IEc

Evaluation of Building America and Selected Building Energy Codes Program Activities

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February 21, 2018

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APPENDIX A. BUILDING AMERICA'S WORK ON MOISTURE MANAGEMENT AND VENTILATION PRACTICES

OVERVIEW

According to building science experts interviewed for this evaluation, 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.[1] 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.

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.[2] 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, which is explