factors. The Delphi panel process is described in the Primary Data Collection section above.

### Qualitative Attribution Methods: Builder Interviews and Citation Analysis

We used two additional methods during the implementation phase of the evaluation – builder interviews and citation analysis – to further assess attribution.

As described above, we used the builder interviews to examine the BA program's role in supporting the development and demonstration of the selected practices, and the subsequent adoption of these practices in the new residential construction market.

Finally, the IEc used a citation analysis to further probe attribution. Because the BA program rarely generates patents or other intellectual property, the evaluation employed a publication citation analysis to measure the dissemination of knowledge that can be traced back to BA. Details about the citation analysis are provided below in the section Approach to Estimate Knowledge Benefits.

## APPROACH TO ESTIMATE BA PROGRAM BENEFITS

This section describes the methodology used to estimate benefits in each of the four main impact categories covered in this evaluation.

### Approach to Estimate Energy Savings

Our approach for estimating energy impacts of the BA program is to model the impacts of the four selected practices. The impacts of those practices were estimated using energy modeling to account for interactive effects. The modeling also accounts for differences across states/climate zones and progressions in market penetration over time.

To conduct this analysis the IEc team used BEopt. BEopt was developed with partial funding from BA for multiple purposes, including standardization of energy savings analysis across BA teams. The IEc team considered various modeling programs and determined that BEopt was the most appropriate energy modeling program for this evaluation. BEopt uses state-of-the-art building energy simulation engines (DOE-2 or EnergyPlus) and accounts for interactive effects. Additionally, BEopt has a built-in reference home consistent with IECC 2009, which was leveraged to create other reference homes for this study, and made the modeling process more efficient by streamlining the process of developing counterfactuals. Also, by establishing consistent operating conditions and other assumptions in accordance with the BA House Simulation Protocols (HSP),[52] using BEopt prevents "gamesmanship" in the modeling process, which could exaggerate energy savings through manipulation of hidden variables in the energy models. The standard assumptions built into BEopt were established by NREL through a consensus process of

[52] *2014 BA House Simulation Protocols*. 2014. Wilson, E.; Engebrecht, C. Metzger; Horowitz, S.; Hendron, R. NREL Technical Report TP-5500-60988. National Renewable Energy Laboratory. Golden, CO, Available at: http://energy.gov/sites/prod/files/2014/03/f13/house_simulation_protocols_2014.pdf

leading building scientists, with the sole objective of providing realistic and accurate energy savings estimates for houses constructed as part of BA. Appendix F documents the parameters used in the analysis and provides the results of sensitivity analyses to explore the effects of key modeling assumptions.

The modeling was conducted using a range of housing attributes in several locations throughout the U.S., with adjustment factors applied to the results to accurately extrapolate them over the broad range of housing characteristics and weather conditions present in different parts of the country. The results were rolled up nationwide using state-level weighting factors and data for actual housing starts over the period 2006-2015.

The modeling approach focused on the four selected practices: air leakage and infiltration requirements, duct leakage requirements, insulation requirements, and thermal bridging requirements. "Intervention" homes were modeled with those practices integrated, compared to "counterfactual" homes that would exist at that point in time without those practices integrated. Specifically, each intervention home was defined as a home that meets the applicable statewide code or Energy Star requirements during a specific timeframe, including any of the four studied practices that have been adopted.

To measure the incremental impact provided by the studied practices, the corresponding counterfactual home was defined as a code minimum or ES home that would have existed during that same timeframe in a counterfactual world wherein these practices had not gained enough market acceptance to be included in ES Homes and/or code. For code minimum homes, the counterfactual input was simply the value required by the IECC in the cycle preceding the introduction of the studied practice. For building attributes other than those associated with the four studied practices, the same requirements of the code or ES were used for both the counterfactual and intervention cases. Continuing enhancements to the counterfactual inputs over time due to market forces or inevitable technical advancements were not included in this analysis.

Because the studied practices came online at different points in time, a temporal analysis was necessary to reasonably assess their impact. In addition, states adopt energy codes on their own cycles, which meant that some state-by-state analysis was required to determine impacts at the state level.

The steps in the modeling process are summarized as follows; a more detailed discussion of the modeling approach is included in Appendix F.

- **Step 1: Aggregate by time periods and states** – Develop reasonable groupings of time periods and states based largely on building code cycles and code adoption rates. States were divided into leading, average, and laggard groups according to the rate at which they adopted model building codes. This aggregation is summarized in Table 3-7.
- **Step 2: Select locations** – Identify representative cities based on five climate zones, a relatively active construction market, and not affected by IECC 2004 climate map boundary changes.
- **Step 3: Convert general building practices to modeling attributes** – Translate each of the four practices as expressed in building code and ES Homes terminology into modeling settings, mostly based on climate.

### TABLE 3-7. DATE EACH PRACTICE BECAME MANDATORY IN CODES AND ENERGY STAR HOMES

| STATE GROUPINGS | PRACTICE 1: AIR | PRACTICE 2: DUCTS | PRACTICE 3: INSULATION | PRACTICE 4: THERMAL BRIDGING |
|---|---|---|---|---|
| | Year Required in Code | | | |
| Leaders - Intervention | 2009 | 2009 | 2006 | 2012 |
| Leaders - Counterfactual | - | - | - | - |
| | | | | |
| Average - Intervention | 2012 | 2012 | 2009 | - |
| Average - Counterfactual | - | - | - | - |
| | | | | |
| Laggards - Intervention | - | - | 2012 | - |
| Laggards - Counterfactual | - | - | - | - |
| | | | | |
| | Year Required in Energy Star | | | |
| Intervention - Energy Star | 2006 | 2006 | 2006 | 2012 |
| Counterfactual - Energy Star | - | - | - | - |

- **Step 4: Establish model settings –** Using the simplest version of the prescriptive path, or the reference home for the performance path, or the settings of the BEopt built-in baseline derived from the House Simulation Protocol (prioritized in that order), translate code and ES requirements into BEopt model settings.
- **Step 5: Apply sensitivity analysis –** To manage the number of modeling runs, establish four criteria and employ them to categorize building attributes (such as square footage or foundation type) as requiring (or not) sensitivity analysis and the subsequent development of adjustment factors for post-processing of modeling results.
- **Step 6: Create modeling scenarios** – Create a detailed matrix to ensure that the modeling runs captured all of the results of Steps 1 through 5 above, for a total of 209 unique modeling events.
- **Step 7: Run all energy modeling simulations** – Express modeling run results graphically and review for anomalies and patterns that either “made sense” or warranted double-checking based on the modeling team’s experience with representative savings per home, per climate, and per attribute.
- **Step 8: Post-process modeling results** – Perform spreadsheet post-processing involving the application of sensitivity analysis, adjustment factors, and weighting factors (for example, to represent the correct mix of house sizes and foundation types for each state). Spreadsheet processing also included expansion of modeling results to cumulative interim (pre-Delphi panel adjusted) totals: per time period, per state, and nationwide.

Post modeling, the IEc team used home construction statistics to estimate state-level total site energy savings, and nationwide savings, for each year, sorted by fuel type and practice. The IEc team multiplied the modeled energy savings of the four selected practices by the number of homes that have incorporated the selected practices. This analysis required data on the number of new homes by state and year and the number of new ES homes by state and year. The IEc team used housing permit data from the Census Building Permits Survey for the number of new homes by state and year. EPA provided the number of ES homes by state and year. These data are provided in Appendix G.

We then conducted a Delphi panel to estimate the portion of the energy savings that can be attributed to BA, using the Delphi process described above. The total (gross) energy savings and Delphi panel-adjusted results are presented in Chapter 3.

#### Code Compliance

The Evaluation Plan stated we would downward adjust the aggregate modeled energy savings by applying a code noncompliance factor, using the same methodology developed by PNNL in 2014.[53] However, we subsequently learned the 2014 PNNL study does not quantify "overcompliance." Overcompliance refers to the fact that homebuilders often achieve beyond-compliance performance for some aspects of new homes. Because we hypothesize (and this is borne out by a newer/ongoing PNNL study[54]) that homebuilders who build to code, in practice, frequently exceed the energy use reduction targets in code, the 2014 PNNL study is not an appropriate match for this evaluation. PNNL is currently conducting an updated residential compliance study, which does allow for energy "overcompliance."[55] However, the current PNNL study dataset is not well-suited to estimating noncompliance for the BA program evaluation, for several reasons:

- It is not appropriate to adjust our BA energy modeling results by the state-level compliance rates in PNNL's study. Doing so would require us to assume that compliance is evenly distributed across BA practices and non-BA practices. However, PNNL's data for eight states shows that compliance is lower for BA practices (e.g., air leakage) and higher for non-BA practices. This is problematic since we specifically want to adjust the energy modeling results for BA practices.
- What matters for our analysis is changes in the compliance rate moving from one version of code to the next, but the study only provides a snapshot in time; it does not provide time-series data.
- We cannot extrapolate from compliance trends found in PNNL's study of eight states to 50 states. A state's energy code compliance rate is a function of adoption and enforcement. The PNNL study finds that states that are lagging in terms of adoption (e.g., still using IECC 2009 in 2016) have high compliance rates, presumably because compliance is easier with older, less stringent code. However, the extent to which states enforce compliance with energy codes is a separate and independent variable that cannot be inferred from the PNNL data. For example, Maryland is a leader on code adoption and enforcement; however, other leaders in adoption may not be strong in enforcement and would presumably have lower compliance rates as a result.

[53] Livingston, OV, DB Elliott, PC Cole, and R Bartlett, *Building Energy Codes Program: National Benefits Assessment, 1992-2040*. Pacific Northwest National Laboratory. March 2014.

[54] https://www.energycodes.gov/compliance/energy-code-field-studies

[55] Ibid.

- Our analysis treats ES Homes separately from code-minimum homes, but PNNL's study includes both types of homes. If PNNL's compliance rate estimates include ES Homes, this would skew the result toward a higher compliance rate than if the analysis were limited to code-minimum homes.

PNNL's current data indicate that many (or potentially most) states have new homes that on average are more energy efficient than specified by code, even if some individual buildings are not code compliant. If we take the study results at face value, it suggests that noncompliance in some homes is offset by overcompliance in other homes, and it is quite possible that these factors offset one another and that the actual energy compliance rate is somewhere around 100%. All this is to say, in the absence of better data, it is preferable not to apply any adjustment factor to the energy results rather than to use a flawed adjustment factor.

Gathering better data – for example, understanding how states enforce their code requirements – would require a significant data collection effort that would require a new ICR because it would need input from more than nine non-federal experts.[56] The BA evaluation schedule and resources did not permit seeking approval for an additional ICR beyond our attempts to obtain ICR approval for the planned builder survey. As a result, the evaluation team and DOE agreed not to apply a noncompliance adjustment factor to the energy modeling results.

#### Approach to Estimate Environmental Impacts

The residential electricity savings associated with the BA program will not only result in financial savings to residential electricity customers, but will also result in air quality benefits across much of the U.S. As electricity generation from power plants falls in response to the reduction in residential electricity demand, power plant emissions of carbon dioxide ($CO_2$), sulfur dioxide ($SO_2$), oxides of nitrogen ($NO_x$), and fine particulate matter ($PM_{2.5}$) also decline. As documented extensively in the literature, a reduction in the emissions of these pollutants leads to significant public health improvements, namely reduced incidence of premature mortality and various morbidity impacts.[57]

As described in further detail in Appendix H, our approach for estimating these benefits is based on the magnitude of the emissions reductions achieved and the damage avoided per ton of emissions. The following equation summarizes this approach:

$$A_{t,p} = M_{t,p} \times D_{t,p}$$

where $A_{t,p}$ is the air quality benefits in year $t$ associated with reduced emissions of pollutant $p$ ($CO_2$, $SO_2$, $NO_x$, or $PM_{2.5}$);

$M_{t,p}$ is the emissions reduction for pollutant $p$ in year $t$, and

$D_{t,p}$ is the damage per ton of emissions of pollutant $p$ in year $t$.

We estimate the emissions reductions achieved under the BA program ($M_{t,p}$) based on state-level estimates of the residential electricity savings attributed to the program, by year, and estimates of power

[56] IEc recently conducted a Delphi Panel to estimate compliance rates in New York State, which required input from multiple code officials from different parts of the state, different sectors, etc. – and that is for only one state.

[57] See U.S. EPA, *The Benefits and Costs of the Clean Air Act from 1990 to 2020*, April 2011, available at https://www.epa.gov/sites/production/files/2015-07/documents/fullreport_rev_a.pdf.

plant emissions per megawatt hour (MWh) of generation, frequently referred to as emission factors. This approach is summarized as follows:

$$M_{t,p} = \sum_{s} \left( L_{t,s} \times E_{p,t,s} \right)$$

where $M_{t,p}$ is as defined above;

$L_{t,s}$ is electricity savings in year $t$ and state $s$, and

$E_{p,t,s}$ is the emission factor (tons/MWh) for pollutant $p$ in year $t$ associated with electricity savings in state $s$.

In short, this approach involves multiplying state-level estimates of electricity savings by pollutant-specific emission factors and summing across states to derive a national total. Applying the emission factors derived from these sources to the electricity savings estimated each year, we estimate the emissions reductions for $CO_2$, $SO_2$, $NO_x$, and $PM_{2.5}$. Further details about our approach are described in Appendix H.

To estimate the benefits of the emissions reductions associated with reduced residential electricity consumption, we apply damage-per-ton values published by the U.S. EPA.[58,59] The EPA values represent national averages for emissions from electricity generating stations. These values reflect the full suite of health impacts that the U.S. EPA considers in its regulatory impact analyses of air pollution policy. These impacts include: premature mortality, respiratory emergency room visits, acute bronchitis, lower respiratory symptoms, upper respiratory symptoms, minor restricted activity days, work loss days, asthma exacerbation, cardiovascular hospital admissions, respiratory hospital admissions, and non-fatal heart attacks.

The damage-per-ton values are based on the peer-reviewed epidemiological literature for each of the health effects above as well as peer-reviewed studies and data specifying the value per avoided case. Where possible, these valuation estimates reflect individuals' willingness to pay (WTP) to avoid various adverse health effects. In cases where WTP estimates are not available, the EPA damage-per-ton values reflect the cost of illness associated with a health effect (i.e., the average expenditures on care per case) and/or the lost earnings per individual suffering from the effect.

For each pollutant, we use both the low and high damage-per-ton values published by EPA. These values reflect high and low impact values in the epidemiological literature for premature mortality. Presenting emissions-related benefits as a range to reflect the uncertainty in the concentration-response relationship

[58] See U.S. EPA, Technical Support Document: *Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors*, January 2013 and U.S. EPA, *Sector-based PM2.5 Benefit Per Ton Estimates*, updated on March 22, 2017, available at https://www.epa.gov/benmap/sector-based-pm25-benefit-ton-estimates. Further details about our methodology for using the data are provided in Appendix H.

[59] The approach presented here for monetizing emissions reductions is similar to using the Co-Benefits Risk Assessment (COBRA) model developed by the U.S. EPA. The primary difference is that COBRA would include state- or county-level damage-per-ton estimates rather than the national values described here. Using national damage-per-ton values introduces some uncertainty into the results, but there would also be uncertainty in using county-level dollar per ton values because we do not know the exact location of avoided emissions. In addition, using national average damage-per-ton values rather than county- or state-level values does not bias the results in one direction or the other.

for premature mortality is consistent with EPA practice.[60] Appendix H includes the impact-per-ton values for $NO_x$, $SO_2$, and $PM_{2.5}$ for select years, assuming a discount rate of 3% or 7%.

### Approach to Estimate Energy Security Benefits

DOE/EERE evaluation guidance identifies two types of energy security benefits:[61]

- Reduction in oil consumed as fuel, and the proportion of that consumption that would have been imported, and
- The qualitative treatment of altered threats to the energy infrastructure.

The IEc team followed the steps below to estimate energy security benefits from reduced oil consumption:

1. As described previously, the energy modeling results were broken out by year, state, and fuel source. These figures were then adjusted per the Delphi panel's estimates to arrive at attributed energy savings. The IEc team summed total attributed gallons of oil reduced for each year.
2. We converted gallons to barrels of oil using a standard conversion factor of 42 gallons per barrel.
3. To estimate avoided oil imports, Energy Information Administration (EIA) data on the proportion of internationally sourced fuel was applied to the avoided oil consumption estimates for each year, operating under the assumption that each marginal barrel of oil consumed is sourced proportionate to total consumption.[62]

Technologies that reduce the vulnerability of central power plants to disruptions (for instance, through use of a distributed renewable energy source) or fortify energy infrastructure against natural, accidental, and deliberately caused disruptions (for instance, through improved backup electric generation and energy storage) qualify as technologies that achieve the energy security benefit of altering threats to the energy infrastructure. Since BA practices under consideration in this evaluation do not include energy generating projects or projects that directly impact energy infrastructure, these particular benefits were not assessed in this evaluation.

### Approach to Estimate Knowledge Benefits

The evaluators conducted the citation analysis with three goals:

- To explore further evidence of causal linkages between the BA program and the market diffusion of energy efficient building practices;
- To measure the extent to which the BA-generated knowledge has been disseminated through the new residential building community; and

[60] For example, see U.S. EPA, *Regulatory Impact Analysis for the Final Revisions to the National Ambient Air Quality Standards for Particulate Matter*, December 2012 and U.S. EPA, *Regulatory Impact Analysis of the Final Revisions to the National Ambient Air Quality Standards for Ground-Level Ozone*, September 2015.

[61] *Evaluating Realized Impacts of DOE/EERE R&D Programs: Standard Impact Evaluation Method* (referred to hereafter as *The Guide*). Prepared by Rosalie Ruegg (TIA Consulting Inc.), Alan C. O'Connor (RTI International), and Ross J. Loomis (RTI International). August 2014. pg 72.

[62] To estimate remaining effective useful life benefits from houses constructed during the study period, projections were interpolated from Figure MT-56 in EA Outlook 2016: https://www.eia.gov/outlooks/aeo/pdf/0383(2016).pdf.

- To measure the extent to which the BA-generated knowledge has "spilled over" into the housing retrofit sector – i.e., we explored whether practices that were initially developed for new residential homes were discussed in publications that focus on housing retrofits.

Knowledge outputs of DOE/EERE programs include explicit knowledge, which is recorded, communicated, and disseminated primarily through publications, presentations, and patents. EERE program outputs also include tacit knowledge, which is more difficult to capture and measure as it is transferred by experience and human interactions.

For programs that focus on technology development, patents and patent analysis are often the focus of knowledge impact assessments. For programs that are research intensive, bibliometric analysis of scientific papers is often the focus of knowledge impact assessments. For the BA program, which focuses more on advancing energy efficient building practices and less on technology development, patents and scientific papers tend to be relatively few in number. BA relies extensively on a number of specialized publications to document and disseminate its research and demonstration findings on construction practices. These include best practice guides, technical reports, BA team member publications, trade publications, innovation profiles, how-to guides, climate maps, databases, guidelines, and protocols.

Initially, we had planned to draw a statistically valid sample of BA publications from a list provided by DOE, search for these publications in Google Scholar,[63] and analyze the resulting citation information (e.g., counts and organizational linkages). However, after compiling a list of publications from PNNL and NREL and drawing our sample, we did not find any of the sampled publications in Google Scholar. This result does not mean, however, that BA was ineffective in disseminating its research findings. BA deliberately established the BA Solutions Center as the central repository for its publications; as such, these publications may not be published outside of the Solution Center. In fact, the format of the case studies, fact sheets, and other products featured in the Solution Center would not necessarily lend themselves to being published in peer-reviewed journals or even in the "grey" literature.

BA program managers, building science experts, and production builders interviewed for this evaluation reported that BA's research was influential in changing building practices. However, interviewees stated that BA's research frequently spreads through professional networks (e.g., trade allies and energy raters), conferences, and trade journals. If this theory is true, we should be able to find articles in trade journals that discuss the ideas, methods, and practices that were advanced through the program's applied research. Furthermore, we would expect some of these articles to refer explicitly to the BA program, even if they were not official BA publications.

To test the theory that BA's research (and the BA program) would be cited in trade journals, we revised our citation method to focus on 15 trade journals that building science experts identified as key information sources for homebuilders: *ASHRAE Journal*, *Builder, Buildings*, *Construction Today*, *Engineering News-Record*, *Fine Homebuilding*, *Journal of Light Construction*, *Professional Builder*, *Walls & Ceilings*, *Green Builder*, *Greenbuildingadvisor*, *Remodeling*, *Professional Remodeler*, *Journal of*

[63] Past experience has shown that the use of a search engine such as Google Scholar provided more comprehensive coverage for reports, guidelines, and other forms of grey literature that are outside the scope of the major peer-reviewed journals, compared to the journal databases such as The Web of Science and Scopus. Preliminary testing compared two candidate search engines, Google Scholar and Scopus, and found that Google Scholar has more comprehensive coverage of publications citing BA research. Therefore, we used Google Scholar to conduct the citation search. In addition, we searched directly in the online archives of trade journals to identify publications that are not indexed in Google Scholar. Appendix I provides further details about the methods used to conduct the citation analysis.

*the National Institute of Building Sciences*, and *National Institute of Building Sciences* newsletter. Appendix I provides further details about the 15 trade journals and the methods used to conduct the citation analysis.

First, we searched within each trade journal using the advanced search function in Google Scholar. The reason we conducted the search in Google Scholar, rather than simply searching each journal's website, was to obtain the citation count (the number of times relevant articles were cited) and citation source (who cited the articles). The citation information was only available through Google Scholar; citation counts are not provided on the journals' individual websites. However, as our search progressed, it became clear that Google Scholar only includes a portion (relatively small, in some instances) of the total number of articles published in each journal. When we visited the journals' own websites, and searched their archives, we found a much larger number of results than when we searched Google Scholar alone. Therefore, we also searched the individual websites to make sure we were not omitting important articles from our search. The disadvantage to searching on the journals' websites is that we could not obtain citation counts (or other citation details). Therefore, the citation counts provided in our analysis provide a conservative, lower-bound estimate of the total number of citations.

We searched for articles in all 15 journals, in Google Scholar and on the individual websites, using 32 search terms.[64] The search terms include the four main practices selected for evaluation – air leakage, duct leakage, thermal bridging, and insulation – as well as related keywords, plus additional practices that the interview respondents told us BA was instrumental in advancing in the market. As such, the citation analysis expands our evaluation of BA's influence by covering practices that we did not include in the energy modeling analysis. We searched each term in combination with Building America (e.g., "air leakage" + "Building America"), and without BA (e.g., "air leakage"). While the former provides stronger evidence of BA's influence, we also wanted to search without the BA qualifier to see if the ideas and practices advanced by the program were cited without explicitly mentioning BA.

For search results that we found in Google Scholar, we recorded basic information about each article (including title, author, journal, and date), the number of times it was cited, and where it was cited. For search results directly on a journal's website, we recorded the same information about the article, but did not have citation information.

Given the wide breadth of the searches, we filtered our search results based on relevance, and prioritized the search results that were most relevant. In Google Scholar, relevance appears to be determined by a combination of factors, including but not limited to the number of times an article was cited. For individual journal websites, many (but not at all) provide an option to sort by relevance in the search function. Focusing on the most relevant search results was particularly important for the subset of individual websites that did not allow us to search on exact terms. For example, while Google Scholar and most of the websites allowed us to search for the exact phrase "Building America," a few websites

[64] We selected the search terms based on our interviews with building science experts, and the review of BA project data conducted during the scoping phase of the evaluation. Search terms include: (1) Building America; (2) Air leakage; (3) Duct leakage; (4) Insulation; (5) Thermal bridging; (6) Advanced framing; (7) Air barrier; (8) Air infiltration; (9) Air sealing; (10) Thermal bypass; (11) Attic insulation; (12) Radiant barrier; (13) Attic interface; (14) Ceiling interface; (15) Floor insulation; (16) Insulated Concrete Forms; (17) Thermal alignment; (18) Insulation placement; (19) Structural insulated panels; (20) Unconditioned + Infiltration; (21) Unconditioned + Insulation; (22) Unconditioned + Sealing; (23) Unvented crawl spaces; (24) Combined water and space heating systems OR Combined space and water heating systems; (25) Whole-building pressurization testing; (26) Blower door testing; (27) Duct pressure testing; (28) Ducts + conditioned space; (29) Moisture management; (30) Whole-home approach OR home as a system; (31) Vapor retarder classification system; and (32) Bulk water management.

returned search results if the term "building" and the term "America" were included anywhere in the article; we did not want to count these articles as references to the BA program. We used a similar prioritization method for citations – i.e., for articles that were cited numerous times, we recorded the total number of citations, but we limited the specific citation details beyond counts to the most relevant results.

### APPROACH TO CALCULATE ECONOMIC PERFORMANCE METRICS

The IEc team used the attributed monetized energy savings and attributed monetized environmental health impacts to calculate measures of economic performance:

- For the basic analysis, we computed the rate of return by comparing energy benefits valued in dollars against portfolio investment costs.
- As an extension of the analysis, we added in environmental health benefits valued in dollars to energy resource benefits, and compared combined benefits against portfolio investment costs.

To calculate economic performance measures for energy savings, year-by-year cash flows of estimated energy impacts and year-by-year cash flows for investment costs were both expressed in 2015 dollars. We used the total summary year-by-year benefit and cost cash flows to calculate the following economic performance metrics:

- **Undiscounted Investment Costs and Benefits:** Total year-by-year constant dollar undiscounted investment costs and year-by-year constant dollar undiscounted benefits based on energy and other resource impacts. The latter provides undiscounted gross benefits.
- **Net Benefits:** Year-by-year undiscounted benefits less year-by-year undiscounted costs.
- **Net Present Value:** Year-by-year constant dollar investment costs and year-by-year constant dollar benefits based on energy and other resource impacts, discounted using a 7% discount rate and a 3% discount rate.[65] The net present value is calculated as the present value of benefits less the present value of investment costs, discounted at both a 3% and 7% real discount rate.
- **Benefit-to-Cost Ratio at 3% and 7%:** Present value economic benefits over present value costs, discounted at 7% and 3%.
- **Internal Rate of Return:** The real interest rate value for which the present value of benefits equals the present value of costs, net present value equals 0, and benefit-cost ratio equals 1.

We then added in the environmental health benefits to energy benefits and compared combined benefits against total portfolio investment costs to calculate the five economic performance measures listed above.

[65] The use of a 7% and 3% discount rate is specified in the Guide (see, for example, Table II.7-2, p. 88): "Use 7% and 3% real discount rates for discounting all constant dollar cash flows per OMB Circulars A-94 and A-4, respectively. The 7% discount rate is the primary rate for this evaluation, with the 3% rate presented for informational purposes."

Investments are defined as economically worthwhile if they meet the following threshold criteria:[66]

- Net Present Value ≥ 0, when discount rate = 7%
- Benefit Cost Ratio ≥ 1, when discount rate = 7%
- Internal Rate of Return ≥ 7%

We follow the assumption that the larger the measures, the more economically worthwhile the investment has been. However, as discussed previously, these estimates are conservative, because they are based on partial benefits compared to total investment costs.

### Energy Prices

For historical energy prices, we used state-level data for 2006-2015 from the EIA.[67] This data was reported in current year dollars; to account for inflation, IEc adjusted the reported figures to constant 2015 dollars using the Gross Domestic Product (GDP) Implicit Price Deflator.[68] IEc also converted price data from $/MMBtu to the units used to estimate BA program energy savings (kilowatt-hours of electricity, therms of natural gas, and gallons of heating oil), using standard conversion factors from the EIA.[69]

We also used EIA data for future energy price projections, covering 2016-2039.[70] This data was in constant 2016 dollars; again, IEc adjusted the prices to 2015 dollars using the GDP Implicit Price Deflator. Unlike historical data, these projections were available only on a nationwide basis. To estimate future prices for a given state, IEc therefore multiplied the national average price in each year by the ratio of that state's actual price to the nationwide average price for 2015 for the relevant fuel type. For example, in 2015, Alabama's average residential electricity price was $34.28 per MMBtu, while the nationwide average was $37.08 per MMBtu, yielding a ratio of 0.924; thus, Alabama's future residential electricity prices were estimated by multiplying the projected nationwide average price in each year by 0.924.

### Calculating Net Present Value, Benefit-Cost Ratio, and Internal Rate of Return

We express costs and benefits in three forms: constant 2015 dollars; net present value as of January 1, 1994 (the first year of investment costs) using a 3% discount rate (expressed in 2015 dollars); and net present value as of January 1, 1994 using a 7% discount rate (expressed in 2015 dollars).

To apply the discount rates and calculate net present value, we used a multiplier for each year, calculated by exponentiating the discount rate by number of years between the year in question and 1994. For

[66] The Guide pg 97

[67] 2006 – 2014 data is from "U.S. EIA State Energy Data System (SEDS): 1960-2014 (complete)." https://www.eia.gov/state/seds/seds-data-complete.php. Accessed on March 29, 2017. 2015 data is from "State Energy Data System (SEDS): 2015 (updates by energy source)." https://www.eia.gov/state/seds/seds-data-fuel.php?sid=US. Accessed on March 29, 2017.

[68] U.S. Department of Commerce Bureau of Economic Analysis. Table 1.1.9: Implicit Price Deflators for Gross Domestic Product. Last Revised on March 30, 2017. https://www.bea.gov/iTable/iTable.cfm?reqid=9&step=3&isuri=1&903=13#reqid=9&step=3&isuri=1&903=13 Accessed on March 29, 2017.

[69] See https://www.eia.gov/energyexplained/index.cfm?page=about_energy_units and https://www.eia.gov/tools/faqs/faq.php?id=45&t=8. Accessed on March 31, 2017.

[70] U.S. Energy Information Administration. Annual Energy Outlook 2017. Table 3: Energy Prices by Sector and Source. https://www.eia.gov/outlooks/aeo/ Accessed on April 3, 2017.

example, using the 7% discount rate, the present value multiplier for January 1, 1995 is 1 ÷ 1.07^1; the January 1, 1996 multiplier is 1 ÷ 1.07^2; and so on. Constant dollar values for each year are converted to present value figures simply by multiplying them by the appropriate multiplier, as follows:

$$PV = CF_y \frac{1}{(1+r)^{1994-y}}$$

where $CF_y$ is constant dollars in year $y$;
$r$ is discount rate;
$1/_{(1+r)}n$ is the PV multiplier; and
$1994\text{-}y$ is the number of years between the year in question and 1994.

Appendix J provides the PV multipliers used in this study.

The (total) net present value is simply the sum of all present value figures across all years, subtracting the present value of all costs from the present value of all benefits:[71]

$$NPV = \left\{ \sum_{y=2006}^{2015} B_y(1+r)^{1994-(y+1)} \right\} - \left\{ \sum_{y=1994}^{2015} C_y(1+r)^{1994-y} \right\}$$

where $B_y$ is benefits in year $y$;
$C_y$ is costs in year $y$; and
$r$ is discount rate.

Note that while program costs were incurred starting in 1994, energy savings and associated benefits from the four selected practices began to accrue starting in 2006. Consistent with DOE/EERE evaluation guidance, we assume that all costs in a given year are incurred on the first day of the year and all benefits in a given year take place on the last day of the year.[72]

The benefit-cost ratio is simply the present value of economic benefits over present value of costs:

$$BCR = \left\{ \sum_{y=2006}^{2015} B_y(1+r)^{1994-(y+1)} \right\} \Big/ \left\{ \sum_{y=1994}^{2015} C_y(1+r)^{1994-y} \right\}$$

The IRR (r*) follows from:

$$\left\{ \sum_{y=2006}^{2015} B_y(1+r^*)^{1994-(y+1)} \right\} = \left\{ \sum_{y=1994}^{2015} C_y(1+r^*)^{1994-y} \right\}$$

[71] As shown in the equations, the retrospective economic analysis goes through 2015. The equations for effective useful life analysis are the same, except benefits go through 2039.

[72] Thus, benefits are discounted using an exponent of the number of years between 1994 and the year in which the benefits accrue plus 364 ÷ 365 (to account for the time between January 1, 1994 and December 31, 1994).

### ANALYSIS OF REMAINING EFFECTIVE USEFUL LIFE BENEFITS

Although the evaluation primarily has a retrospective focus, it includes a separate, extended analysis to account for benefits from BA-influenced homes built during our retrospective study period that will continue beyond 2015. DOE/EERE evaluation guidance recognizes this issue by allowing evaluators to conduct a separate analysis inclusive of the remaining effective useful life (EUL) of investments already made. DOE/EERE evaluation guidance defines EUL as the period over which an asset, with normal maintenance and repair, is expected to continue to be usable for its intended purpose.[73]

Applying the EUL concept as defined in DOE/EERE evaluation guidance might lead to an overestimation of benefits in this case, because many homeowners renovate well before components reach the end of their useful life. For example, homeowners tend to remodel kitchens and bathrooms to reflect current fashions, even though counters, cabinets, appliances, and fixtures are still functional. Therefore, the IEc team defined EUL based on conservative assumptions of the number of years between the construction of a new house and the first major renovation of that house, when new energy code provisions kick in. Triggers for new energy code applicability during home renovations tend to vary by local government, but common triggers include renovation of more than 50% of square footage, home additions, changes to structural walls, and changes to the exterior envelope.

Although some literature is available on the EUL of home components, the IEc team was not able to locate literature on the average time between home construction and major renovation. According to building science experts interviewed for this evaluation, this timing is variable and is driven by an array of factors including disposable income, economic conditions, tenure of residence, and likelihood of selling the home. However, the building science experts converged on a range of 20-30 years between construction and first major renovation. This is a conservative method to estimate remaining EUL, because many of the individual components used in the four selected practices (e.g., walls) are expected to last much longer than 20-30 years. However, because a major renovation sometimes triggers new energy code provisions, we limit our EUL analysis from home construction until the first major renovation.

We calculate remaining EUL benefits using 1) range of time between the construction of a new house and the first major renovation of that house (we used the midpoint of the range, 25 years), 2) year of home construction, and 3) the 2015 cutoff for the retrospective portion of the evaluation. For example, a house built in 2010 would accrue retrospective benefits in our analysis for 2010-2015, and remaining EUL benefits for 2016-2035.

### SOURCES OF UNCERTAINTY AND STUDY LIMITATIONS

Throughout the analysis, the evaluators made every attempt to use conservative assumptions, so that we know that the evaluation provides a conservative, lower-bound estimate of the value of the BA program. Table 3-8 summarizes the sources of uncertainty in our analysis, how the uncertainty affects the analysis, and how it was addressed. Overall, the study’s treatment of uncertainty provides a conservative, lower-bound estimate of the BA program’s impacts.

[73] The Guide pg 99

**TABLE 3-8. SOURCES OF UNCERTAINTY AND APPROACH FOR ADDRESSING**

| SOURCE OF UNCERTAINTY | DIRECTIONALITY | APPROACH FOR ADDRESSING |
|---|---|---|
| **Code compliance rates** | Unclear | The energy modeling exercise assumes full compliance with code, as there is no defensible way to adjust for non-compliance in the context of this study's modeling approach. PNNL field study suggests compliance may average 100% because of over-compliance – i.e., builders who comply with code frequently exceed the energy use reduction targets in code. |
| **Exclusion of California from energy modeling analysis** | Understates program benefits | The study excluded California from the estimate of energy savings because of the inability to clearly attribute aspects of CA Title 24 (California's state energy code) to BA. However, qualitative evidence suggests that BA helped builders comply with CA Title 24 in a cost-effective manner. |
| **Selection of BA activities to evaluate** | Understates program benefits | The study only quantified the benefits of four practices that BA worked on, and there are many more the study did not quantify that may have produced additional energy savings. Also, many building science experts interviewed stated there are benefits associated with BA moisture management, but the study was not able to quantify moisture management benefits. The study was also not able to quantify the benefits of "enablers," such as climate maps, that facilitate but do not directly produce energy savings. |
| **Timeframe for effective useful life benefits: from home construction to first major renovation** | Understates program benefits | The study limits BA benefits to the average time until major renovation (25 years). This is because *some* renovations trigger the need to update to the current code. However, the effective useful life of the affected components in three of the four studied building practices (e.g., walls) is much longer than 25 years. |
| **Energy modeling assumptions** | Understates program benefits | The study takes a conservative approach to modeling energy savings, such as: 1) excluding California from the energy modeling analysis (see above); excluding energy savings prior to Energy Star version 2.0 (due to the timeline of BA activities and when practices were adopted into ES), which greatly reduces reported savings from duct leakage; and 3) groups six states that have no mandatory energy code with "laggard" states (late adopters of code), as opposed to assuming these states use no energy code. |

While every effort was made to conduct a rigorous and defensible study, the evaluation has some limitations, as discussed below.

- **Inability to use experimental or quasi-experimental design:** We were not able to apply an experimental or quasi-experimental design to attribute benefits to the BA program. Conducting a true experiment would have required the program to randomly assign individuals to a treatment group and a control group prior to delivering services. This was not done, nor would it have been feasible or desirable, since the program is designed to cause spillovers: to share information with wide and diverse audiences beyond the boundaries of the program. Given the inability to use experimental design, the evaluation contemplated a quasi-experimental comparison of BA program participants to non-participants. However, given the inability to obtain an ICR, we were not able to interview a sufficient number of individuals to conduct a statistically valid comparison.

As such, we relied primarily on a Delphi panel of experts to assess attribution. Beyond the Delphi panel, the evaluation relies on counterfactual analysis, which is generally weaker than experimental or quasi-experimental design.

- **Limited interview coverage.** While interviews play an important role in this evaluation, the Paperwork Reduction Act limits systematic data collection from non-federal entities to nine people/organizations without obtaining an ICR, which was not able to be obtained for this evaluation. As such, the builder interviews and Delphi panel were limited to nine non-federal respondents per type of interview.

  We selected Delphi panelists based on their professional reputation and experience, and their ability to provide informed responses to our specific questions. However, the small number of respondents may not be representative of their peer groups. It should be noted, however, that guidance on Delphi panel construction indicates that panels with as few as 10 individuals are recommended where qualifications for panelists are homogeneous, as they were for this panel.[74] Furthermore, some guidance indicates that "researchers should use the minimally sufficient number of subjects for the task at hand."[75]

  The evaluation used multiple methods to address uncertainties related to small sample sizes. First, a tiered approach to attribution was used, so that different interview groups provided input on the selection of the practices and the attribution of energy savings to BA. Additionally, a sensitivity analysis was conducted with the Delphi panel estimates, using the highest and the lowest attribution estimates for each practice; as noted above, the four selected practices exceed the cost of the BA program even if we use the lowest estimates. Finally, the builder interviews and citation analysis provide anecdotal support for the Delphi panel's estimates. These confirmatory methods provide greater confidence in the estimates even with the low sample sizes.

- **Threats to validity:**[76] We acknowledge threats to internal validity including:
  - Confounding: Several variables contribute to market acceptance of energy efficiency practices that BA championed.
  - Selection bias: It is possible that we have some degree of potential selection bias in our interview samples as indicated above. Response rates for builder interviews were low. Recruiting builders to participate in the interview was difficult, particularly for builders that did not participate in the BA program

[74] Okoli and Pawlowski, "The Delpi method as a research tool: an example, design considerations and applications," *Journal of Information Systems and Management,* 42 (2004), p. 15-29 and Hsu and Sanford, "The Delphi Technique: Making Sense of Consensus," *Practical Assessment, Research and Evaluation*, Volume 12, No. 10, 2007.

[75] Hsu and Sanford, "The Delphi Technique: Making Sense of Consensus," *Practical Assessment, Research and Evaluation*, Volume 12, No. 10, 2007.

[76] The potential threats to validity are included in DOE/EERE evaluation guidance, as follows: **Internal Validity Threats**: 1) Temporal antecedence; 2) confounding; 3) selection bias; 4) maturation; 5) history; 6) selection-maturation interaction; 7) selection-history interaction; 8) regression to the mean; 9) differential attrition; 10) experimenter bias; 11) testing; 12) instrumentation; 13) contamination; 14) resentful demoralization; and 15) "John Henry effect." **External Validity Threats**: 1) Interaction effect of testing / pre-test effect; 2) interaction of selection and treatment; 3) reactive effects of experimental arrangements; and 4) multiple treatment interference.

Other potential threats to internal validity do not play a significant role in this study. Note that regression to the mean as a validity threat should not be confused with the deliberate consensus-building approach of the Delphi panel method. Regarding external validity, the original builder survey approach developed by the IEc team would potentially have allowed the results of these interviews to be extrapolated to the entire population of builders. However, as outlined above, the revised approach does not provide statistical power, and as such, we make no extrapolation claims of the builder interviews. We also are not attempting to extrapolate from the four selected practices to the broader universe of BA activities.

- **Limited technology coverage:** This evaluation focuses primarily on four practices that result in significant energy savings and in which BA played a direct role. However, BA has worked on many additional technologies and practices that the evaluation was not able to address. Therefore, the evaluation provides a conservative, lower-bound estimate of the program's impact and EERE's return on investment. We also understand that focusing the evaluation on selected /practices runs counter to the BA program's integrated "house as a system" approach. Although we focused on a subset of practices, our energy modeling looked at the combined impacts of these practices on the energy use of the home as a whole.
- **Inability to monetize some impact categories:** The evaluation did not monetize knowledge benefits or energy security impacts because the valuation methods are not settled in the literature. This is a standard constraint in evaluations of EERE's R&D programs. In addition, we understand that one of BA's most significant achievements was to use value engineering to drive down energy use cost-effectively in order to mainstream the value engineering approach, but the evaluation was not able to measure that directly. (We did measure the outcomes of this achievement indirectly via market penetration of selected BA-supported technologies and practices.) Finally, as discussed elsewhere in this report, we were not able to monetize health impacts from improved IAQ resulting from improved moisture control and reduced mold in homes, although BA conducted work in this area.

# IV. ENERGY IMPACTS

Chapters 4-7 present the evaluation results for each of the four benefit categories featured in this study: energy impacts (Chapter 4), environmental health impacts (Chapter 5), energy security impacts (Chapter 6), and knowledge impacts (Chapter 7).

As described previously, the IEc team modeled the energy savings for the four selected practices in BEOpt. Chapter 4 begins by presenting the total (gross) modeled energy savings from BEopt. Next, we present the attribution estimates provided by the Delphi panel and the attribution-adjusted energy savings. Given the importance of the Delphi panel for determining attribution, the chapter presents the detailed findings and discussion of the Delphi panel results. Next, we present a range of sensitivity and breakeven analyses using the estimates provided by the Delphi panel. The chapter concludes with the presentation of monetized attributed energy savings for the four practices.

## ENERGY MODELING RESULTS (GROSS SAVINGS)

Post modeling, the IEc team used home construction statistics to estimate state-level total site energy savings, and nationwide savings, for each year, sorted by fuel type and practice. A summary of estimated total cumulative nationwide site energy savings for all four studied practices combined is provided in Table 4-1. The cumulative site energy savings estimate of 250 trillion Btu represents about 5.9% of the estimated counterfactual energy use in new homes built between 2006 and 2015, excluding California.

### TABLE 4-1. TOTAL NATIONWIDE SITE ENERGY SAVINGS BASED ON MODELING STUDY (CUMULATIVE 2006-2015)

| | TOTAL SAVINGS (2006-2015) |
|---|---|
| Total Site Electricity Savings (GWh) | 17,808 |
| Total Site Natural Gas Savings (Million Therms) | 1,826 |
| Total Site Fuel Oil Savings (Million Gallons) | 47 |
| **Total Site Energy Savings - All Fuels (Trillion Btu)** | **250** |

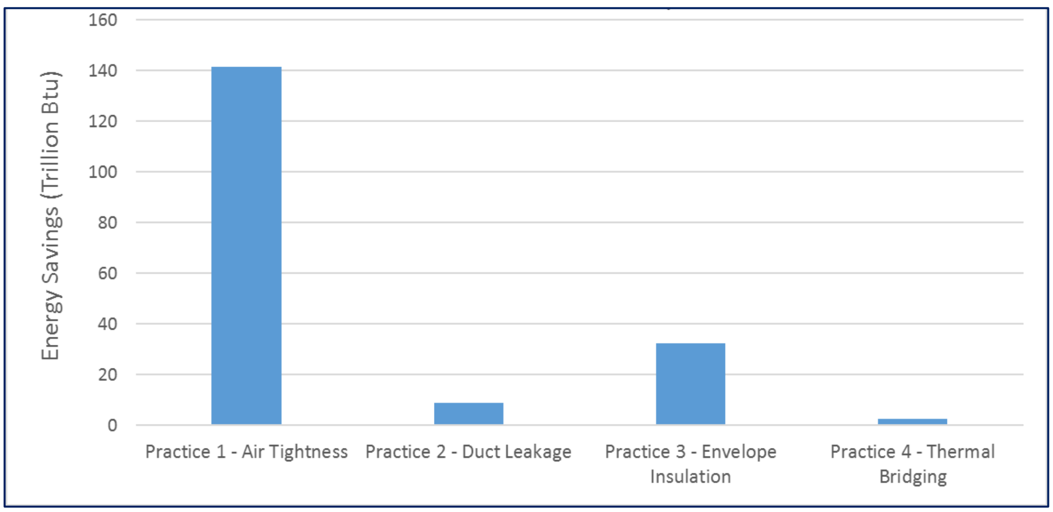
The energy savings from the four studied practices are summarized in Table 4-2 below. Appendix F provides the detailed energy modeling outputs.

**TABLE 4-2. SUMMARY OF ENERGY SAVINGS FROM THE FOUR STUDIED PRACTICES (CUMULATIVE 2006-2015)**

| PRACTICE | TOTAL ENERGY SAVINGS (2006 - 2015) (TRILLION BTU) |
|---|---|
| Air leakage and infiltration requirements | 182.5 |
| Duct leakage requirements | 25.5 |
| Insulation requirements | 38.6 |
| Thermal bridging requirements | 3.2 |
| **Total** | **249.8** |

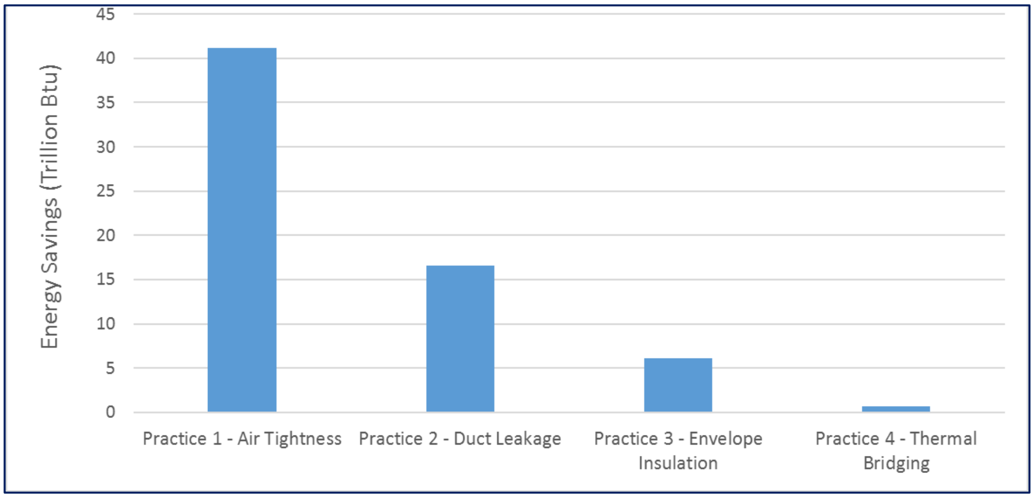
The breakdown of site energy savings for each of the four studied practices in code minimum homes is shown in Figure 4-1 below.

**FIGURE 4-1. BREAKDOWN OF TOTAL NATIONWIDE SITE ENERGY SAVINGS BY INDIVIDUAL PRACTICE (CODE MINIMUM HOUSES)**




As shown in Figure 4-2, the impact of tighter ducts is more significant in ES homes, while the trends for other practices are about the same as code minimum homes.

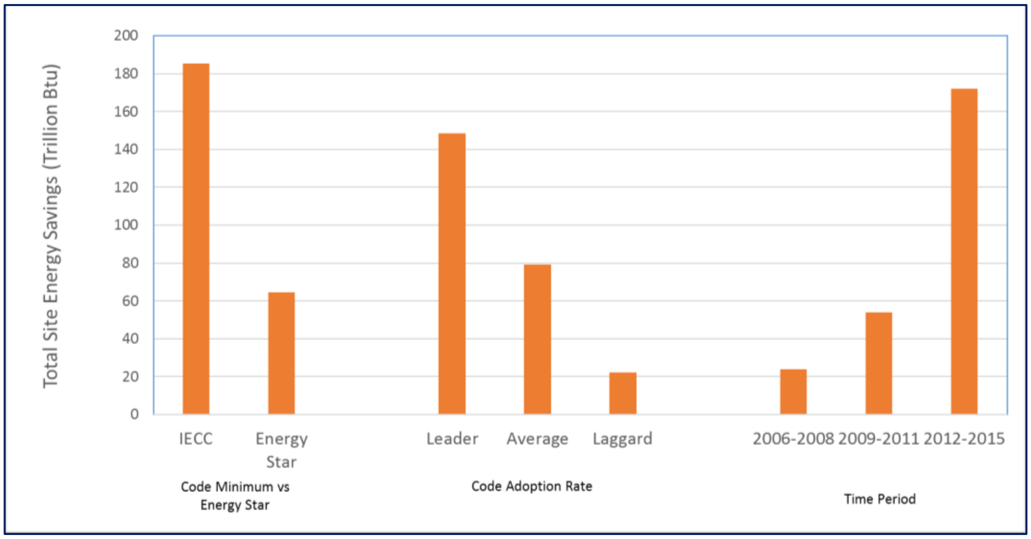
FIGURE 4-2. BREAKDOWN OF TOTAL NATIONWIDE SITE ENERGY SAVINGS BY INDIVIDUAL PRACTICE (ENERGY STAR HOUSES)




The IEc team disaggregated these interim (pre-Delphi panel adjusted) results in several ways to provide insights into the largest contributors to energy savings. Figures 4-3 through 4-7 provide a variety of breakdowns of nationwide site energy savings, including by efficiency program (code vs. ES Homes), code adoption rate, time period, state, and individual practice.

As shown in Figure 4-3, because they constitute the final step in the deployment of energy innovations into broad residential markets, energy codes contribute the bulk of the estimated interim energy savings compared to the ES Homes program, which focuses on early adopters. Despite the higher estimated savings from ES on a per-house basis, ES-certified homes represent only about 1 million of the 9 million homes built between 2006 and 2015. About 60% of the estimated energy savings is contributed by the 20 states categorized as "leaders" when it comes to code adoption, while the 14 "laggards" contribute only 8%, with the 16 "average" states contributing the remainder. Leaders are the only states that have adopted IECC 2012, which is much stricter in terms of the energy efficiency requirements associated with the four selected practices. It is also not surprising that the time period 2012-2015 accounts for the majority of estimated energy savings, because this period reflects stronger codes, covers four years of construction, and includes ongoing energy savings from the earlier time periods.

**FIGURE 4-3. BREAKDOWNS OF ESTIMATED INTERIM CUMULATIVE NATIONWIDE SITE ENERGY SAVINGS FOR THE FOUR PRACTICES BY PROGRAM, CODE ADOPTION RATE, AND TIME PERIOD**




Figures 4-4 and 4-5 show the interim state-wide site energy savings estimates for the states encompassed by our analysis, which includes the District of Columbia but excludes California. Texas, Pennsylvania, Illinois, New Jersey, and Massachusetts achieved the highest estimated savings, partly because of their relatively high construction rates, but also (with the exception of Texas) because they are all leaders in terms of code adoption rate and are all mostly cold climates where savings are higher. Texas is an exception because its construction rate is the highest in the country, much higher than the other four states combined. Conversely, the states with the lowest estimated cumulative savings tend to be in warmer climates, with lower construction rates and slower code adoption.

**FIGURE 4-4. BREAKDOWN OF ESTIMATED INTERIM CUMULATIVE NATIONWIDE SITE ENERGY SAVINGS FOR THE FOUR PRACTICES BY STATE (25 MOST IMPACTED STATES, EXCLUDING CALIFORNIA)**

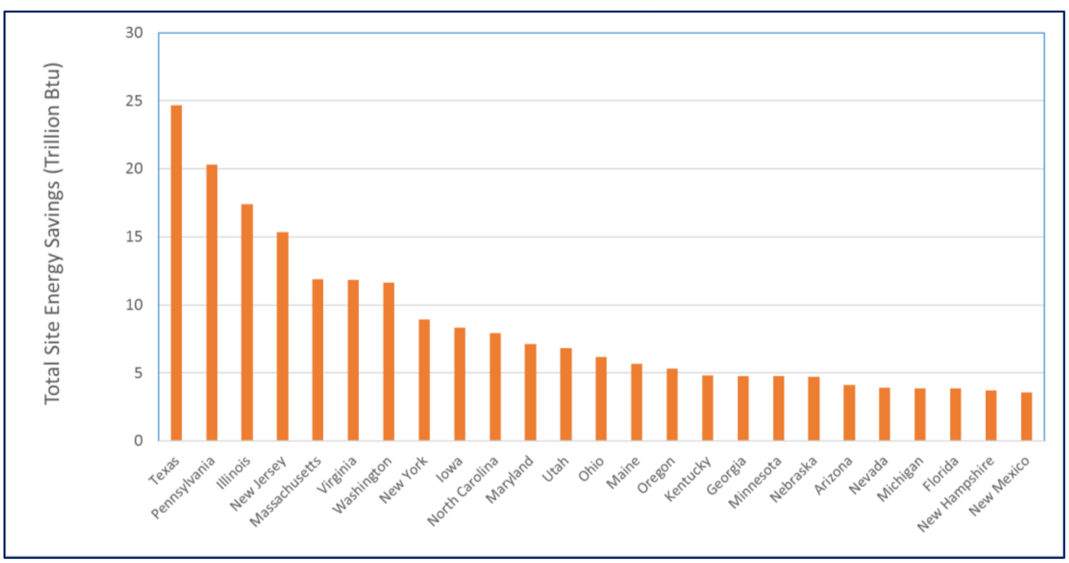
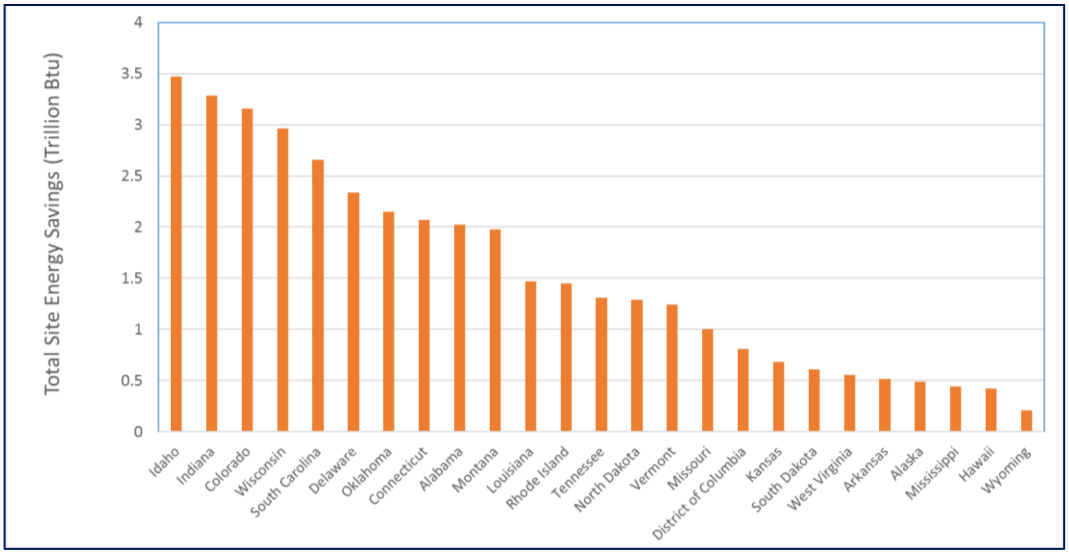


**FIGURE 4-5. BREAKDOWN OF ESTIMATED INTERIM CUMULATIVE NATIONWIDE SITE ENERGY SAVINGS FOR THE FOUR PRACTICES BY STATE (25 LEAST IMPACTED STATES, EXCLUDING CALIFORNIA)**




Figures 4-6 and 4-7 show the per-house average interim site energy savings estimates for new homes in each state over the evaluation period. We made the calculation by simply dividing the cumulative savings in Figures 4-4 and 4-5 by the total number of houses built between 2006 and 2015. In this case, all five of the top states (Maine, Rhode Island, New Hampshire, Massachusetts, and Iowa) are in cold climates and are classified as "leaders" in code adoption. States in hot climates with slower code adoption rates are ranked near the bottom.

**FIGURE 4-6. ESTIMATED INTERIM AVERAGE SITE ENERGY SAVINGS PER HOUSE FOR THE FOUR PRACTICES ORDERED BY STATE (25 MOST IMPACTED STATES, EXCLUDING CALIFORNIA)**

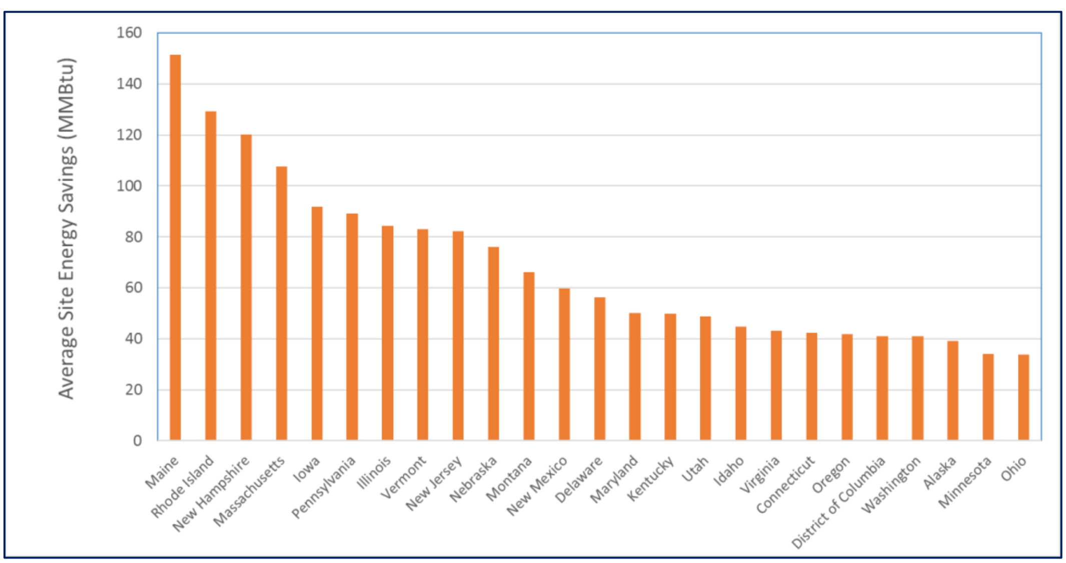
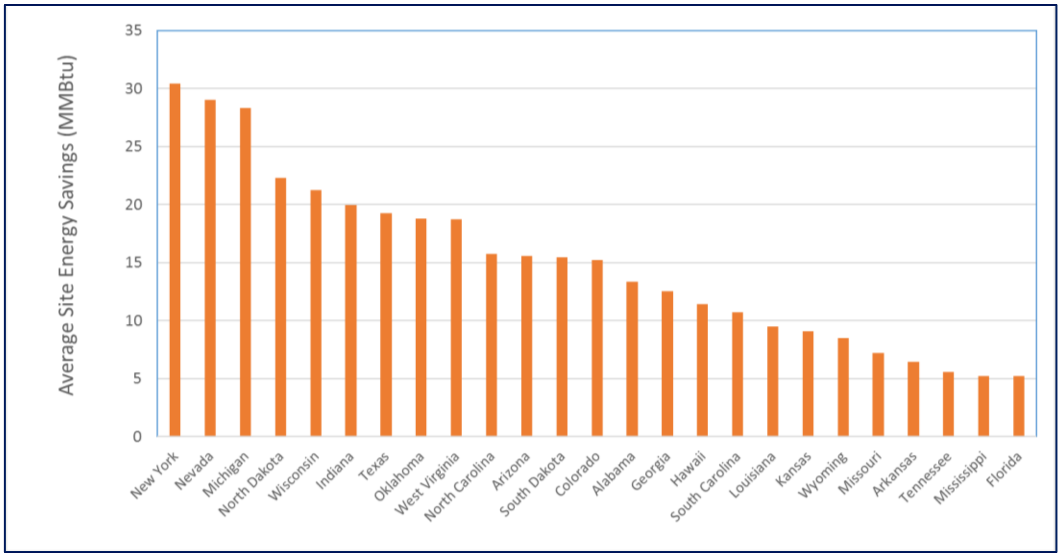


FIGURE 4-7. ESTIMATED INTERIM AVERAGE SITE ENERGY SAVINGS PER HOUSE FOR THE FOUR PRACTICES ORDERED BY STATE (25 LEAST IMPACTED STATES, EXCLUDING CALIFORNIA)




## DELPHI PANEL RESULTS: ATTRIBUTION-ADJUSTED SAVINGS

An important aspect of the evaluation is to investigate what share of these modeled estimated benefits can be fairly attributed to the BA program as opposed to alternative (or rival) causes. The primary method the IEc team used to conduct this investigation was to convene a Delphi panel. As discussed in Chapter 3, IEc convened a group of nine experts to review the practice-specific energy reduction benefits estimated by the modeling exercise and consider the role of the BA program versus rival factors in advancing market acceptance of the four selected energy efficiency practices.[77] For each practice, panel members provided estimates of the portion of the modeled energy savings that can be attributed to the BA program, in their opinion. The average of these apportionments was applied to downward adjust the benefits for each practice.

Chapter 3 described the Delphi panel process. In the current section, we present: the final results of the panel's estimation of the impacts of the BA program; a summary of adjustments made between the first round and second round of the panel; the results of sensitivity analyses of the final results; and an analysis of the breakeven point for attribution.

### BA Program Influence - Overall

In both rounds of interviews, we asked panel members to consider BA's influence on the scale and timing of the market's acceptance of the four selected practices. Overall, panel members mostly agreed that the selected practices would have been adopted by the market at a smaller scale – and at a later point in time – without the BA program. Not surprisingly, panel members differed in the level of attribution they assigned to BA compared to rival factors in promoting the market's acceptance of the selected practices, as shown in the exhibits on the following pages.

[77] Due to the requirements of the Paperwork Reduction Act, we limited the panel to nine members.

Collectively, the nine Delphi panel members identified a number of channels for BA's influence:

- Showing builders how to apply the practices and proving that the practices work (i.e., the practices are feasible, beneficial, and cost-effective) through testing and demonstration projects. In particular, the BA program was effective at striking a balance between building science and construction, and performance and cost-effectiveness.
- Packaging and disseminating the results of demonstration projects through case studies, reports, and conferences to: (i) raise the market's awareness of the practices, and (ii) provide building science "packages" that others (builders, voluntary above-code programs such as ES Homes, home energy raters, and other programs) can adopt.
- Directly engaging leading production builders and manufacturers who have significant reach and influence on the market. Given the highly competitive nature of the construction industry, other builders quickly adopted the practices of the leading builders who participated in BA. The nature of the industry means that word of mouth is an effective way to disseminate information; BA took advantage of this.
- Creating and supporting a stable of building scientists and energy efficiency advocates who championed BA's whole home approach to energy efficiency, including the four selected practices.
- One panel member explained, "The alignment and education of these experts by BA was a smart thing to do – it created credentialed market capacity… BA's influence isn't just its publications; they created experts along with that body of knowledge." This panel member stated that BA funding allowed these experts to conduct research they would not otherwise have been able to undertake.
- A different panel member stated that Joe Lstiburek (a building scientist/advocate identified by several panel members) would have done his work without BA – but BA "amplified" his impact by providing a national framework with broader reach.
- Several panelists commented on BA's position in the market transformation cycle – after the basic research stage, and before widespread market adoption. According to these panelists, BA is relatively "upstream" in the market transformation process, and influences the market through a number of pathways, including influencing practices included in the ES Homes program, which has gained widespread market acceptance, and helping to create the market for home energy ratings, which also helped to mainstream many practices demonstrated by BA. Some panelists characterized these pathways as "indirect," but important.
- A smaller number of panelists stated that the BA program played a critical role in establishing ES Homes and RESNET, and stated that these market pathways would not exist in their current form or at the same scale without BA.

IEc's interviews with builders echoed the Delphi panel's general findings about BA's position in the market transformation cycle. BA builders reported a variety of benefits from participating in the program, including, most fundamentally, the opportunity that participation affords them to learn about whole-home approaches to energy efficiency. Builders indicated that their professional networks are very important to them, and that they receive a lot of their information about new energy efficiency practices, and information on how to implement them, through relationships with their contractors and energy raters, through connections they make at conferences and trade shows, and by participating in programs such as LEED and Energy Star.

The builder interviews did not indicate major differences between the BA and non-BA builders in the timing of when they adopted the four selected practices. However, most BA builders indicated that they would still implement the four practices if they were not required by code. More often, non-BA builders reported being unable to offset the cost of energy efficiency practices by charging higher prices to their customers. In other words, non-BA builders perceive a lower willingness to pay a premium for homes that adopt energy efficiency practices than BA builders. Two BA builders stated that the BA program helped them make these practices standard practice, primarily through assistance (audits) provided by IBACOS (one of the BA teams).

Finally, builder interviewees indicated that all four practices have spilled over into the renovation market. It should be noted that these practices are sometimes required by code in the renovation market; in several markets, a major retrofit of more than 50 percent of square feet triggers code requirements. In addition, some interviewees reported that some utilities subsidize energy efficiency practices more often, and with larger incentives, in the renovation market than in the new construction market.

#### Air Tightness and Infiltration Requirements

For air tightness and infiltration requirements, Delphi panel members stated that the BA program was effective at creating replicable technical solutions ("packages") for builders. Panel members also stated that the BA program helped to advance the use of performance testing for air leakage, primarily through blower door testing, a process that was created prior to the BA program's work but was popularized as a way of measuring efficiency gains from energy conservation practices including those advanced by BA. Several panel members stated that BA's case studies and technical demonstrations were essential tools for production builders, home energy raters, manufacturers, and the ES Homes program. A few panel members stated that while technical research on air sealing has existed since the 1930s, BA spurred the uptake of air sealing practices in the U.S. by working with leading production builders to demonstrate their efficacy.

Drivers external to the BA program that influenced the market acceptance of air leakage practices, as reported by the panel, are summarized in Table 4-3. Top external drivers cited include:

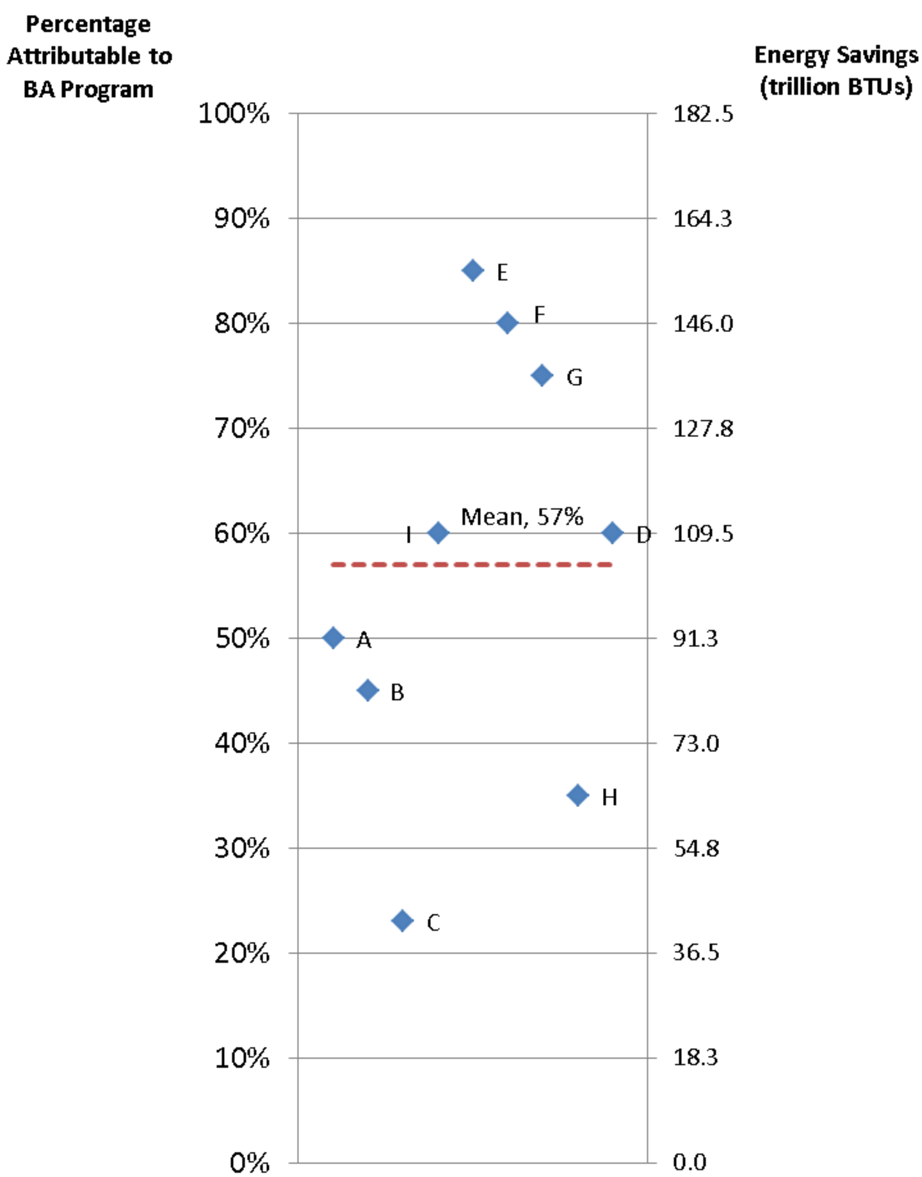
- Voluntary above-code programs (7) – Programs such as Energy Star (4) and Passive House (3) increased the market's awareness and acceptance of air tightness and infiltration practices.
- Utility programs/incentives (5) – These helped to advance the acceptance of air tightness practices through incentive and education programs.
- Product Manufacturers/New Products (5) – The availability of products to test for air leakage, such as the blower door, were instrumental to the advancement of this practice in the industry.
- Energy efficiency experts and advocates (4) – In particular, Joe Lstiburek and BSC's work were reported as having greatly influenced the market's understanding and acceptance of this practice (3). Although BSC's work began before BA, one panelist stated that the BA program helped amplify his work by providing a national framework to reach a broader audience.

TABLE 4-3. SUMMARY OF EXTERNAL DRIVERS – AIR TIGHTNESS AND INFILTRATION REQUIREMENTS

| DRIVER | COUNT (PANELISTS) |
|---|---|
| Voluntary Above-Code Program | 7 |
| Energy Star | 4 |
| Passive House | 3 |
| Utility Programs/Incentives | 5 |
| Product Manufacturers/New Products | 5 |
| EE Experts/Advocates | 4 |
| Joe Lstiburek | 3 |
| Energy Raters | 4 |
| RESNET | 3 |
| Regional EE Organization/Conferences | 4 |
| Increase Comfort | 2 |
| Canadian Research | 2 |
| Research Organization/Government Labs/Universities | 2 |
| Weatherization Programs | 2 |
| Army Corps of Engineers | 1 |
| Code | 1 |
| Energy Costs | 1 |
| Reduce Mold Growth | 1 |
| Small Builders | 1 |

Figure 4-8 provides a summary of the nine Delphi panelists' estimates of the percentage of modeled energy savings for air tightness that can be attributed to the BA program. The nine diamonds in the figure correspond to the individual estimates from each of the nine Delphi panelists. To preserve anonymity, we assign each of the nine panelists a unique identifier (A – I). Overall, the mean estimate of savings attributed to the program for air tightness and infiltration requirements is 57%, which translates to 104.0 trillion BTUs of energy savings.

FIGURE 4-8. SUMMARY OF SAVINGS ATTRIBUTABLE TO BA - AIR TIGHTNESS AND INFILTRATION REQUIREMENTS




### Duct Leakage Requirements

Panel members reported that the BA program played an important role in helping production builders understand the value of whole-building strategies to address duct leakage – e.g., bringing ducts into conditioned spaces or inside basement crawlspaces. In particular, the BA program helped builders understand that higher standards were in fact achievable. Several panel members stated that the BA program helped expand the application of duct leakage practice and disseminated information about the practice on a national scale.

Drivers external to the BA program that influenced the market acceptance of this practice, as reported by the panel, are summarized below in Table 4-4. Top external drivers cited include:

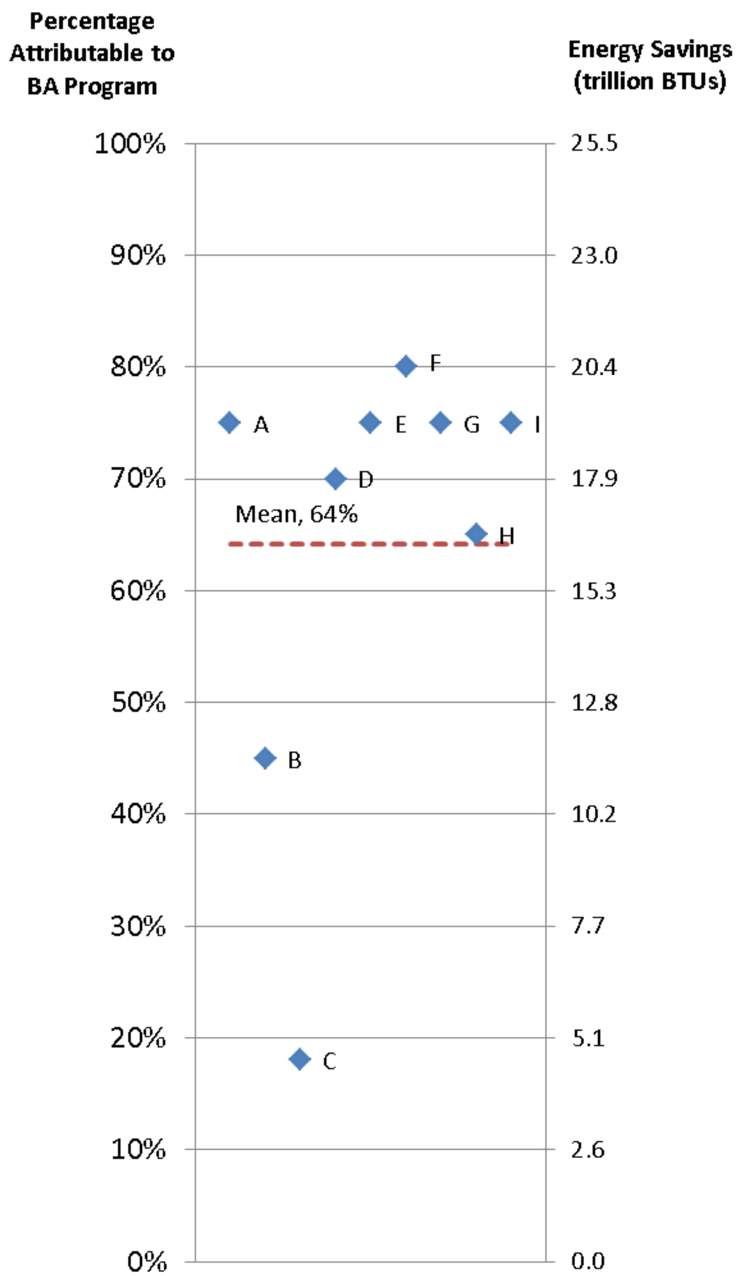
- Energy efficiency experts and advocates (7) – In particular, John Tooley's research (Advanced Energy) in the early 1980s and early 1990s helped to advance duct leakage practices (5).
- Product manufacturers/new products (6) – This includes the development of the duct blaster test, and independent research conducted by manufacturers.
- Research organizations, government labs, and universities (5) – Testing and demonstration of solutions conducted by other research organizations helped to advance duct leakage practices. In particular, panelists cited LBNL's high profile research on the ineffectiveness of using duct tape to seal ducts (which also led to the advancement of alternative products).
- Regional energy efficiency organizations and conferences (3) – These primarily demonstrated new technologies and diffused information that fostered acceptance of duct leakage control practices.

#### TABLE 4-4. SUMMARY OF EXTERNAL DRIVERS - DUCT LEAKAGE REQUIREMENTS

| DRIVER | COUNT (PANELISTS) |
|---|---|
| EE Experts/Advocates | 7 |
| John Tooley | 5 |
| Joe Lstiburek | 1 |
| Product Manufacturers/New Products | 6 |
| Research Organization/Government Labs/Universities | 5 |
| Regional EE Organization/Conferences | 3 |
| Energy Raters | 3 |
| RESNET | 1 |
| Voluntary Above-Code Program | 3 |
| Energy Star | 2 |
| Passive House | 1 |
| Energy Costs | 2 |
| Weatherization Programs | 2 |
| Canadian Research | 1 |
| Energy Advocacy Group | 1 |
| Training Program | 1 |
| Utility Programs/Incentives | 1 |
| Customer Feedback | 1 |
| Increase Comfort | 1 |
| No Other Drivers | 1 |

Figure 4-9 provides a summary of the nine Delphi panelists' estimates of the percentage of modeled energy savings for duct leakage that can be attributed to the BA program. Overall, the mean estimate of savings attributed to the program is 64%, which translates to 16.4 trillion BTUs of energy savings.

FIGURE 4-9. SUMMARY OF SAVINGS ATTRIBUTABLE TO BA – DUCT LEAKAGE REQUIREMENTS




### Insulation Requirements

Panel members identified that one of BA's primary contributions in this area was showing that advanced insulation practices are cost-effective as part of a whole-building approach. Research existed on this topic prior to BA, but BA's demonstrations helped influence the market to accept the practice. Overall, however, several panel members indicated that the timing and scale of adoption of this practice was not as heavily influenced by the BA program as the other three practices, because it was in the economic interest of insulation manufacturers to sell more insulation and to push for standards that would require the use of more insulation. However, the BA program's demonstrations gave manufacturers evidence when taking their products to market and advocating for higher insulation standards.

Drivers external to the BA program that influenced the market acceptance of this practice, as reported by the panel, are summarized in Table 4-5. Top external drivers cited include:

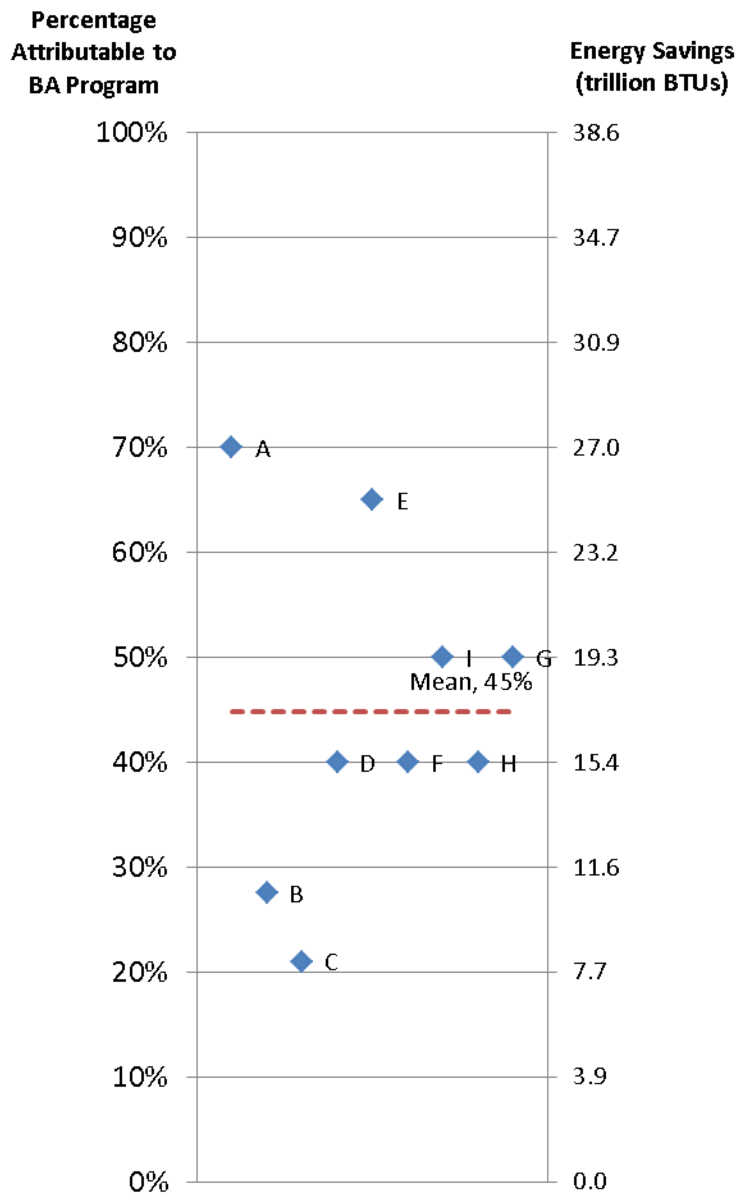
- Product manufacturers and new products (6) – As noted above, panelists stated that increased insulation requirements were heavily influenced by factors external to the BA program, namely insulation manufacturers. Manufacturers also influenced the advancement of this practice through their trade organizations (e.g., NEMA).
- Voluntary above-code programs (4) – For example, the Passive House Program (2) demonstrated that an aggressive insulation target was achievable. Panelists also cited Energy Star (2) as an important above-code program for the acceptance of this practice.
- Energy costs (4) – Rising energy costs, particularly in the wake of the 1970s energy crisis, increased the focus on reducing energy usage in homes.

### TABLE 4-5. SUMMARY OF EXTERNAL DRIVERS - INSULATION REQUIREMENTS

| DRIVER | COUNT (PANELISTS) |
|---|---|
| Product Manufacturers/New Products | 6 |
| Voluntary Above-Code Program | 4 |
| Energy Star | 2 |
| Passive House | 2 |
| Energy Costs | 4 |
| Energy Raters | 3 |
| RESNET | 1 |
| Research Organization/Government Labs/Universities | 3 |
| Code | 3 |
| Canadian Research | 2 |
| DOE Codes Program | 1 |
| EE Experts/Advocates | 1 |
| Joe Lstiburek | 1 |
| Increase Comfort | 1 |
| Structural Requirements | 1 |
| Utility Programs/Incentives | 1 |
| ASTM/ASHRAE | 1 |
| Regional EE Organization/Conferences | 1 |
| No Other Drivers | 1 |

Figure 4-10 provides a summary of the nine Delphi panelists' estimates of the percentage of modeled energy savings for insulation requirements that can be attributed to the BA program. Overall, the mean estimate of savings attributed to the program is 45%, which translates to 17.3 trillion BTUs of energy savings.

### FIGURE 4-10. SUMMARY OF SAVINGS ATTRIBUTABLE TO BA - INSULATION REQUIREMENTS




#### Thermal Bridging Requirements

Panel members' opinions of BA's influence were most divided on this practice: Some thought that the BA program was primarily responsible for the market acceptance of this practice, while others believed that BA had very little influence on its acceptance. For those who thought the program was responsible for its market acceptance, reasons include: BA's ability to move the issue into the national dialogue, and BA's research and communication efforts around the energy savings possible with the practice.

Drivers external to the BA program that influenced the market acceptance of this practice, as reported by the panel, are summarized in Table 4-6. Top external drivers cited include:

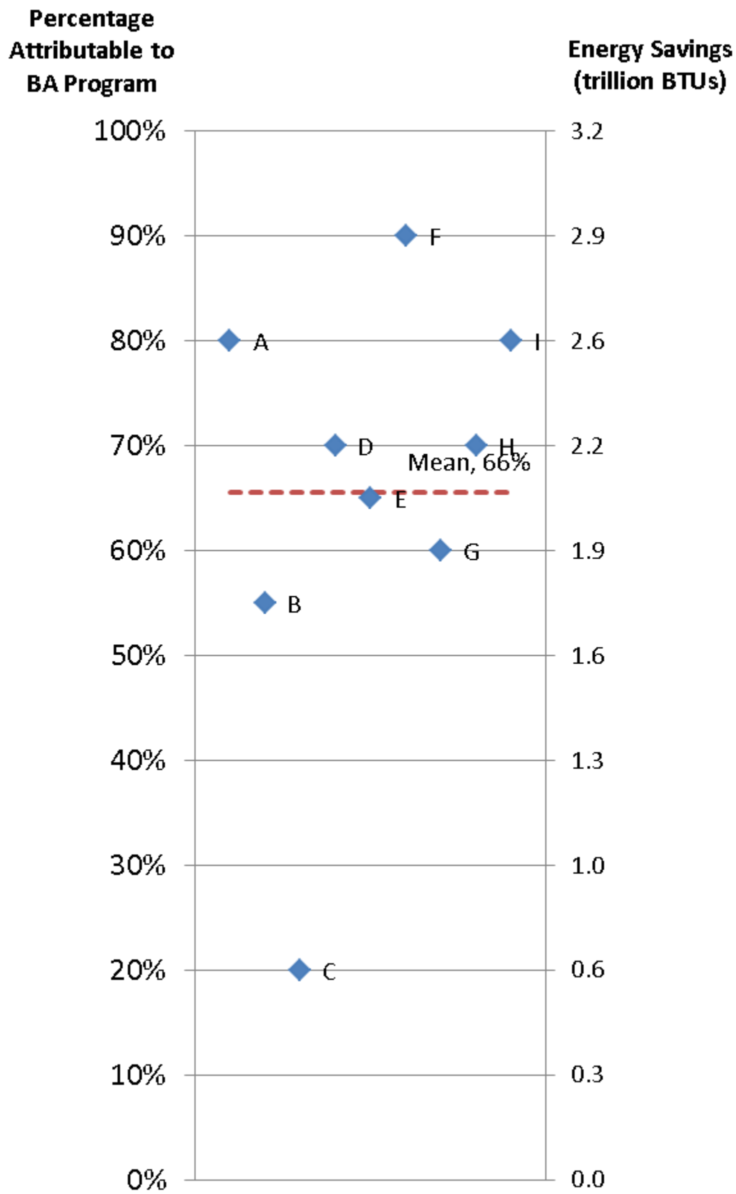
- Voluntary above-code programs (6) – The Passive House Program (4) made thermal bridging a focus and a priority. Panelists also cited Energy Star (2) as an important external driver.
- Product manufacturers and new products (4) – Manufacturers have an economic incentive to advance the acceptance of this practice, and they have been effective at disseminating information about the benefits of the practice.
- Energy efficiency experts and advocates (3) – In particular, Joe Lstiburek's research (3); however, at least one panelist attributed Joe Lstiburek's work to BA.

#### TABLE 4-6. SUMMARY OF EXTERNAL DRIVERS - THERMAL BRIDGING REQUIREMENTS

| DRIVER | COUNT (PANELISTS) |
|---|---|
| Voluntary Above-Code Program | 6 |
| Passive House | 4 |
| Energy Star | 2 |
| Product Manufacturers/New Products | 4 |
| EE Experts/Advocates | 3 |
| Joe Lstiburek | 3 |
| Code | 2 |
| Reduce Mold Growth | 2 |
| Research Organization/Government Labs/Universities | 2 |
| Reduce Lumber | 2 |
| No Other Drivers | 2 |
| Energy Costs | 1 |
| Energy Raters | 1 |
| RESNET | 1 |
| Training Program | 1 |
| US HUD | 1 |
| ASTM/ASHRAE | 1 |
| Canadian Research | 1 |
| Increase Comfort | 1 |
| Regional EE Organization/Conferences | 1 |

Figure 4-11 provides a summary of the nine Delphi panelists' estimates of the percentage of modeled energy savings for thermal bridging requirements that can be attributed to the BA program. Overall, the mean estimate of savings attributed to the program is 66%, which translates to 2.1 trillion BTUs of energy savings.

**FIGURE 4-11. SUMMARY OF SAVINGS ATTRIBUTABLE TO BA - THERMAL BRIDGING REQUIREMENTS**




### Overall Savings Estimates

Taken in aggregate, the panel members assign 56% of the modeled energy savings to the BA program, which translates to 139.8 trillion BTUs of energy savings. Table 4-7 below presents an overall summary of the savings attributable to the BA program based on the results of the Delphi panel.

### TABLE 4-7. SUMMARY OF ENERGY SAVINGS ATTRIBUTABLE TO BA

| PRACTICE | TOTAL MODELED ENERGY SAVINGS (TRILLION BTUS) | MEAN ATTRIBUTION ESTIMATE | ESTIMATED ATTRIBUTED ENERGY SAVINGS (TRILLION BTUS) |
|---|---|---|---|
| Air Tightness | 182.5 | 57% | 104.0 |
| Duct Leakage | 25.5 | 64% | 16.4 |
| Insulation | 38.6 | 45% | 17.3 |
| Thermal Bridging | 3.2 | 66% | 2.1 |
| Overall | 249.8 | 56%[1] | 139.8 |
| Note: 1) This average is weighted by energy savings across the four practices. | | | |

## ADJUSTMENTS BETWEEN ROUNDS 1 AND 2

As described above, we asked the panel members a similar set of questions in both rounds of interviews, covering the same topics. In the second round, the panelists were given a chance to reconsider their answers from the first round, with the added knowledge of how their fellow members responded to the first set of interview questions. Overall, panel members' estimates converged more closely to the mean, and the members made some adjustments to their thinking from the first round.

### BA Program Influence

Regarding the overall channels of influence of the BA program on the market acceptance of the four practices, most panel members did not fundamentally change their thinking between rounds. One panelist reallocated some of the influence of external drivers he had assigned in the first round to the influence of the BA program, meaning that he thought the program had more direct influence on the practices after reading his peers' thoughts. Most panelists agreed with their peers' identifications of the channels of influence of the BA program.

### External Drivers

Overall, most panel members did not substantially change the external drivers they identified that influenced the market acceptance of the four practices. However, in several cases, panelists agreed with drivers identified by their peers, and added them to the list of drivers they thought influenced the acceptance of the practices. Specifically:

- **Air Tightness:** For each of the following drivers, one more panelist identified the driver in the second round of interviews: voluntary above-code programs, product manufacturers/new products, research organization/government labs/universities, and weatherization programs.
- **Duct Leakage:** Several panel members reported additional external drivers related to duct leakage. Three additional panelists mentioned the influence of energy efficiency experts/advocates. Two additional panelists added product manufacturers/new products and research organizations/ government labs/universities to their lists of drivers. Finally, one

additional panelist mentioned energy raters, voluntary above-code programs (specifically Energy Star), and energy costs.

- **Insulation:** One panelist added product manufacturers/new products to their list of drivers for this practice; no other changes were reported.
- **Thermal Bridging:** Two additional panelists identified voluntary above-code programs, specifically Passive House in the second round. One additional panelist added energy efficiency experts/advocates, specifically Joe Lstiburek, to their list of drivers for this practice.

#### Disagreements

In some cases, panel members disagreed with external drivers identified by their peers. Specifically:

- **Energy efficiency experts/advocates:** While all panel members agreed that these experts were instrumental in advancing these practices, there was some disagreement about whether their work should be considered internal or external to BA. In other words, should work that was funded in part by the BA program (e.g., some or most of Joe Lstiburek's and BSC's work) be counted as an external driver? Or is that a channel of influence of the program itself? Some panelists thought that the import placed on these experts as external drivers unfairly downplays the influence of the BA program.
- **Passive House Program:** Several panel members identified the Passive House Program as an important external driver for more than one practice. However, some panelists noted that the work and influence of the Passive House Program in the U.S. post-dates the study time frame. The program has been active in Canada since the 1970s, but the first Passive House built in the U.S. was in 2003. It appears that the program's influence began gaining traction around 2010, when its fifth annual conference welcomed more than 350 participants and the first U.S. Passive House Alliance (network of practitioners) was launched. The program was sanctioned by RESNET in 2011, and the program began partnering with BA in 2013.[78] As the study period covers energy savings from 2006-2015 (including activities that may have led to those energy savings before 2006), it is unclear how influential this program was in the market acceptance of these practices.
- **Energy Star:** Some panel members were conflicted on the channel of influence between this voluntary above-code program and the BA program. Some thought that the BA program was partially, if not wholly, responsible for the content and direction of the Energy Star program. Others thought that the Energy Star program was an external driver to the market acceptance of the practices.
- **RESNET:** Similarly, some panel members thought that the RESNET program should not be considered an external driver. Instead, they argued that the program was highly influenced by BA – and that while RESNET existed before the BA program, the support it received from BA expanded RESNET's reach.

[78] Sources: https://passipedia.org/basics/the_passive_house_-_historical_review/poineer_award/saskatchewan_conservation_house; https://buildingscience.com/documents/insights/bsi-025-the-passivhaus-passive-house-standard; http://www.phius.org/phius-certification-for-buildings-and-products/phius-2015-project-certification/about-passive-house-institute-us/phius-milestones

- **Air Barrier Association:** One panelist noted that the Air Barrier Association is a small organization with limited reach, and that it focuses primarily on commercial buildings, not residential.
- **Regional Organizations:** One panelist disagreed that regional organizations have interacted with or had much influence on U.S. production builders.
- **ASTM/ASHRAE:** One panelist noted that ASTM is more concerned with testing and ASHRAE is more commercially-focused, and that these did not influence the residential market.

### Summary of Changes to Attribution Estimates

Overall, the weighted average percentage the panel members assigned to the BA program was virtually unchanged between Round 1 (55%) and Round 2 (56%), as shown in Table 4-8. All estimates increased, with the largest change in the thermal bridging practice. The overall increase is primarily a result of one panelist substantially increasing all of his initial estimates.

#### TABLE 4-8. SUMMARY OF CHANGES TO ATTRIBUTION ESTIMATES

| PRACTICE | ROUND 1 MEAN | ROUND 2 MEAN | DIFFERENCE |
|---|---|---|---|
| Air Tightness | 56% | 57% | +1% |
| Duct Leakage | 62% | 64% | +2% |
| Insulation | 43% | 45% | +2% |
| Thermal Bridging | 60% | 66% | +6% |
| Overall | 55%[1] | 56%[1] | +1% |
| Note: 1) This average is weighted by energy savings across the four practices. | | | |

The majority of panel members did not adjust their estimates (61% of panelists) (Table 4-9). The most common changes in attribution estimates were to increase estimates (25% of panelists). Of those panel members that raised their estimates, most reported that they raised their estimates because of additional channels of influence they were compelled to consider after reviewing their peers' rationales. One panelist in particular adjusted all estimates upward, as a result of adjusting his overall approach to assign more value to the influence the BA program has on other drivers. On the other hand, those panelists who decreased their estimates did so because they reconsidered the influence of external drivers on market acceptance of the practice. In other words, they felt that the impact of the BA program was less than they originally estimated after reading the thoughts of their peers.

#### TABLE 4-9. SUMMARY OF DIRECTION OF CHANGE IN ATTRIBUTION ESTIMATES

| PRACTICE | COUNT OF CHANGES IN ATTRIBUTION ESTIMATES | | |
|---|---|---|---|
| | INCREASED | DECREASED | STAYED THE SAME |
| Air Tightness | 1 | 1 | 7 |
| Duct Leakage | 2 | 1 | 6 |
| Insulation | 2 | 1 | 6 |
| Thermal Bridging | 4 | 2 | 3 |
| Total (%) | 9 (25%) | 5 (14%) | 22 (61%) |

### Measures of Variation

As expected, overall the panels' estimates display less variation in the second round, indicating a convergence around the mean. Although the overall estimate increased only 1% between Rounds 1 and 2, more importantly, the panel members' estimates tightened around this new mean. In other words, the variation in the estimates from the first round significantly decreased in the second round. This decrease in variation is a result of the panelists with lower original estimates *increasing* their estimates, and the panelists with higher original estimates *decreasing* their estimates, with most of the panelists near the mean maintaining their original estimates.

The standard deviation is a measure of the variation in a group of data points. In the second round of interviews, the standard deviation of the panels' estimates was lower than the first round, for all four practices (Table 4-10). Another measure of the variation between the two rounds is to compare the difference between the highest and lowest estimates. Again, for all four practices, this difference is substantially lower in the second round, up to 30% smaller for thermal bridging. Finally, we can examine the difference between the 25th and 75th percentiles. For one practice, air tightness, there is no difference between the first and second round; however, for the remaining three practices, the difference is smaller in the second round.

TABLE 4-10. MEASURE OF VARIATION BETWEEN ROUNDS 1 AND 2

| VALUE | AIR TIGHTNESS | | | DUCT LEAKAGE | | | INSULATION | | | THERMAL BRIDGING | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R1 | R2 | DIFF | R1 | R2 | DIFF | R1 | R2 | DIFF | R1 | R2 | DIFF |
| Standard deviation | 27% | 21% | -6% | 26% | 20% | -6% | 21% | 16% | -5% | 31% | 20% | -10% |
| Diff btw min and max | 87% | 62% | -25% | 88% | 62% | -26% | 66% | 49% | -17% | 100% | 70% | -30% |
| Diff btw 25th and 75th percentiles | 30% | 30% | 0% | 25% | 10% | -15% | 30% | 10% | -20% | 35% | 20% | -15% |

## FINANCIAL BENEFITS OF ENERGY SAVINGS

Table 4-11 summarizes the net energy savings, overall and by fuel source, and the associated energy cost savings attributable to the BA program for the four practices. In keeping with DOE's evaluation guidance, this study uses the 7% real discount rate set by OMB as the primary discount rate. At the 7% real discount rate, energy cost savings through 2015 are estimated at over $689 million.

TABLE 4-11. ENERGY SAVINGS (2006-2015)

| METRIC | UNIT OF MEASURE | SAVINGS |
|---|---|---|
| Total energy savings – all fuels | Million MMBtu | 139.8 |
| Electricity savings | Million kWh | 9,992 |
| Natural gas savings | Million therms | 1,021 |
| Fuel oil savings | Million gallons | 26 |
| Monetary value of energy savings @ 7% real discount rate | Million, 2015$ | $689 |

Table 4-12 breaks down total benefits by fuel type undiscounted, and discounted at 3% and 7% (program costs are not subtracted from these tables). Per DOE's evaluation guidance, our analysis primarily uses the 7% discount rate, which yields estimated energy cost savings of $689 million.

TABLE 4-12. SAVINGS BY FUEL TYPE (CONSTANT 2015$)

| FUEL TYPE | UNDISCOUNTED | 3% DISCOUNT RATE | 7% DISCOUNT RATE |
|---|---|---|---|
| Electricity | $1,212,037,395 | $685,944,839 | $332,011,017 |
| Natural Gas | $1,187,830,035 | $678,043,987 | $332,130,848 |
| Fuel Oil | $91,872,649 | $52,165,736 | $25,341,779 |
| Total | $2,491,740,079 | $1,416,154,562 | $689,483,644 |

### Net Present Value Analysis

As noted above, the final step in our analysis was to conduct a financial analysis to derive total energy savings from the BA program over the study timeframe. The total energy savings before applying the panel's attribution estimates is $1,230 million.[79] Applying the panel's aggregate estimate of attribution results in total savings of $689 million. Total expenditures on the BA program from inception through 2015 were $162 million. To determine if the benefits of the program surpass the costs, we compare these two values. Using the panel's attribution estimates, the difference between the benefits and costs of the program is a net positive $527 million.

## SENSITIVITY ANALYSES

One way to determine the stability of our estimates is to conduct sensitivity analyses.

Our first set of sensitivity analyses change an assumption about how we calculate the final energy benefits. We conducted three sensitivity analyses on our mean estimates for each practice (Table 4-13):

1. **Remove the highest estimate:** If the maximum value is significantly higher than the rest of the distribution, it could be pulling the overall mean up. By removing the highest value, we can assess how much influence the high value is having on the mean. Across the four practices,

[79] For the period 2006-2015, using a 7% discount rate.

removing the highest value reduces the mean by about 3% for each practice. This translates to an aggregate decrease of 8.2 trillion BTUs (6%) in savings.

2. **Remove the lowest estimate:** Similarly, the lowest estimate could be pulling the overall mean down if it is significantly lower than the rest of the distribution. Across the four practices, removing the lowest estimate raises the mean by 3% to 6% for each practice. This translates to an aggregate increase of 10.6 trillion BTUs (8%) in savings.
3. **Use the median value:** If the distribution of estimates is highly variable, the median value will be substantially different than the mean value (in one direction). There is more variation in the results of this sensitivity analysis. For three practices – air tightness, duct leakage, and thermal bridging – the median is higher than the mean (by 3%, 11%, and 4%, respectively), indicating that lower values are pulling down the mean. For the other practice (insulation), the median is lower than the mean, indicating that higher values are pulling up the mean. Using the median instead of the mean translates to a net gain of 6.5 trillion BTUs (5%) in savings.

Overall, the results of these sensitivity analyses do not indicate that our results are particularly sensitive to the distribution of estimates; we feel comfortable using the mean value for all four practices.

**TABLE 4-13. SENSITIVITY ANALYSES OF DELPHI PANEL ESTIMATES**

| | AIR TIGHTNESS | | DUCT LEAKAGE | | INSULATION | | THERMAL BRIDGING | |
|---|---|---|---|---|---|---|---|---|
| VALUE | VALUE | DIFF FROM MEAN | VALUE | DIFF FROM MEAN | VALUE | DIFF FROM MEAN | VALUE | DIFF FROM MEAN |
| Mean | 57% | | 64% | | 45% | | 66% | |
| Mean - Drop High Estimate | 54% | -3% | 62% | -2% | 42% | -3% | 63% | -3% |
| Mean - Drop Low Estimate | 61% | +4% | 70% | +6% | 48% | +3% | 71% | +6% |
| Median | 60% | +3% | 75% | +11% | 40% | -5% | 70% | +4% |

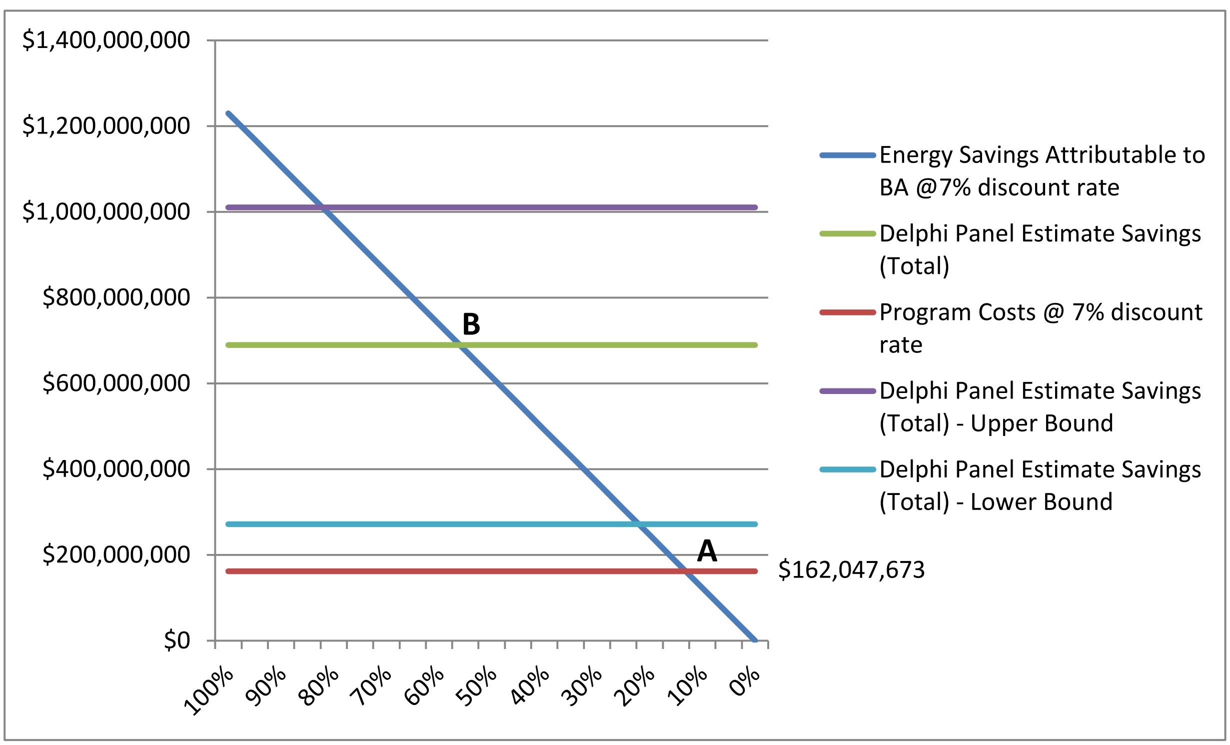
We also conducted a sensitivity analysis of the estimated financial savings based on attributed energy savings. Our analysis uses the maximum and minimum attribution percentages from the Delphi panel to calculate upper- and lower-bound figures. As shown in Table 4-14, the upper-bound estimate yields attributed energy savings of over $1 billion, while the lower-bound estimate yields $271.4 million in attributed energy savings.

TABLE 4-14. ENERGY AND ENERGY COST SAVINGS (2006-2015)

| METRIC | UNIT OF MEASURE | BASE CASE | LOW-END ESTIMATE | HIGH-END ESTIMATE |
|---|---|---|---|---|
| Total energy savings – all fuels | Million MMBtu | 139.8 | 55.3 | 205.5 |
| Electricity savings | Million kWh | 9,992 | 3,889 | 14,544 |
| Natural gas savings | Million therms | 1,021 | 406 | 1,504 |
| Fuel oil savings | Million gallons | 26 | 10 | 39 |
| Monetary value of energy savings @ 7% real discount rate | Million, 2015$ | $689 | $271 | $1,010 |

We can also use these values to estimate the attribution percentages that would present the breakeven point for program costs, or the point at which the program costs equal the benefits. Using an overall attribution estimate, the breakeven point for program costs of $162 million is 13.2%. In other words, the percentage of the benefits that need to be attributed to the BA program to meet the program costs is 13.2% (Point "A" in Figure 4-12). The overall percentage of attribution assigned by the Delphi panel is 56% (Point B), well above the breakeven point. Carrying forward the figures from our sensitivity analysis, the upper-bound estimate yields energy savings of over $1 billion, while even the lower-bound figure ($271.4 million) is well above the program cost of $162 million. Moreover, this analysis does not account for monetary benefits that result from environmental health impacts (discussed in the following section); if those benefits were included, the breakeven point would be even lower.

FIGURE 4-12. BREAKEVEN ANALYSIS



# V. ENVIRONMENTAL HEALTH IMPACTS

This chapter carries forward the attributed energy impacts from the previous chapter to estimate environmental health benefits that result from reduced air emissions due to avoided electricity generation. Avoided mortality and morbidity are reported two ways: in terms of incident rates and in terms of the dollar value of avoided adverse health events.[80]

## EMISSIONS REDUCTIONS

Applying the emission factors derived using the methods in Chapter 3 and Appendix H, we estimate the emissions reductions shown in Table 5-1. The estimated emissions reductions are largest for $CO_2$, followed by $SO_2$, $NO_x$, and $PM_{2.5}$.

### TABLE 5-1. EMISSIONS REDUCTIONS ASSOCIATED WITH BUILDING AMERICA (TONS), 2006-2015

| YEAR | $PM_{2.5}$ | $SO_2$ | $NO_x$ | $CO_2$ |
|---|---|---|---|---|
| 2006 | 18 | 388 | 166 | 148,589 |
| 2007 | 26 | 657 | 275 | 293,034 |
| 2008 | 31 | 750 | 312 | 328,789 |
| 2009 | 35 | 827 | 334 | 357,330 |
| 2010 | 38 | 924 | 405 | 456,584 |
| 2011 | 44 | 997 | 454 | 538,910 |
| 2012 | 56 | 1,172 | 570 | 711,420 |
| 2013 | 68 | 1,385 | 726 | 908,250 |
| 2014 | 77 | 1,548 | 881 | 1,103,705 |
| 2015 | 94 | 1,876 | 1,065 | 1,338,187 |
| **Total** | **486** | **10,525** | **5,188** | **6,184,797** |

## AVOIDED MORBIDITY AND MORTALITY

Based on the methods described in Chapter 3 and Appendix H, we estimate the monetized emissions-related benefits for $PM_{2.5}$, $SO_2$, and NOx shown in Table 5-2. As indicated in the table, the present value of the BA program's emissions-related benefits through 2015 ranges from slightly less than $113 million to more than $574 million, depending on the discount rate and choice of damage-per-ton values (i.e., low or high). The economic performance analyses in Chapters 8 and 9 use the average values.

[80] As previously noted, this analysis does not account for health improvements resulting from IAQ improvements in homes.

### TABLE 5-2. PRESENT VALUE OF EMISSIONS-RELATED BENEFITS (2015$)

| YEAR | 3% DISCOUNT RATE | | | 7% DISCOUNT RATE | | |
|---|---|---|---|---|---|---|
| | LOW | HIGH | AVERAGE | LOW | HIGH | AVERAGE |
| 2006 | $9,547,400 | $21,366,788 | $15,457,094 | $5,190,210 | $11,916,391 | $8,553,300 |
| 2007 | $16,044,727 | $35,346,169 | $25,695,448 | $8,083,353 | $18,739,533 | $13,411,443 |
| 2008 | $17,877,408 | $40,129,045 | $29,003,227 | $9,003,173 | $20,807,726 | $14,905,449 |
| 2009 | $19,832,699 | $44,577,175 | $32,204,937 | $9,676,132 | $22,172,468 | $15,924,300 |
| 2010 | $22,112,241 | $49,597,752 | $35,854,997 | $10,417,551 | $23,591,142 | $17,004,347 |
| 2011 | $24,390,817 | $54,173,675 | $39,282,246 | $10,790,105 | $24,738,970 | $17,764,537 |
| 2012 | $29,032,663 | $64,374,100 | $46,703,382 | $12,415,238 | $28,139,318 | $20,277,278 |
| 2013 | $34,482,730 | $76,631,605 | $55,557,167 | $14,227,435 | $32,130,647 | $23,179,041 |
| 2014 | $37,799,766 | $85,417,207 | $61,608,487 | $15,423,330 | $34,916,043 | $25,169,687 |
| 2015 | $46,164,451 | $102,809,625 | $74,487,038 | $17,740,285 | $40,061,318 | $28,900,801 |
| **Total** | **$257,284,903** | **$574,423,141** | **$415,854,022** | **$112,966,811** | **$257,213,556** | **$185,090,184** |

For additional detail on the results shown in Table 5-2, Table 5-3 presents the average annual change in incidence for each of the health impacts reflected in the benefits estimates. These results show that the BA program, on average, reduced the incidence of premature mortality by 4.8 to 10.9 cases per year during the 2006-2015 period. The average annual changes in incidence for the other health effects shown in the table vary across different health effects.

**TABLE 5-3. AVERAGE ANNUAL CHANGE IN INCIDENCE, BY HEALTH EFFECT**

| HEALTH EFFECT | AVERAGE ANNUAL CHANGE IN INCIDENCE (2006-2015) |
|---|---|
| Premature Mortality | |
| Low | 4.82 |
| High | 10.85 |
| Respiratory emergency room visits | 2.50 |
| Acute bronchitis | 6.92 |
| Lower respiratory symptoms | 88.32 |
| Upper respiratory symptoms | 129.97 |
| Minor Restricted Activity Days | 3,579.30 |
| Work loss days | 592.27 |
| Asthma exacerbation | 272.18 |
| Cardiovascular hospital admissions | 1.65 |
| Respiratory hospital admissions | 1.30 |
| Non-fatal heart attacks | |
| Low | 0.56 |
| High | 5.18 |

## VI. ENERGY SECURITY IMPACTS

Reductions in oil imports have energy security benefits. The evaluation carries forward the attributed energy savings presented in Chapter 4 to estimate energy security impacts. This is a relatively small benefits area for the BA program because only a small fraction of U.S. homes use heating oil. These impacts are not factored into the benefit-cost calculations, in keeping with DOE's evaluation guidance.

The energy modeling analysis broke out energy savings into electricity, natural gas, and fuel oil. As reported in the energy savings analysis, attributed fuel oil savings was 26.2 million gallons. We converted the 26.2 million gallons to barrels using a standard conversion factor of 42 gallons per barrel. As shown in Table 6-1, this results in 0.62 million barrels.

To estimate energy security impacts, we look at net oil imports as a percent of total oil supplied during each year of the analysis that produced energy benefits. This percentage declined from a high of 59.9% in 2006 to 24.1% in 2015. We multiply the import percentage in each year by the total number of barrels avoided in each year to calculate displaced fuel oil imports. Of the 0.62 million barrels, 0.23 million is from displaced imports.

### TABLE 6-1. REDUCTIONS IN OIL IMPORTS FROM ENERGY SAVINGS ASSOCIATED WITH BUILDING AMERICA, 2006-2015

| YEAR | TOTAL FUEL OIL SAVINGS (GALLONS) | TOTAL FUEL OIL SAVINGS (BARRELS) | NET OIL IMPORTS AS A % OF TOTAL OIL SUPPLIED | NET OIL IMPORTS (BARRELS) |
|---|---|---|---|---|
| 2006 | 535,401 | 12,748 | 60% | 7,636 |
| 2007 | 964,492 | 22,964 | 58% | 13,365 |
| 2008 | 1,270,736 | 30,256 | 57% | 17,246 |
| 2009 | 1,609,241 | 38,315 | 52% | 19,732 |
| 2010 | 1,976,007 | 47,048 | 49% | 23,148 |
| 2011 | 2,306,667 | 54,921 | 45% | 24,659 |
| 2012 | 3,012,764 | 71,732 | 40% | 28,621 |
| 2013 | 3,893,829 | 92,710 | 33% | 30,502 |
| 2014 | 4,850,901 | 115,498 | 27% | 30,607 |
| 2015 | 5,810,264 | 138,340 | 24% | 33,340 |
| **Total** | **26,230,302** | **624,531** | - | **228,856** |

# VII. KNOWLEDGE IMPACTS

IEc used both a citation analysis and interviews with builders to assess knowledge impacts of the program. The results of each of these analyses are described in this chapter.

## CITATION ANALYSIS

As described in Chapter 3 and Appendix I, IEc searched in 15 trade journals identified by building experts as important sources of information for builders, to identify the term "Building America" and key practices that BA worked on.[81] We first searched for the key words in Google Scholar, and then on the journals' own websites. While this provided a more complete picture of relevant articles, only Google Scholar provided a citation count. Therefore, the citation numbers presented in this chapter should be considered a conservative, lower-bound estimate of the total number of citations.

We conducted an initial search using the phrase "Building America." This search yielded more than 2,043 results. However, some search engines did not allow us to search for the exact phrase "Building America," and instead returned all articles that used the terms "building" and "America" anywhere in the article. As such, this figure is inflated. To ensure that we captured the most relevant search results in an efficient way, we sorted by relevance and prioritized the top results in each journal for a more in-depth analysis, as described in Chapter 3. This reduced the number of results from 2,043 to 306. We found 306 unique articles that mention BA, alone or in combination with one or more other search terms. Many articles cited more than one search term.

The number of articles mentioning BA was relatively flat from the program's inception in 1994 through 2000, then spiked in 2003, which coincided with an IECC code update. We also observe spikes in 2009 and 2011, which coincide with the 2009 and 2012 updates to the IECC. One possible (but non-definitive) interpretation is that BA, and practices advanced by BA, have been most frequently published during discussions about code updates. Over the entire timeframe, articles that discuss air sealing, air barriers, and/or insulation in combination with BA were the most frequent, which further reinforces this evaluation's focus on the energy efficiency results of these practices. Articles mentioning bulk water management were the least frequent.

We found 977 unique articles that contain the keywords (practices) without mentioning BA,[82] which is more than three times the number of articles that mention BA by name. However, the total number of articles that mention each practice was frequently higher when the practice was mentioned in combination with BA than when the practice was mentioned without BA.[83] Although we cannot draw any firm

[81] As explained in Chapter 3, our initial approach was to draw a statistically valid sample of BA publications, which we searched for in Google Scholar; however, none of the 64 publications in our sample was in Google Scholar.

[82] Based on the top search results.

[83] The exceptions were insulation, thermal bridging, air infiltration, attic interface, structural insulated panels, unconditioned + insulation, unconditioned + sealing, unvented crawl spaces, and duct pressure testing.

conclusions based on this single finding, it is highly consistent with our overall findings about BA's influence in diffusing the selected practices in the market. Appendix K provides the results (counts) from searches that directly mention BA and the practices versus those that only mention the practices (without directly mentioning BA).

Beyond looking for original articles, we also looked for citations of those articles. Of the 306 articles that mention BA, 21 were cited by another publication at least once (6.9%). Again, it is important to note that 21 is a lower-bound estimate because of the previously-mentioned limitations we encountered in searching Google Scholar. All 21 original articles mention BA. Sixteen mention insulation, 11 mention air leakage, seven mention ducts and conditioning, six mention air sealing, and the rest of the practices are mentioned five times or fewer. The first article to be cited was published in 2001. We do not observe a clear trend over time, which is not surprising given the small number of citations. We also looked at the number of times each article was cited. Overall, the 21 articles were cited 174 times in other publications (8.3 times on average). However, there was substantial variation; as shown in Figure 7-1, just over half of the articles were cited five times or less, but 11% were cited more than 20 times each. The highest number of citations was for articles that addressed insulation (134 citations) and air leakage (84 citations).[84]

We also looked at citations of articles that did not mention BA. Of the 977 articles that did not mention BA, 218 were cited at least once – a much higher percentage than the number mentioning BA (22% vs. 6.9%). However, this does not account for the fact that some articles may reflect BA's influence indirectly (to the degree they mention a particular practice due to knowledge the authors gained from the program), even if the article does not explicitly mention BA. Articles that address insulation were cited the most (93 times), followed by air leakage (37 times) and air infiltration (30 times). The 218 articles were cited a total of 3,985 times (18.3 times on average). Figure 7-2 shows the distribution of citations. Of the articles that were cited, most were cited between two and five times, but the second-most common was 20 or more citations. Articles mentioning insulation were cited 2,544 times, followed by air leakage (802 times), ducts and conditioning (408 times), air infiltration (369 times), air barriers (305 times), duct leakage (174 times), insulation in unconditioned spaces (100 times), and the rest less than 100 times.

We also looked at who is citing these articles.[85] A few observations stand out.

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[84] These numbers are not additive because an article often addresses multiple topics.

[85] These include: Building Science Corporation; IBACOS; 8th International conference on durability of building material and components, Vancouver, Canada, May; John Wiley & Sons; Zaštita materijala; masters theses and doctoral dissertations; ACS applied materials & interfaces; Advances in Building Energy Research; Advances in Engineering Software; Amirkabir University of Technology; Andrews University Digital Commons; APT Bulletin-Fredericksburg VA; ASHRAE Transactions; ASTM International; Automation in construction; BioResources; Building and Environment; Building Research and Information; Building Simulation; Buildings; Cityscape; Colorado State University; Construction Engineering Research Lab (Army) in Champaign IL; Construction Innovation; DOE; Energy; Energy and Buildings; Energy Technology; Engineering, Construction, and Architectural Management; Environmental Impact Assessment Review; Environment and Planning B: Planning and Design; Environmental Research Letters; Habitat International; Healthy House Inst; Housing Policy Debate; iea-shc.org; International Journal of 3-D Information Modelling; International Journal of Energy Research; International Journal of Environment and Waste Management; International Journal of Mass Customization; International Journal of Sustainable Engineering; International Journal of the Constructed Environment; International Wood Products Journal; Journal of Architectural Engineering; Journal of Civil Engineering and Management; Journal of Cleaner Production; Journal of Financial Management of Property and Construction; Journal of Thermal Envelope and Building Science; JSTOR; masscustomhome.com; NREL; New Society Publishers; Proceedings from the Ewing Marion Kaufman Foundation 2013 Industry Studies Conference, Kansas City, MO; Proceedings of the Human Factors and Ergonomics Society Annual Meeting; Proceedings of the ISES 2005 Solar World Congress; Proceedings of the Second World Construction Symposium; Radiation protection dosimetry; Renewable and Sustainable Energy Reviews; San Francisco Department of the Environment; Science and Technology for the Built Environment; Society for Computer Simulation International; Sustainable Cities and Society;

- Articles are cited in a number of trade journals with an energy and/or engineering focus.
- There appears to be some degree of cross-citing by the 15 journals on our list, although most of the citing entities are not among these 15 journals.
- DOE, NREL, and BA teams are in some cases citing the research in the journal articles.
- Many of the citing publications are professional conference proceedings; this aligns with interviewees' observations that BA disseminates knowledge through conferences, and is consistent with the program's theory of change as shown in the logic model.
- Several international journals have cited the articles, bringing the research to audiences outside of the U.S.
- Educational institutes and a number of masters theses/doctoral dissertations are citing entities, which suggests the research is being disseminated to the next generation of building professionals, engineers, and students in related fields of study.

Another goal of the citation analysis was to examine evidence of knowledge spillovers from the new residential market to the retrofit market. In this regard, our citation analysis finds that journals that cater to the retrofit market mention the practices, sometimes with a direct reference to BA (e.g., in *Professional Remodeler)*. In addition, the titles of the journal articles themselves (in various journals) sometimes refer to remodeling. This provides some anecdotal evidence that knowledge spillovers have occurred. It should also be noted that some journals on our list do not cater specifically to either the new residential market or the renovation market, and are likely read by both audiences.

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Sustainable Energy Technologies and Assessments; The Advanced Educational Modeling Laboratory, The Concord Consortium; The Physics Teacher; University of Minnesota; U.S. Patent and Trademark Office; Worcester Polytechnic Institute; and World Scientific.

FIGURE 7-1. DISTRIBUTION OF 21 ARTICLES MENTIONING BA THAT WERE CITED

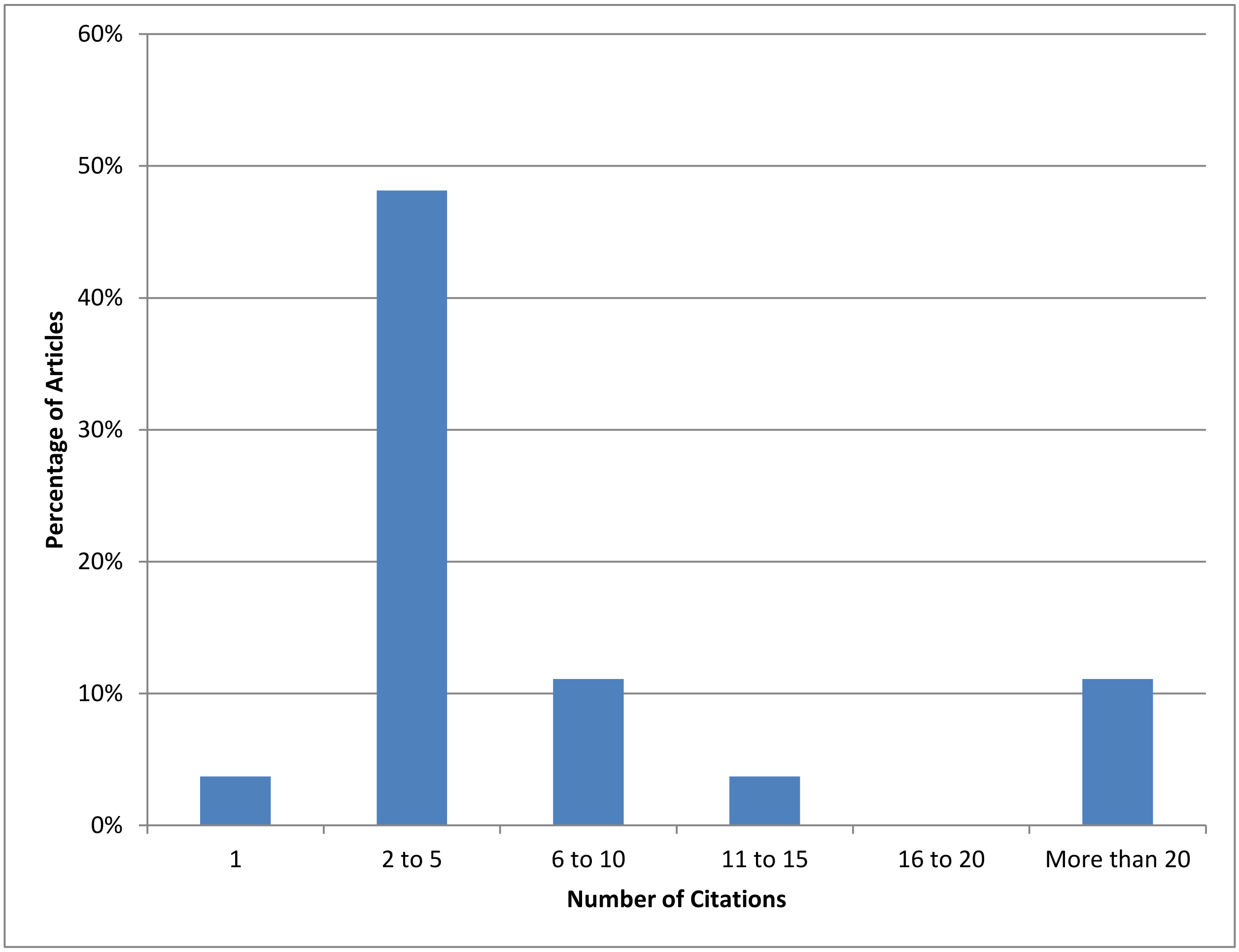
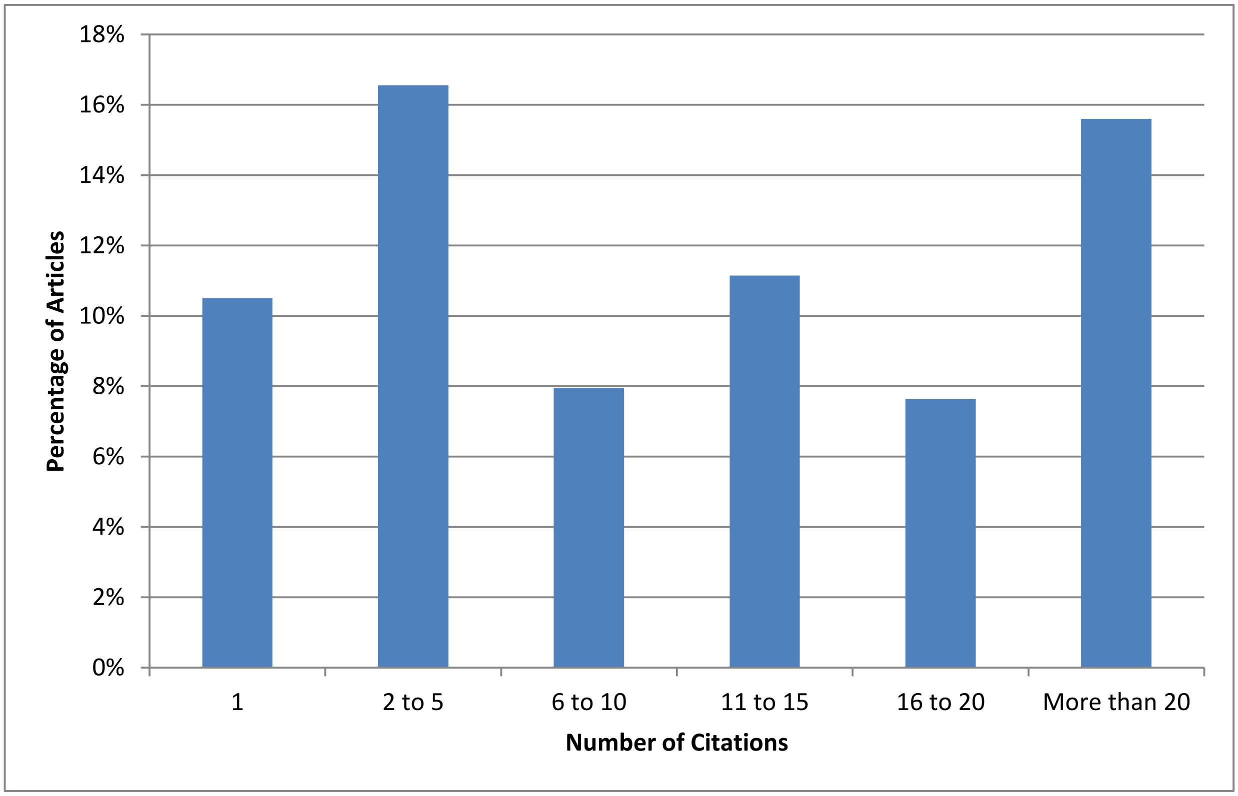


FIGURE 7-2. DISTRIBUTION OF 218 ARTICLES NOT MENTIONING BA THAT WERE CITED



### BUILDER INTERVIEWS

During interviews, IEc asked builders where they get their information on energy efficiency. Both BA and non-BA builders indicate that they rely on their consultants and energy raters, networking and personal relationships, and publications/online resources for energy efficiency information. BA builders interviewed report relying on resources provided by the BA program as a source of knowledge. BA builders are more likely to rely on BA resources for this information than non-BA builders. Specifically, BA builders called out IBACOS, BSC, and BA case studies as BA "resources" on which they frequently rely.

Non-BA builders do not generally report using BA resources, and indicated that they rely more on their contractors and/or energy raters to pass along information on new energy efficiency practices. They acknowledge that their contractors may use BA resources to obtain information, but they cannot be certain. While BA resources do not appear to be used directly by non-BA builders, it is possible that the information provided in these BA resources is reaching non-BA builders through their contractors and/or raters. In fact, this point was made during the Delphi panel interviews as well, and it is consistent with the program theory as shown in the logic model.

The BA program offers three resources in particular as enabling tools for learning and adoption of energy efficiency practices: DOE climate maps, the BEopt modeling tool, and the vapor retarder classification system. Only one builder reported having used the BEopt tool. Other builders were aware of the tool but had not used it themselves, and were unsure about its impact in facilitating increased energy efficiency in new homes. Builders were more aware of and more favorably rated the DOE climate maps, and think of them as helpful tools, particularly when building in new climates. Builders were also generally aware of the vapor retarder classification system, and think it is effective at facilitating increased energy efficiency in new homes by simplifying a complicated system and helping to avoid mistakes. One builder noted that before the vapor retarder classification system, builders were not paying attention to moisture management at such a detailed level. Also, builders reported that their contractors and raters rely on these resources more often and more directly than they do.

IEc also used the interviews with builders to explore whether BA helped California builders come into compliance with Title 24 (or go beyond compliance) in a more cost-effective manner. California builders report that they rely on their contractors and energy raters, and to a lesser extent their trade contractors, for information on how to comply with Title 24. Two BA builders in California report using several BA resources to comply with Title 24, including energy efficiency construction approaches developed by BA or its teams, case studies, or other documentation of lessons learned from BA demonstration projects. These BA resources helped them comply with Title 24 primarily through assistance from IBACOS, including their modeling and construction methodologies. These builders also reported that information gleaned from BA advanced the uptake of these practices by other divisions outside California, through advances in critical learning and modeling techniques. However, the majority of builders in California that we interviewed did not mention directly using BA resources to assist with Title 24 compliance.

## VIII. RETROSPECTIVE ECONOMIC IMPACT ASSESSMENT

Chapter 8 compares the monetized benefits of the four practices to EERE's portfolio investment costs.

Table 8-1 shows DOE's investments in the BA program from 1994 through 2015. During this time period, EERE invested $369 million in the BA program (constant $2015, undiscounted). Investments are discounted back to the beginning of 1994 at 7% and 3% in constant $2015.

### TABLE 8-1. BA PORTFOLIO INVESTMENT COSTS

| YEAR | NOMINAL (CURRENT-YEAR) $ (THOUSANDS) | GDP IMPLICIT PRICE DEFLATOR | CONSTANT 2015$, UNDISCOUNTED (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS) |
|---|---|---|---|---|---|
| 1994 | $3,020 | 73.785 | $4,502 | $4,502 | $4,502 |
| 1995 | $4,435 | 75.324 | $6,477 | $6,053 | $6,288 |
| 1996 | $3,898 | 76.699 | $5,590 | $4,883 | $5,269 |
| 1997 | $4,562 | 78.012 | $6,432 | $5,251 | $5,887 |
| 1998 | $4,537 | 78.859 | $6,329 | $4,828 | $5,623 |
| 1999 | $5,570 | 80.065 | $7,652 | $5,456 | $6,601 |
| 2000 | $9,674 | 81.887 | $12,995 | $8,659 | $10,883 |
| 2001 | $11,463 | 83.754 | $15,055 | $9,375 | $12,241 |
| 2002 | $11,589 | 85.039 | $14,990 | $8,725 | $11,834 |
| 2003 | $11,558 | 86.735 | $14,658 | $7,973 | $11,234 |
| 2004 | $12,354 | 89.120 | $15,248 | $7,751 | $11,346 |
| 2005 | $15,959 | 91.988 | $19,084 | $9,066 | $13,786 |
| 2006 | $14,759 | 94.814 | $17,123 | $7,603 | $12,009 |
| 2007 | $16,775 | 97.337 | $18,957 | $7,866 | $12,909 |
| 2008 | $23,725 | 99.246 | $26,295 | $10,198 | $17,384 |
| 2009 | $20,021 | 100.000 | $22,022 | $7,982 | $14,135 |
| 2010 | $25,597 | 101.221 | $27,817 | $9,422 | $17,334 |
| 2011 | $34,106 | 103.311 | $36,314 | $11,496 | $21,971 |
| 2012 | $28,597 | 105.214 | $29,898 | $8,846 | $17,562 |
| 2013 | $25,303 | 106.913 | $26,029 | $7,197 | $14,844 |
| 2014 | $22,297 | 108.828 | $22,537 | $5,824 | $12,478 |
| 2015 | $12,799 | 109.998 | $12,799 | $3,091 | $6,880 |
| **Total** | **$322,598** | | **$368,802** | **$162,048** | **$253,000** |

Notes: Nominal costs were converted to constant 2015 dollars by multiplying by the 2015 GDP implicit price deflator (109.998) and then dividing by the current-year deflator. GDP implicit price deflators are from the Bureau of Economic Analysis, Table 1.1.9: Implicit Price Deflators for Gross Domestic Product, available at https://bea.gov/, accessed July 12, 2017.

Table 8-2 presents the monetized attributed energy savings for each of the four practices in constant (undiscounted) 2015 dollars. Benefits for the four selected practices started to accrue in 2006. From 2006 through 2015, the four practices generated nearly $2.5 billion in benefits.

#### TABLE 8-2. MONETIZED ATTRIBUTED ENERGY SAVINGS BY PRACTICE (THOUSANDS OF CONSTANT 2015$)

| YEAR | PRACTICE | | | | |
|---|---|---|---|---|---|
| | AIR TIGHTNESS | DUCT TIGHTNESS | INSULATION | THERMAL BRIDGING | TOTAL |
| 2006 | $43,356 | $7,185 | $4,676 | $0 | $55,218 |
| 2007 | $73,420 | $11,395 | $8,080 | $0 | $92,895 |
| 2008 | $99,985 | $16,121 | $11,011 | $0 | $127,117 |
| 2009 | $119,846 | $19,605 | $16,123 | $0 | $155,574 |
| 2010 | $142,885 | $23,854 | $20,316 | $0 | $187,055 |
| 2011 | $166,023 | $28,061 | $25,097 | $0 | $219,181 |
| 2012 | $209,424 | $39,340 | $37,217 | $3,303 | $289,285 |
| 2013 | $258,140 | $51,843 | $50,851 | $6,854 | $367,688 |
| 2014 | $322,720 | $66,529 | $66,672 | $10,717 | $466,639 |
| 2015 | $361,130 | $76,992 | $79,281 | $13,686 | $531,089 |
| **Total** | **$1,796,929** | **$340,926** | **$319,324** | **$34,561** | **$2,491,740** |

Table 8-3 combines the attributed energy savings reported above with attributed health benefits to show the total monetized attributed benefits for the BA program through 2015. Over this time period, the four practices produced nearly $3.2 billion in energy and health benefits (constant $2015, undiscounted). Benefits are discounted back to the beginning of 1994 at 7% and 3% in constant $2015, assuming benefits start on the last day of each year.

TABLE 8-3. MONETIZED ATTRIBUTED ECONOMIC AND ENVIRONMENTAL HEALTH BENEFITS OF THE FOUR SELECTED PRACTICES, 2006-2015

| YEAR | ENERGY SAVINGS BENEFITS | | | HEALTH BENEFITS | | | TOTAL BENEFITS | | |
|---|---|---|---|---|---|---|---|---|---|
| | CONSTANT 2015$, UNDISCOUNTED (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS) | CONSTANT 2015$, UNDISCOUNTED (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS) | CONSTANT 2015$, UNDISCOUNTED (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS) |
| 2006 | $55,218 | $22,918 | $37,604 | $21,653 | $8,553 | $15,457 | $76,871 | $31,471 | $53,061 |
| 2007 | $92,895 | $36,033 | $61,419 | $36,719 | $13,411 | $25,695 | $129,614 | $49,444 | $87,115 |
| 2008 | $127,117 | $46,082 | $81,598 | $43,150 | $14,905 | $29,003 | $170,267 | $60,987 | $110,602 |
| 2009 | $155,574 | $52,708 | $96,956 | $49,339 | $15,924 | $32,205 | $204,913 | $68,632 | $129,161 |
| 2010 | $187,055 | $59,228 | $113,180 | $56,481 | $17,004 | $35,855 | $243,536 | $76,232 | $149,035 |
| 2011 | $219,181 | $64,860 | $128,756 | $63,451 | $17,765 | $39,282 | $282,631 | $82,624 | $168,038 |
| 2012 | $289,285 | $80,004 | $164,988 | $77,604 | $20,277 | $46,703 | $366,889 | $100,282 | $211,692 |
| 2013 | $367,688 | $95,035 | $203,596 | $95,007 | $23,179 | $55,557 | $462,694 | $118,214 | $259,153 |
| 2014 | $466,639 | $112,720 | $250,862 | $109,399 | $25,170 | $61,608 | $576,038 | $137,890 | $312,470 |
| 2015 | $531,089 | $119,896 | $277,194 | $135,366 | $28,901 | $74,487 | $666,455 | $148,797 | $351,681 |
| **Total** | **$2,491,740** | **$689,484** | **$1,416,155** | **$688,168** | **$185,090** | **$415,854** | **$3,179,908** | **$874,574** | **$1,832,009** |

As shown in Table 8-4, net economic benefits (benefits minus costs) through 2015 totaled over $2.8 billion ($2015, undiscounted). Three-quarters ($2.1 billion) of the $2.8 billion in net economic benefits was from energy savings, and the remainder was from environmental health benefits.

**TABLE 8-4. NET ECONOMIC BENEFITS THROUGH 2015**

| YEAR | CONSTANT 2015$, UNDISCOUNTED (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS) |
|---|---|---|---|
| 1994 | $(4,502) | $(4,502) | $(4,502) |
| 1995 | $(6,477) | $(6,053) | $(6,288) |
| 1996 | $(5,590) | $(4,883) | $(5,269) |
| 1997 | $(6,432) | $(5,251) | $(5,887) |
| 1998 | $(6,329) | $(4,828) | $(5,623) |
| 1999 | $(7,652) | $(5,456) | $(6,601) |
| 2000 | $(12,995) | $(8,659) | $(10,883) |
| 2001 | $(15,055) | $(9,375) | $(12,241) |
| 2002 | $(14,990) | $(8,725) | $(11,834) |
| 2003 | $(14,658) | $(7,973) | $(11,234) |
| 2004 | $(15,248) | $(7,751) | $(11,346) |
| 2005 | $(19,084) | $(9,066) | $(13,786) |
| 2006 | $59,748 | $23,868 | $41,051 |
| 2007 | $110,657 | $41,578 | $74,206 |
| 2008 | $143,972 | $50,789 | $93,217 |
| 2009 | $182,890 | $60,650 | $115,026 |
| 2010 | $215,719 | $66,810 | $131,701 |
| 2011 | $246,318 | $71,128 | $146,068 |
| 2012 | $336,991 | $91,436 | $194,130 |
| 2013 | $436,665 | $111,017 | $244,309 |
| 2014 | $553,502 | $132,066 | $299,992 |
| 2015 | $653,657 | $145,706 | $344,801 |
| **Total** | **$2,811,106** | **$712,526** | **$1,579,008** |

Based on the information presented above, Table 8-5 shows three economic performance measures for the program: net present value, benefit-to-cost ratio, and internal rate of return. Each is presented at a 7% discount rate (the primary discount rate for this study, per DOE's evaluation guidance) and at a 3% discount rate (shown for informational purposes). At a 7% discount rate, the net benefits of the four energy efficiency practices totaled over $712 million in reduced energy costs and reduced mortality and morbidity from avoided electricity generation. The benefit-cost ratio is 5.4. The evaluation calculates the social return on EERE's investment as 30.2%. Based on the economic analysis, DOE's investment in BA has been worthwhile.

**TABLE 8-5. ECONOMIC PERFORMANCE MEASURES FOR BUILDING AMERICA**

| METRIC | UNIT OF MEASURE | RETROSPECTIVE ANALYSIS THROUGH 2015 | |
|---|---|---|---|
| | | ENERGY BENEFITS | COMBINED ENERGY & ENVIRONMENTAL HEALTH BENEFITS |
| Portfolio investment cost – undiscounted | Million, 2015$ | $369 | $369 |
| Gross economic benefits – undiscounted | Million, 2015$ | $2,492 | $3,180 |
| Net economic benefits – undiscounted | Million, 2015$ | $2,123 | $2,811 |
| Net present value @ 7% real discount rate | Million, 2015$ | $527 | 713 |
| Net present value @ 3% real discount rate | Million, 2015$ | $1,163 | 1,579 |
| Benefit-to-cost ratio (BCR) @ 7% real discount rate | Ratio | 4.3 | 5.4 |
| Benefit-to-cost ratio (BCR) @ 3% real discount rate | Ratio | 5.6 | 7.2 |
| Internal rate of return | Percent | 27.0% | 30.2% |

**The benefits presented in Table 8-5 are lower-bound estimates** because the evaluation compares the total cost of the BA program from 1994-2015, $162 million,[86] to the benefits of only these four practices, which started to accrue in 2006. The evaluation also does not include BA's work on construction practices that manage moisture, which protect indoor air quality and provide occupant comfort. Although these are important benefit areas for BA, IEc was not able to quantify them with the resources available for this project. This evaluation also does not include energy savings and associated benefits that accrued to the home renovation market due to knowledge spillover.

[86] Discounted at 7%. Program costs total $253 million discounted at 3%.

## IX. ECONOMIC ANALYSIS INCLUSIVE OF REMAINING USEFUL LIFE BENEFITS

The evaluation has a primarily retrospective focus; however, because energy savings in affected homes persist over time, the study also analyzed the energy savings and associated benefits that persist beyond 2015 from homes built during the study period. The evaluators calculated remaining useful life benefits based on assumptions about the number of years between the construction of a new house and the first major renovation of that house, when new energy code provisions take effect, which industry experts estimated at 25 years on average. Thus, the last year of the analysis of projected benefits is 2039. This chapter shows how including remaining useful life savings for homes built during the study period affects the estimated benefits and economic performance measures. Appendix L provides detailed output tables for the analysis of energy, environmental health, and energy security impacts inclusive of effective useful life considerations.

- **Energy impacts:** As shown in Table 9-1, attributed energy savings through 2039 are estimated at 798.0 million MMBtu, compared to 139.8 million MMBtu in savings realized through 2015.

### TABLE 9-1. ATTRIBUTED ENERGY SAVINGS ESTIMATED THROUGH 2039

| METRIC | UNIT OF MEASURE | RETROSPECTIVE ANALYSIS THROUGH 2015 | EXTENDED ANALYSIS THROUGH 2039 |
|---|---|---|---|
| Total energy savings – all fuels | Million MMBtu | 139.8 | 798.0 |
| Electricity savings | Million kWh | 9,992 | 56,699 |
| Natural gas savings | Million therms | 1,021 | 5,841 |
| Fuel oil savings | Million gallons | 26 | 145 |

- **Environmental health impacts:** Table 9-2 shows estimated emissions reductions attributed to the BA program through 2039. This includes over 30 million tons in avoided $CO_2$, 24,000 in avoided $SO_2$, 19,000 in avoided NOx, and 2,000 in avoided $PM_{2.5}$.

### TABLE 9-2. ATTRIBUTED EMISSION REDUCTIONS ESTIMATED THROUGH 2039

| METRIC | UNIT OF MEASURE | RETROSPECTIVE ANALYSIS THROUGH 2015 | EXTENDED ANALYSIS THROUGH 2039 |
|---|---|---|---|
| Avoided carbon dioxide emissions ($CO_2$) | Tons | 6,184,797 | 30,542,032 |
| Avoided particulate matter emissions ($PM_{2.5}$) | Tons | 486 | 2,408 |
| Avoided sulfur dioxide emissions ($SO_2$) | Tons | 10,525 | 24,732 |
| Avoided nitrogen oxides (NOx) | Tons | 5,188 | 19,036 |

To the extent that additional controls are installed on power plants to control $PM_{2.5}$ emissions, this approach may underestimate the reduction in $PM_{2.5}$ emissions factors over time and may therefore overestimate benefits of the BA program associated with reduced $PM_{2.5}$ emissions. To account for this possibility, IEc conducted a sensitivity analysis. If remaining effective useful life benefits related to $PM_{2.5}$ emissions reductions are excluded from the estimates of monetized benefits, the remaining effective useful life air benefits of the BA program are 30% to 31% lower than presented above and benefits over the full 2015-2039 period are 14% to 18% lower than the estimates presented above. This potential for overestimation, however, is likely to be limited, as the IPM base case projection shows that the capacity of power plants installed with fabric filters (one of the main controls for $PM_{2.5}$) is relatively constant over the model time horizon.[87] This suggests that additional installations of $PM_{2.5}$ controls at power plants are likely to be limited.

Table 9-3 shows the attributed average annual change in incidence for each of the health impacts reflected in the benefits estimates. The estimates suggest that the BA program, on average, reduced the incidence of premature mortality by 4.82 to 10.85 cases per year during the 2006-2015 period. Extending the analysis through 2039 results in an average reduction of 9.17 to 20.69 cases per year. The average annual changes in incidence for the other health effects shown in the table vary across different health effects. It should be noted that the changes in incidence for each health effect are slightly lower during the remaining effective useful life period (2016-2039) than during the retrospective period (2006-2015). This reflects a projected downward trend in $SO_2$ emission factors over time in those NERC regions projected to experience the largest declines in electricity generation.

**TABLE 9-3. ATTRIBUTED AVERAGE ANNUAL REDUCTION IN INCIDENCES OF MORTALITY AND MORBIDITY ESTIMATED THROUGH 2039**

| METRIC | UNIT OF MEASURE | RETROSPECTIVE ANALYSIS THROUGH 2015 | EXTENDED ANALYSIS THROUGH 2039 |
|---|---|---|---|
| Premature Mortality | | | |
| Low | # of incidents | 4.82 | 9.17 |
| High | # of incidents | 10.85 | 20.69 |
| Respiratory emergency room visits | # of incidents | 2.50 | 4.75 |
| Acute bronchitis | # of incidents | 6.92 | 13.10 |
| Lower respiratory symptoms | # of incidents | 88.32 | 167.48 |
| Upper respiratory symptoms | # of incidents | 129.97 | 244.35 |
| Minor Restricted Activity Days | # of incidents | 3,579.30 | 6,646.20 |
| Work loss days | # of incidents | 592.27 | 1,109.56 |
| Asthma exacerbation | # of incidents | 272.18 | 484.78 |
| Cardiovascular hospital admissions | # of incidents | 1.65 | 3.25 |
| Respiratory hospital admissions | # of incidents | 1.30 | 2.61 |
| Non-fatal heart attacks | | | |
| Low | # of incidents | 0.56 | 1.11 |
| High | # of incidents | 5.18 | 10.21 |

[87] U.S. EPA, Power Sector Modeling Platform v.5.15: Results Using EPA's Base Case v.5.15, SSR file. August 3, 2015.

- **Energy security impacts:** The study estimated a reduction of 0.62 million barrels of oil through 2015, of which 0.23 million is from displaced imports. Through 2039, the study estimates a 3.46 million barrel reduction in petroleum, of which 0.70 million barrels are due to displaced imports, shown in Table 9-4.

### TABLE 9-4. ATTRIBUTED REDUCTIONS IN OIL IMPORTS ESTIMATED THROUGH 2039

| METRIC | UNIT OF MEASURE | RETROSPECTIVE ANALYSIS THROUGH 2015 | EXTENDED ANALYSIS THROUGH 2039 |
|---|---|---|---|
| Displaced petroleum consumption | Million barrels | 0.62 | 3.46 |
| Displaced imported petroleum consumption | Million barrels | 0.23 | 0.70 |

- **Economic performance metrics:** Table 9-5 shows undiscounted (constant 2015$) attributed energy savings for the BA program through 2039 for each of the four practices analyzed. These four practices produced $2.5 billion in energy savings benefits through 2015, and $16.7 billion in savings through 2039.

### TABLE 9-5. MONETIZED ATTRIBUTED ENERGY SAVINGS BY PRACTICE ESTIMATED THROUGH 2039

| YEAR | PRACTICE | | | | |
|---|---|---|---|---|---|
| | AIR TIGHTNESS | DUCT TIGHTNESS | INSULATION | THERMAL BRIDGING | TOTAL |
| **2006 - 2015** | **$1,796,929** | **$340,926** | **$319,324** | **$34,561** | **$2,491,740** |
| 2016 | $350,417 | $74,842 | $77,059 | $13,276 | $515,596 |
| 2017 | $364,216 | $76,980 | $79,743 | $13,840 | $534,779 |
| 2018 | $364,368 | $76,786 | $79,647 | $13,856 | $534,658 |
| 2019 | $369,822 | $77,894 | $80,803 | $14,065 | $542,584 |
| 2020 | $376,044 | $79,265 | $82,179 | $14,298 | $551,786 |
| 2021 | $379,718 | $80,021 | $82,970 | $14,438 | $557,147 |
| 2022 | $386,399 | $81,662 | $84,514 | $14,680 | $567,255 |
| 2023 | $390,868 | $82,677 | $85,515 | $14,846 | $573,906 |
| 2024 | $393,234 | $83,022 | $85,973 | $14,944 | $577,173 |
| 2025 | $398,706 | $84,158 | $87,159 | $15,152 | $585,176 |
| 2026 | $403,501 | $85,141 | $88,194 | $15,336 | $592,172 |
| 2027 | $411,614 | $86,462 | $89,835 | $15,666 | $603,576 |
| 2028 | $414,337 | $86,922 | $90,393 | $15,776 | $607,428 |
| 2029 | $417,205 | $87,417 | $90,979 | $15,891 | $611,491 |
| 2030 | $419,115 | $87,737 | $91,358 | $15,967 | $614,177 |
| 2031 | $420,981 | $87,998 | $91,711 | $16,045 | $616,734 |
| 2032 | $421,884 | $88,087 | $91,861 | $16,084 | $617,916 |

| YEAR | PRACTICE | | | | |
|---|---|---|---|---|---|
| | AIR TIGHTNESS | DUCT TIGHTNESS | INSULATION | THERMAL BRIDGING | TOTAL |
| 2033 | $421,571 | $87,982 | $91,780 | $16,075 | $617,408 |
| 2034 | $423,153 | $88,193 | $92,077 | $16,141 | $619,564 |
| 2035 | $427,043 | $88,863 | $92,874 | $16,297 | $625,076 |
| 2036 | $429,161 | $89,187 | $93,283 | $16,384 | $628,014 |
| 2037 | $430,923 | $89,462 | $93,634 | $16,456 | $630,475 |
| 2038 | $432,167 | $89,669 | $93,884 | $16,506 | $632,226 |
| 2039 | $433,874 | $89,934 | $94,216 | $16,576 | $634,601 |
| **2006 - 2039** | **$11,477,250** | **$2,371,286** | **$2,430,965** | **$403,157** | **$16,682,657** |

Table 9-6 shows the monetized attributed benefits for the BA program through 2039, including both energy savings and health benefits. Through 2015, total attributed benefits totaled $3.2 billion in constant (undiscounted) 2015 dollars, or $874.6 million at a 7% discount rate. Extending the analysis through 2039 increases this figure to over $2.5 billion (using the 7% discount rate).

TABLE 9-6. MONETIZED ATTRIBUTED ECONOMIC AND ENVIRONMENTAL HEALTH BENEFITS OF THE FOUR SELECTED PRACTICES THROUGH 2039

| YEAR | ENERGY SAVINGS BENEFITS | | | HEALTH BENEFITS | | | TOTAL BENEFITS | | |
|---|---|---|---|---|---|---|---|---|---|
| | CONSTANT 2015$, UNDISCOUNTED (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS) | CONSTANT 2015$, UNDISCOUNTED (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS) | CONSTANT 2015$, UNDISCOUNTED (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS) |
| **2006 - 2015** | **$2,491,740** | **$689,484** | **$1,416,155** | **$688,168** | **$185,090** | **$415,854** | **$3,179,908** | **$874,574** | **$1,832,009** |
| 2016 | $515,596 | $108,783 | $261,269 | $68,364 | $13,648 | $36,506 | $583,960 | $122,431 | $297,775 |
| 2017 | $534,779 | $105,449 | $263,097 | $69,500 | $12,982 | $35,993 | $604,279 | $118,432 | $299,090 |
| 2018 | $534,658 | $98,528 | $255,376 | $70,362 | $12,252 | $35,461 | $605,020 | $110,780 | $290,837 |
| 2019 | $542,584 | $93,448 | $251,614 | $72,591 | $11,822 | $35,494 | $615,175 | $105,270 | $287,108 |
| 2020 | $551,786 | $88,816 | $248,428 | $73,936 | $11,260 | $35,079 | $625,722 | $100,076 | $283,508 |
| 2021 | $557,147 | $83,812 | $243,536 | $74,335 | $10,550 | $34,329 | $631,481 | $94,362 | $277,865 |
| 2022 | $567,255 | $79,750 | $240,732 | $74,693 | $9,949 | $33,364 | $641,948 | $89,699 | $274,096 |
| 2023 | $573,906 | $75,406 | $236,461 | $75,920 | $9,433 | $32,981 | $649,826 | $84,839 | $269,442 |
| 2024 | $577,173 | $70,874 | $230,881 | $76,230 | $8,888 | $32,035 | $653,403 | $79,762 | $262,915 |
| 2025 | $585,176 | $67,156 | $227,264 | $76,537 | $8,316 | $31,306 | $661,713 | $75,473 | $258,570 |
| 2026 | $592,172 | $63,513 | $223,283 | $77,593 | $7,913 | $30,696 | $669,765 | $71,426 | $253,979 |
| 2027 | $603,576 | $60,501 | $220,954 | $78,462 | $7,438 | $30,283 | $682,038 | $67,939 | $251,237 |
| 2028 | $607,428 | $56,904 | $215,887 | $80,354 | $7,152 | $29,983 | $687,782 | $64,056 | $245,870 |
| 2029 | $611,491 | $53,537 | $211,001 | $81,223 | $6,721 | $29,563 | $692,714 | $60,259 | $240,564 |
| 2030 | $614,177 | $50,254 | $205,755 | $82,282 | $6,389 | $28,972 | $696,459 | $56,643 | $234,727 |
| 2031 | $616,734 | $47,162 | $200,594 | $74,851 | $5,432 | $25,588 | $691,585 | $52,594 | $226,182 |

| YEAR | ENERGY SAVINGS BENEFITS | | | HEALTH BENEFITS | | | TOTAL BENEFITS | | |
|---|---|---|---|---|---|---|---|---|---|
| | CONSTANT 2015$, UNDISCOUNTED (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS) | CONSTANT 2015$, UNDISCOUNTED (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS) | CONSTANT 2015$, UNDISCOUNTED (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS) |
| 2032 | $617,916 | $44,161 | $195,125 | $69,124 | $4,688 | $22,942 | $687,040 | $48,849 | $218,067 |
| 2033 | $617,408 | $41,238 | $189,286 | $64,148 | $4,066 | $20,670 | $681,556 | $45,304 | $209,956 |
| 2034 | $619,564 | $38,675 | $184,414 | $58,284 | $3,453 | $18,234 | $677,848 | $42,128 | $202,648 |
| 2035 | $625,076 | $36,467 | $180,636 | $52,157 | $2,888 | $15,842 | $677,234 | $39,354 | $196,478 |
| 2036 | $628,014 | $34,241 | $176,199 | $46,364 | $2,399 | $13,672 | $674,378 | $36,640 | $189,871 |
| 2037 | $630,475 | $32,126 | $171,738 | $35,578 | $1,720 | $10,185 | $666,053 | $33,847 | $181,923 |
| 2038 | $632,226 | $30,108 | $167,199 | $23,537 | $1,064 | $6,542 | $655,763 | $31,172 | $173,741 |
| 2039 | $634,601 | $28,244 | $162,938 | $11,514 | $486 | $3,107 | $646,115 | $28,730 | $166,046 |
| **2006 - 2039** | **$16,682,657** | **$2,178,640** | **$6,579,822** | **$2,256,109** | **$356,000** | **$1,044,681** | **$18,938,766** | **$2,534,640** | **$7,624,503** |

Notes: Projected energy prices for 2016 - 2039 are from https://www.eia.gov/outlooks/aeo/ and were reported by EIA in constant 2016 dollars. The IEc team converted these prices to 2015 dollars using the GDP implicit price deflators for 2015 (109.998) and 2016 (111.445). GDP implicit price deflators are from Bureau of Economic Analysis Table 1.1.9: Implicit Price Deflators for Gross Domestic Product, available at https://bea.gov/, accessed July 12, 2017.

Net economic benefits (benefits minus costs) through 2015 totaled over $2.8 billion ($2015, undiscounted). Extending the analysis through 2039 brings this number to over $18.5 billion, as shown in Table 9-7.

### TABLE 9-7. NET ECONOMIC BENEFITS ESTIMATED THROUGH 2039

| | NET BENEFITS | | |
|---|---|---|---|
| YEAR | CONSTANT 2015$, UNDISCOUNTED (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS) | CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS) |
| **Total: 2006 - 2015** | **$2,811,106** | **$712,526** | **$1,579,008** |
| 2016 | $583,960 | $122,431 | $297,775 |
| 2017 | $604,279 | $118,432 | $299,090 |
| 2018 | $605,020 | $110,780 | $290,837 |
| 2019 | $615,175 | $105,270 | $287,108 |
| 2020 | $625,722 | $100,076 | $283,508 |
| 2021 | $631,481 | $94,362 | $277,865 |
| 2022 | $641,948 | $89,699 | $274,096 |
| 2023 | $649,826 | $84,839 | $269,442 |
| 2024 | $653,403 | $79,762 | $262,915 |
| 2025 | $661,713 | $75,473 | $258,570 |
| 2026 | $669,765 | $71,426 | $253,979 |
| 2027 | $682,038 | $67,939 | $251,237 |
| 2028 | $687,782 | $64,056 | $245,870 |
| 2029 | $692,714 | $60,259 | $240,564 |
| 2030 | $696,459 | $56,643 | $234,727 |
| 2031 | $691,585 | $52,594 | $226,182 |
| 2032 | $687,040 | $48,849 | $218,067 |
| 2033 | $681,556 | $45,304 | $209,956 |
| 2034 | $677,848 | $42,128 | $202,648 |
| 2035 | $677,234 | $39,354 | $196,478 |
| 2036 | $674,378 | $36,640 | $189,871 |
| 2037 | $666,053 | $33,847 | $181,923 |
| 2038 | $655,763 | $31,172 | $173,741 |
| 2039 | $646,115 | $28,730 | $166,046 |
| **Total: 2006 - 2039** | **$18,569,964** | **$2,372,592** | **$7,371,502** |

Including remaining effective useful life benefits has the following impacts on the economic performance metrics, as shown in Table 9-8:

- **Social return on EERE investment:** increases from 30.2% to 32.4%.
- **Net present value at 7% real discount rate:** increases from $713 million to nearly $2.4 billion.
- **Net present value at 3% real discount rate:** increases from $1.6 billion to $7.4 billion.
- **Benefit-to-cost ratio at 7% real discount rate:** increases from 5.4 to 15.6.
- **Benefit-to-cost ratio at 3% real discount rate:** increases from 7.2 to 30.1.

TABLE 9-8. ECONOMIC PERFORMANCE MEASURES ESTIMATED THROUGH 2039

| | | RETROSPECTIVE ANALYSIS THROUGH 2015 | | |
|---|---|---|---|---|
| METRIC | UNIT OF MEASURE | ENERGY BENEFITS | COMBINED ENERGY & ENVIRONMENTAL HEALTH BENEFITS | EXTENDED ANALYSIS THROUGH 2039 |
| Portfolio investment cost - undiscounted | Million, 2015$ | $369 | $369 | $369 |
| Gross economic benefits - undiscounted | Million, 2015$ | $2,492 | $3,180 | $18,939 |
| Net economic benefits - undiscounted | Million, 2015$ | $2,123 | $2,811 | $18,570 |
| Net present value @ 7% real discount rate | Million, 2015$ | $527 | $713 | $2,373 |
| Net present value @ 3% real discount rate | Million, 2015$ | $1,163 | 1,579 | $7,372 |
| Benefit-to-cost ratio (BCR) @ 7% real discount rate | Ratio | 4.3 | 5.4 | 15.6 |
| Benefit-to-cost ratio (BCR) @ 3% real discount rate | Ratio | 5.6 | 7.2 | 30.1 |
| Internal rate of return | Percent | 27.0% | 30.2% | 32.4% |

# X. ANALYSIS OF BECP SUPPORT FOR MODEL BUILDING ENERGY CODE DEVELOPMENT

## OVERVIEW

While the previous chapters focused on the evaluation of the BA program, Chapter 10 presents a separate, targeted analysis for BECP.

BECP aims to increase building energy efficiency by supporting the development, adoption, and implementation of progressively more advanced building energy codes. BECP was established in response to the Energy Policy Act of 1992, which required DOE to participate in the model national codes development process and assist states in adopting and implementing more energy-efficient codes.

In this chapter, we analyze BECP's role and influence in the **development** of the **residential** chapter of the IECC 2009 and 2012. PNNL has conducted extensive analyses of energy impacts, emissions reductions, and economic benefits resulting from energy savings in the IECC.[88] PNNL finds a 14% improvement in residential energy efficiency from the 2006 to 2009 edition of the IECC, and a 24% improvement from 2009 to 2012.[89] The current evaluation does not duplicate PNNL's effort, but instead focuses on BECP's contribution to energy-saving proposals that were incorporated into the 2009 and 2012 IECC residential chapter. Our analysis does not cover BECP's contribution to the commercial chapter, or BECP's role in code adoption and enforcement; these topics are outside the scope of this evaluation.

In this chapter, we begin by providing an overview of the BECP, including a program logic model developed by DOE. Next, we provide an overview of the code development process as context for understanding BECP's involvement. We then describe IEc's methodology for assessing BECP's contribution to the development of a progressively more efficient code in 2009 and 2012. The remainder of the chapter presents the results of our analysis, and concludes with a discussion of the relationship between BA and BECP in advancing code changes.

## DESCRIPTION OF THE BECP

BECP supports building energy code development, adoption, and implementation processes "to achieve the maximum practicable, cost-effective improvements in energy efficiency while providing safe, healthy buildings for occupants."[90] Federal statute requires DOE to: participate in the model national codes

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[88] OV Livingston, PC Cole, DB Elliott, and R Bartlett. Pacific Northwest National Laboratory. *Building Energy Codes Program: National Benefits Assessment, 1992-2040.* March 2014; and V Mendon, R Lucas, and S Goel. Pacific Northwest National Laboratory. *Cost-Effectiveness Analysis of the 2009 and 2012 IECC Residential Provisions - Technical Support Document.* April 2013.

[89] *Building Energy Codes Program: National Benefits Assessment, 1992-2040*, op. cit., p. 4.5.

[90] U.S. Department of Energy. Building Energy Codes Program. "About Building Energy Codes." https://www.energycodes.gov/about. Accessed on March 23, 2017.

development process; issue determinations as to whether the latest version of the IECC (for low-rise residential buildings) and ASHRAE Standard 90.1 (for commercial and multi-family high-rise residential buildings) will improve energy efficiency compared to the previous edition; and provide technical assistance to states to implement and comply with the codes.[91]

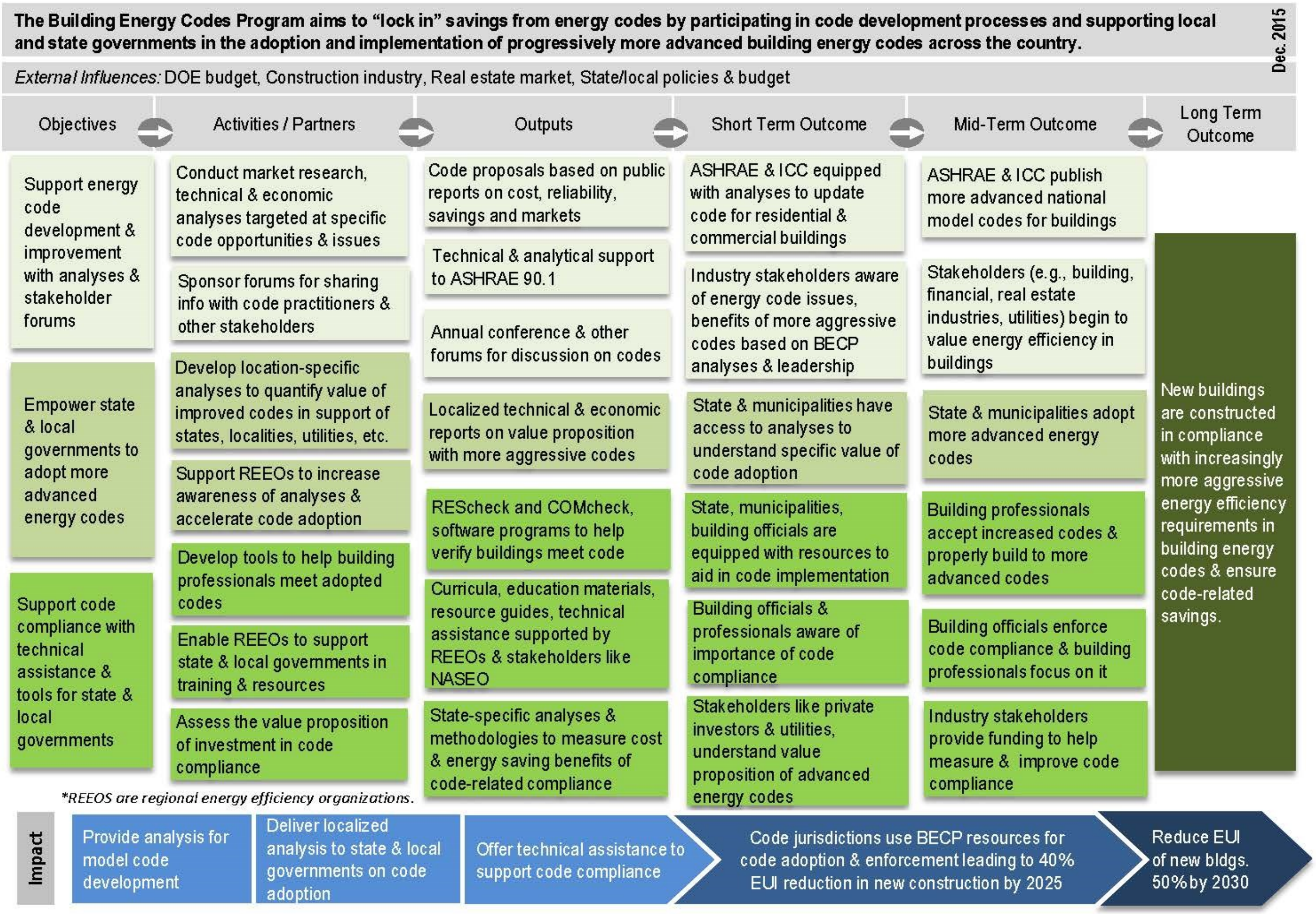
The logic model in Figure 10-1, developed by DOE, describes the major components of the BECP.[92] As shown in the logic model, the program has three main objectives. The current evaluation focuses on the first objective: support energy code development and improvement with analyses and stakeholder forums. In support of this objective, BECP conducts market research and analyses targeted at specific code opportunities and issues, and sponsors forums for sharing information with code practitioners and other stakeholders. These activities result in code proposals, technical and analytical support, and annual conferences and other forums for discussing codes.

Equipped with these analyses and knowledge, the International Code Council (ICC) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) update building energy codes, and industry stakeholders become aware of the benefits of advanced codes. This ultimately results in the publication of more advanced national model building codes and the construction of more energy-efficient buildings. As noted above, the current evaluation focuses on BECP's code development and analysis activities directed at supporting new residential efficiency.

[91] Energy Conservation and Production Act (ECPA) (Pub. L. No. 94-385), as amended by the Energy Policy Act of 1992 (EPACT 1992) (Pub. L. No. 102-486), the Energy Policy Act of 2005 (EPACT 2005) (Pub. L. No. 109-58) and the Energy Independence and Security Act of 2007 (EISA 2007) (Pub. L. No. 110-140). More information about statutory requirements that define DOE's role in building energy codes is available at: https://www.energycodes.gov/about/statutory-requirements.

[92] DOE/EERE, *Codes Logic Models*, Slide 1, February 8, 2016.

**FIGURE 10-1. BECP LOGIC MODEL**




Source: DOE/EERE, *Codes Logic Models*, Slide 1, February 8, 2016.

### CODE DEVELOPMENT PROCESS

This section describes the code development process as context for understanding BECP's role in the 2009 and 2012 IECC code cycles. The IECC is one of 15 "I-Codes" that get developed through the ICC's code development process. The I-Codes are coordinated and compatible with one another, and are developed following a multi-stakeholder process. The process is open to all parties; the final vote to approve a new version of the code rests with those who administer, formulate, or enforce regulations.[93]

Changes to the code in each cycle result from interactions and negotiations among many stakeholders, who range from energy efficiency advocates to industry associations. The codes development cycle includes the following main steps:[94]

- **Submission of code change proposals:** Anyone can submit a proposal. Code change proposals include proposed code language, a reason statement and supporting documentation, and expected impacts on the cost of construction (substantiated with a cost statement).[95] ICC staff review code change proposals for compliance with code development procedures (e.g., form and format) and follow up with proponents as needed to clarify submissions. At the end of this step, the ICC posts the code change agenda and the proposed changes on its website.
- **Committee Action Hearings (CAH):** The committee plays an important role in the codes development process. The ICC Board of Directors appoints committee members following an application and review process. ICC rules require that not less than one-third of committee members are regulators. On the residential committee, ICC has a Memorandum of Understanding with the National Association of Home Builders (NAHB) that guarantees them four seats. Other members on both committees are selected in a manner to ensure balanced stakeholder participation. The IECC residential committee includes regulators, code officials, government agencies, manufacturers, design professionals, homebuilders/contractors, and NAHB. Voting occurs in two steps: (1) committee vote and (2) assembly vote. In Step 1, the committee may: approve proposals as submitted, approve proposals with modifications, or disapprove proposals. Committee approval requires a simple majority. In Step 2, all members of the ICC can vote in response to committee action (assembly action).[96] Proposals that were approved by the committee require a simple majority to pass in the assembly; if a proposal was rejected by the committee, it can still pass in the assembly if it receives a two-thirds majority. Committee and assembly actions are noted in the public comment agenda.
- **Public comments on CAH results:** Anyone can submit a comment in response to the results of the CAH. Comments may express disagreement with a committee action or assembly action, or they may propose revisions to the code change, as long as proposed revisions are within the scope

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[93] International Code Council. *ICC Code Development Process*. Updated August 2011. Available at http://www.iccsafe.org/codes-tech-support/codes/code-development-process/code-development-2/.

[94] *ICC Code Development Process* (op. cit.) and interviews.

[95] Previously, proponents were required to indicate whether (and in what direction) the cost of construction would change, but were not required to substantiate the cost statement. No requirements were delineated for the cost statement and no analysis was required. Professional judgement was accepted by ICC as meeting the intent of the cost statement.

[96] Starting in 2014, the ICC introduced online assembly motion voting, which expanded the number of potential voters.

of the original proposal. ICC reviews public comments and contacts commenters as necessary to assist in processing the comment. At the end of this step, the ICC posts a public comment agenda.

- **Public Comment Hearings (PCH):** Anyone can attend and testify at the PCH (previously, the "Final Action Hearing"). After the PCH, ICC holds a block vote on all code changes that did not receive a public comment or successful assembly action (the "consent agenda"), and an individual vote on each code change that received a public comment or successful assembly action. The final vote on whether or not to change the code rests with the ICC Governmental Member Representatives – those who administer, formulate, or enforce regulations and are charged with the public's health, safety, and welfare.[97]

### EVALUATION METHOD

As discussed above, PNNL conducted an extensive National Benefits Assessment of BECP's support for codes.[98] The analysis assesses the influence of BECP's activities by estimating the historical (1992-2012) and projected (2013-2040) energy savings, consumer energy cost savings, and avoided emissions. As explained in PNNL's report, their study measures the impacts of BECP by comparing a "with BECP" scenario to the "without BECP" (counterfactual) scenario. The counterfactual scenario specifies that energy savings would still have occurred, but at a slower pace and with a lower compliance rate.

The National Benefits Assessment assessed attribution based on the professional judgment of program staff. As stated in the report: "For the 2006, 2009 and 2012 IECC, BECP is credited with 75%, 30%, and 30% of the code-to-code energy efficiency improvement, respectively. These internal estimates are based on the professional judgment of staff involved in code support."[99]

IEc's evaluation uses a different approach, with the goal of understanding BECP's contribution to the code changes that have resulted in significant energy savings. First, this evaluation aims to identify the code proposals that resulted in significant energy savings between the IECC 2006 and IECC 2012. Second, the evaluation uses interviews with experts to develop a qualitative understanding of BECP's role and contribution to these code changes.

IEc conducted the analysis in two steps:

1. Identified energy-reducing code changes to the IECC in the 2009 and 2012 code cycles, and categorized code change proponents, based on available documentation.
2. Conducted interviews with experts knowledgeable about the code development process to obtain qualitative insights about BECP's role and influence in the 2009 and 2012 IECC cycles.

BECP participates in the code development process for the IECC by proposing code changes and testifying at code development hearings. As the first step in assessing BECP's role and influence in the development of the 2009 and 2012 IECC, IEc downloaded documentation on proposals submitted during the 2009 and 2012 code cycles. The documents include all code change proposals for the residential

[97] Along with the online assembly motion vote, the ICC introduced an online government consensus vote.

[98] Livingston, OV, DB Elliott, PC Cole, and R Bartlett, *Building Energy Codes Program: National Benefits Assessment, 1992-2040*. Pacific Northwest National Laboratory. March 2014.

[99] National Benefits Assessment, page 4.5.

chapter of the IECC and the final decision for each proposal. Sixteen out of 131 proposals were approved in the 2006-07 cycle, and 33 out of 207 proposals were approved in the 2007-08 supplemental cycle, resulting in a total of 49 approved proposals that changed the residential chapter of the IECC between 2006 and 2009. In the 2009-10 cycle, 54 out of 166 proposals were approved, which resulted in changes to the residential chapter of the IECC between 2009 and 2012.

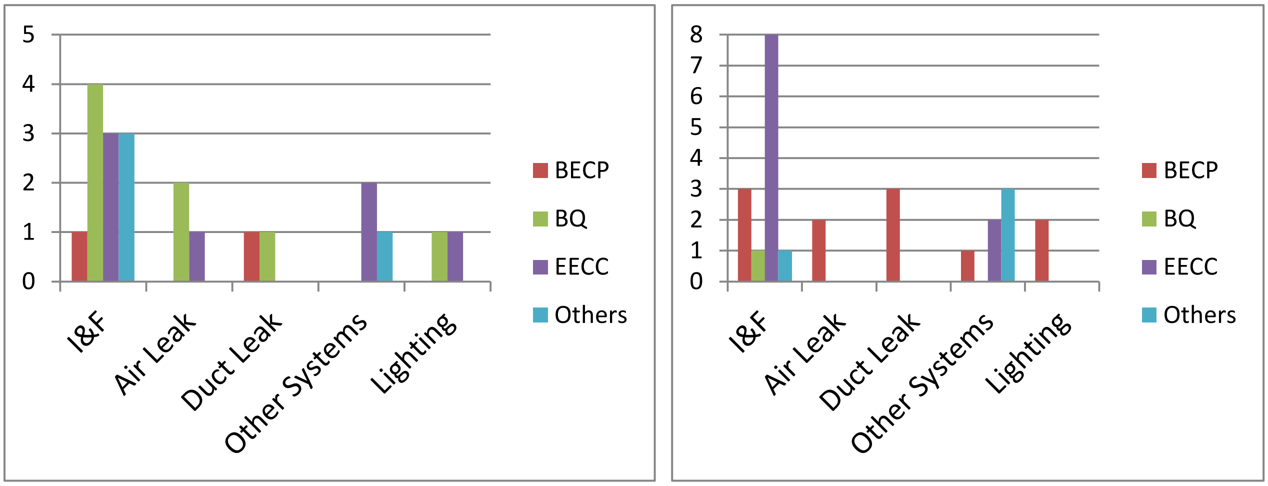
Using the proposal number from the list of approved proposals, IEc searched ICC's online documentation of proposal details from the relevant code cycles to determine which code changes could have a major impact on residential energy efficiency.[100] IEc made this determination based on (i) the presence of keywords related to energy efficiency in the reason statement (the descriptive statement required for each code change proposal), and (ii) IEc's general knowledge of major improvements in home energy efficiency. To ensure that the analysis captured all energy-saving code changes, IEc cross-referenced the results of this analysis with DOE's determinations on the 2009 and 2012 IECC, and confirmed the changes during interviews with DOE and PNNL.

Proposals that were modified based on committee review during the code development hearing or public comments required a deeper analysis, as the provisions ultimately incorporated into code could have differed from the original proposal. Therefore, IEc downloaded the 2006, 2009, and 2012 editions of the IECC, and verified the actual changes to the IECC based on each approved proposal. IEc also documented the proponent organization (the entity that submitted each proposal) for each energy efficiency code change. The reason statement occasionally listed the name of the organization or program that motivated the code change through a particular study or experiment. For example, proposal EC27-09/10 improved the thermal integrity of the building envelope by decreasing the allowed U-factors as demonstrated by ES Homes and BA. IEc documented the names of such programs or organizations whose work was cited as a motivating factor in an energy-saving proposal.

IEc organized the energy-reducing code changes for the 2009 and 2012 IECC in a summary spreadsheet, which we shared with experts at DOE and PNNL to verify that we captured all major energy-saving code changes. Based on feedback from DOE and PNNL, we classified the code changes into the five categories shown in Figure 10-2: (i) insulation & fenestration (I&F), (ii) air leakage, (iii) duct leakage, (iv) other systems (including HVAC systems and piping insulation), and (v) lighting. The first two categories are commonly referred to as the building envelope. According to energy code experts interviewed, these five categories combined account for the vast majority of energy-saving improvements in the 2009 and 2012 IECC. Figure 10-2 classifies the proponents of approved energy-saving proposals in each of the five categories. Proponents include BECP, the Energy Efficient Codes Coalition (EECC), Building Quality, and various other entities.

[100] As several interviewees commented, code changes only result in real-world energy savings when code is adopted and enforced. While this observation is noted, the scope of the current evaluation was limited to code development, not code adoption or enforcement.

**FIGURE 10-2. PROPONENT ORGANIZATIONS WITH APPROVED ENERGY-SAVING PROPOSALS, BY CATEGORY**




Approved IECC Code Change Proposals between 2006 and 2009 in Major Categories

Approved IECC Code Change Proposals between 2009 and 2012 in Major Categories

Note: Some proposals have multiple proponents; therefore the numbers shown in the figures are greater than the number of approved energy-saving proposals.

While the analysis of approved code change proposals captured key information from ICC's archives, the following considerations required interviews with code experts to supplement the document review:

- The code change proponent (entity that submitted the proposal) may not be the same entity that originated the idea for the proposal. Sometimes an organization withdraws a proposal midway through the process for political reasons, and/or decides that another organization is better-positioned to submit the proposal. Sometimes one organization submits a proposal, and another organization provides supporting testimony without submitting a separate proposal.
- The documentation does not provide details about BECP's role at the code change hearings, such as testifying on behalf of code change proposals.
- Other important aspects of BECP's role, such as conducting analyses of the potential impacts of proposed changes and hosting stakeholder forums to discuss code changes, are not captured in proposal documents.
- The ICC codes development process has evolved since the 2006-2012 time period. Interviews were necessary to better understand the nuances of the codes development process and BECP's role in it.

IEc developed an interview guide (Appendix E) in consultation with DOE, which included questions about BECP's role, the program's interaction with other stakeholders in the process, and perspectives on whether/how the 2009 and 2012 IECC residential chapter would be different if BECP had not been involved (i.e., the counterfactual). IEc selected the experts based on the following criteria:

1. Achieving balanced representation for a variety of sectors, including public, private, and advocacy/interest groups;

2. IECC committee members that participated in at least two of the three code cycles (including the 2007-08 supplemental cycle) between 2006 and 2012;
3. Representatives of proponent organizations that submitted more than one change to the IECC between 2006 and 2012; and
4. Other experts that were recommended by interviewees from either (1) or (2).

IEc conducted nine interviews with individuals from the following organizations: BECP, ICC, EECC, Northeast Energy Efficiency Partnerships, NAHB, Cadmus, Building Quality, City of Aspen, and New Jersey Department of Consumer Affairs.[101] To encourage candor during the interviews, we promised not to attribute comments to individuals or to their organization. Prior to conducting each interview, IEc shared the interview guide including the figures in Figure 10-2. During interviews, the experts were asked to comment on the figures and on BECP's role and influence.

## RESULTS

All of the energy code experts interviewed stated that the 2009 and 2012 IECC would have been weaker (less energy efficient) – and the improvements would have happened later – without BECP. This section presents the study's findings on major energy-saving code changes in the 2009 and 2012 IECC residential chapter and BECP's contribution. The section begins by laying the foundation for these code changes.

### Laying the Foundation: 2006 IECC

While this analysis focuses on code changes between 2006 and 2012 (i.e., IECC 2009 and IECC 2012), some interviewees emphasized BECP's role in laying the foundation for these changes prior to this timeframe. Specifically, BECP supported a major restructuring and simplification of the IECC between 2003 and 2006. These revisions clarified code language and reduced the length of the residential chapter from 38 pages (2003) to nine pages (2006). The reformatting of the code made it significantly easier to follow and more useable. The 2006 IECC also included a "completely rewritten," whole-building Simulated Performance Alternative compliance path.[102]

### 2009 IECC

Between the 1985 Model Energy Code (the predecessor to the IECC) and 2006 IECC, opponents of more stringent code requirements blocked significant energy-saving measures. The industry developed many advanced building technologies during this time period, but these were not added to code. As a result, heading into the 2009 cycle, there was a backlog of energy-saving proposals that efficiency proponents had tried (unsuccessfully) to get into previous versions of the code.

The 2009 IECC provided the first major energy code improvement in 20 years. Beginning in the 2009 code cycle, a shift occurred in which energy efficiency began to gain more traction among committee members. The 2009 IECC included significant energy efficiency improvements in all five major categories identified above: (i) insulation & fenestration, (ii) air leakage, (iii) duct leakage, (iv) other systems, and (v) lighting. It also included the elimination of equipment trade-offs in the simulation

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[101] The individual from the New Jersey Department of Consumer Affairs responded to the interview questions via email.

[102] RG Lucas. Pacific Northwest National Laboratory. *Determination for the 2006 International Energy Conservation Code, Residential Buildings - Technical Support Document*. September 2009.

performance alternative path. According to one interviewee, "One reason we got such a gigantic boost in efficiency between 2006 and 2012 is because there were so many latent technologies out there that had not been able to get into the [previous versions of] code because of the muscle of efficiency opponents."

An important driver of the energy efficiency improvements was the adoption of the integrated "whole-house" approach, which recognized the integration of energy efficiency technologies in different parts of the home. In previous code cycles, each proposed code change was considered separately; however, starting in 2009, more holistic consideration of the entire building structure and the integration of energy efficiency improvements made it possible to "package" complementary technologies that were previously considered as separate proposals.

Two energy efficiency improving proposals that BECP submitted for the residential chapter were approved in the 2009 IECC. BECP's proposal to decrease the maximum U-factor requirement for basement walls in climate zone 3 contributed to improving the building envelope. BECP's proposal to verify duct sealing through testing increased energy efficiency by requiring verifiable energy savings. Additionally, the requirement that 50% of lamps be high-efficacy lamps was initiated by BECP-funded PNNL in the 2006-07 codes cycle.

Other key proponents of energy-reducing code proposals in this time period were EECC and Building Quality. Building Quality was the proponent for eight proposals approved in the 2009 IECC. Interviewees reported that Building Quality submitted proposals that were similar to those drafted (but not ultimately submitted) by BECP. An interviewee explained that in some circumstances, external actors submit proposals that closely mirror those drafted by BECP. Another interviewee stated that DOE deserves some credit for laying the groundwork for code changes even if other entities submitted the final proposal.

As evident from the documentation of proposed code changes, the majority of energy-reducing proposals resulted in a higher initial cost of construction. As such, BECP faced significant resistance from the homebuilding industry during this period, but the program still made an important contribution to the 2009 IECC. As stated by one interviewee, "There was a lot of pushback by the homebuilders association (NAHB), and some of the DOE folks got constrained... but they still played a coordinating role." Despite being listed as the proponent on only two proposals, BECP supported complementary code change proposals submitted by other proponents, testified at code change hearings in favor of these proposals, and made other contributions to bring energy efficiency changes to the IECC between 2006 and 2009 (see the section below on BECP's Role and Influence beyond Code Change Proposals).

#### 2012 IECC

The 2012 IECC built on the 2009 whole-house approach and increased the stringency of the code requirements. One code change proposal in particular (EC-13) contained energy efficiency improvements for the building envelope, air leakage, hot water piping systems, and lighting. EC-13 mandated blower door testing and strengthened ACH requirements. By mandating blower door testing and duct blasters, the code required builders to clearly demonstrate, for the first time, that their homes were code-compliant. Several interviewees identified air leakage and blower door testing requirements as significant code improvements.

BECP played a major role in advancing the energy efficiency improvements in the IECC 2012 residential chapter. BECP's proposals resulted in 11 out of 23 energy-saving code changes in the 2012 IECC.[103] The reason statement of the most notable proposal, the above-described EC-13, reads: "The purpose of this proposal is to substantially improve the energy performance of residential buildings that comply with the IECC. This proposal is one part of an effort by DOE and other stakeholders to improve the energy efficiency of the IECC by 30% compared to the 2006 edition of the code." According to one interviewee, EC-13 would on its own have resulted in the 2012 IECC being 25% more efficient than the 2006 version (building on the gains in 2009). Other proposals that BECP supported increased the energy efficiency gains from 25% to 30%.

The 30% solution was initially put forward by EECC, and was backed by DOE. Interviewees stated that BECP played a major role in supporting the 30% solution and getting the provisions of EC-13 into code. Significantly, DOE declared its intent during the code hearings to increase the energy efficiency of the code by 30% compared to 2006. One interviewee stated that DOE's support made 30% the "benchmark" for what had to be accomplished in the 2012 IECC. According to this interviewee, "Had DOE not set the benchmark, there would have been no push to do it." Many of the experts interviewed for this study stated that DOE's public support for the 30% solution was key to its passage. As one interviewee stated, "DOE's EC-13 was the thing we [energy efficiency proponents] all rallied around… and that became the principal improvement in the 2012 residential code." Notably, EECC put forth a 30% proposal that was not approved, but DOE's EC-13 proposal was accepted.

#### BECP's Role and Influence Beyond Code Change Proposals

In addition to BECP's direct role in submitting code proposals and testifying at code hearings, the program conducts complementary activities that facilitate code development. Specifically, BECP's influence on the 2009 and 2012 IECC spans a spectrum of activities that include the following:

- BECP is perceived by many as an "honest broker" in the codes development process. As described below, BECP conducts objective analyses that other stakeholders perceive as credible sources of information about the potential energy and cost impacts of proposed code changes. Many interviewees commented that BECP's sole motive in submitting proposals is to improve the code; they contrasted BECP's role with other stakeholder groups who put forward proposals that suit their own business interests. This includes resistance by some homebuilders to code changes that could increase their costs, as well as manufacturers whose proposals favor their own technology. BECP's credibility was important to advancing the code changes in 2009 and 2012.
- BECP's technical analysis, tools, and models were helpful for advancing energy-reducing code changes. As one interviewee stated, "The information that DOE brings forward is unbiased and fact-based, which allows the process to move along." BECP sponsors analyses of the energy and cost impacts of code changes. An energy efficiency proponent recalled, "DOE had a tremendous impact on the improvements in 2009 and 2012, and a lot of that was giving us the analytics and support we needed to end this two-decade drought on improvement in the code." Other interviewees stated that BECP's analyses of the potential cost impacts of code changes helped accelerate their adoption in 2012 (even if not all stakeholders agreed with the conclusions about the cost impacts).

[103] According to IEc's analysis, three energy-saving code changes in the 2012 IECC have two proponents each.

- BECP facilitates stakeholder interactions around proposed code changes, which fosters understanding about proposed changes heading into the code cycle. Several interviewees mentioned BECP's stakeholder meetings as a useful platform to share knowledge and perspectives. The meetings also provide an opportunity for efficiency proponents and skeptics to debate proposed code changes before the official vote. An interviewee recalled, "The annual building code [meetings] were very helpful to get all players together… Even though we didn't agree on everything, DOE would bring us together in one room and get us into a dialogue." Prior to the 2012 IECC code hearings, BECP worked with advocacy groups and members of industry to bring along as many stakeholders as possible and coordinate efforts to achieve the "30% solution."[104]

Interviewees also identified two additional ways in which BECP influenced the code, although they are more related to code adoption/enforcement than to code development:

- BECP submits proposals that clarify prior code requirements. Such proposals do not directly impact energy consumption, but can increase energy savings through improved compliance by minimizing the possibility of multiple (erroneous) interpretations of the code.[105] Multiple BECP proposals accepted in the 2012 IECC clarified code provisions for building envelope requirements. These provisions were not the focus of our analysis because they did not directly result in new energy efficiency requirements.

- BECP develops tools and modeling software such as REScheck that helps designers and homebuilders determine whether the proposed design of new homes or alterations to existing homes meet the requirement of the IECC. Several interviewees noted the importance of these tools.

#### BUILDING AMERICA'S INFLUENCE ON CODE DEVELOPMENT

BTO, which houses the BA program and the BECP, develops, demonstrates, and supports the market adoption of energy efficiency practices through its R&D and market transformation activities. As the final step in the market transformation cycle, BECP aims to incorporate proven, cost-effective energy-saving practices into code. Of particular interest for the current evaluation, the BA program works with building scientists, homebuilders, and other stakeholders at an earlier stage in the market transformation process to test and demonstrate new residential construction technologies and practices in real-world settings. As discussed elsewhere in this report, significant work conducted by BA was incorporated into the ES Homes program – which in turn created a critical mass of leading builders applying practices, and proved the viability of the practices to the rest of the market. In other words, BA was influential in advancing home energy solutions in real-world settings to the point where they could be adopted into code. Overall, BA advanced the "whole-home" integrated building approach, which as discussed previously was an important enabler of the energy-saving code changes in the 2009 and 2012 IECC.

Earlier chapters of this report focused on four practices that the BA program helped advance in the market: air tightness, duct tightness, insulation, and thermal bridging solutions. BA teams demonstrated

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[104] In addition to the seminars, BECP lists the code changes that it intends to propose on its website, and receives and reviews comments on its proposals. This helps BECP understand the concerns of various stakeholders, and incorporate their suggestions if feasible.

[105] In addition, BECP provides trainings and webinars that help people understand and use the code.

the efficacy of building practices associated with each of these four areas prior to their inclusion in code. In many cases, practices were first established in the ES Homes program prior to being taken up in the IECC. For example, duct leakage testing requirements in the 2009 IECC were influenced by BA. Research conducted on duct testing was funded through BA's Industrialized Housing Partnership, which was incorporated in the code through a joint proposal by Building Quality and BECP.

Similarly, Building Quality's successful proposal to include more stringent thermal bypass requirements in the IECC was motivated directly by the Thermal Bypass Checklist in ES Homes, which was in turn heavily influenced by BA's work on thermal bypass issues. In addition, in the 2009/10 code cycle, BECP was a proponent in the proposal to lower the fenestration U-value and increase the wood frame R-value for multiple climate zones. The reason statement cited the demonstration of the viability of the proposed levels in ES Homes and BA. In the 2012 IECC, proposal EC13 increased requirements for air leakage testing and mandated continuous insulation for wood frame walls; both of these changes were motivated by BA.

The relationship between the market uptake of practices demonstrated by BA (e.g., in ES Homes) and code changes that BECP contributed to reflects BTO's integrated approach to market transformation. BA demonstrates practices and solutions in an applied "real-world" context; early adopters (leading builders) adopt practices advanced by BA; and, once these practices are proven viable and cost-effective at a sufficient scale, BECP helps get them into code, thereby "raising the bar" on efficiency requirements for the entire market. BA and BECP both played an important role at different stages of the market transformation cycle.

Earlier chapters of this report estimated the quantitative benefits of the four selected practices that were advanced by the BA program. We do not attempt to duplicate that analysis here, or to parse out "credit" between BA and BECP, or between BTO and rival external factors. Our finding is that BA played a key role in demonstrating and supporting the market's adoption of energy-saving practices, while BECP effectively built upon the efforts of BA and other programs to get energy-saving practices included in the IECC.

# XI. IMPLICATIONS FOR BTO STRATEGIES AND PROGRAMS

Based on the evaluation findings, IEc sees the following implications for future BTO strategies and programs.

- **The evaluation findings lend support for continuing BA's hands-on, team-based field demonstration project approach.** The combination of this evaluation's quantified energy reduction results, in conjunction with the qualitative feedback that we collected from building science experts, underscores that BA forms a key link in the market diffusion chain, as the program bridges applied R&D and market acceptance for building-level energy efficiency. The team model, which facilitates communication between the building science community and production builders, is critical for reaching this audience. Production builders confirmed during our interviews that many of them tend to get their information from their network, whether at conferences or directly from other builders. They also prefer more hands-on methods of learning new building and energy-saving techniques. The BA approach of making building scientists central to teams is an effective strategy of transferring energy efficiency knowledge, and testing and refining energy efficient construction practices until they are both effective and cost-effective.
- **The evaluation findings also provide support for complementary avenues of influence.** The builder interviews found that reaching trade allies who work directly with builders is also an effective strategy for reaching builders and influencing their preferred construction techniques. For example, many builders rely on their HVAC contractors and energy raters for information about new energy efficiency practices and how to comply with energy code.
- **Builders and building science experts provided support for BA's moisture management work; additional study of benefits is warranted.** Several experts interviewed for this evaluation indicated that the key and original impetus for production builders to work with BA was to learn how to cost-effectively address moisture management and mold problems. Similarly, three BA builders interviewed responded that a key benefit of participation in the program was to learn how to better manage moisture in homes, and that what they learned from BA projects led to improved comfort for homeowners. This provides support for ongoing BA work in this area, and additional study of the benefits of this work is warranted. As discussed previously in this report, the most definitive study design that links BA to reduced mold to better health is likely cost-prohibitive. However, DOE could explore the feasibility of a narrower study that 1) takes as a given that the practices promoted by BA reduce the likelihood of mold, which a diverse set of experts agree on, and 2) examines the benefits of residential mold prevention in sensitive populations such as adults or children with asthma and/or respiratory allergies, using change in sick days or school absences before and after mold abatement, or house move, as the key metric.
- **The BA strategy of moving energy efficiency practices through market adoption and into code is critical for realizing widespread energy savings.** One of the largest differences we

observed between BA and non-BA builders was in their stated willingness to implement these practices regardless of code requirements. Non-BA builders would be less likely to implement these practices if they were not required by code. Non-BA builders cited cost as a reason for not implementing these practices unless required by code.

  - This finding also suggests a need for additional outreach (and how-to guidance) around the cost issue to non-BA builders. Natural information spillover has not bridged the divide between BA builders and other builders on this issue. Given what we know about how builders prefer to receive information, outreach from other builders or trade allies may be more effective than outreach directly from BA.

- **Analysis of the BECP indicates that it has played a key role in strengthening model code.** All of the experts interviewed stated that the 2009 and 2012 IECC would have been weaker (less energy efficient) – and the improvements would have happened later – without BECP involvement. The 2009 IECC provided the first major energy code improvement in 20 years. BECP played a major role in advancing the energy efficiency improvements in the residential chapter of the 2012 IECC. BECP's proposals resulted in 11 out of 23 energy-reducing code changes in 2012.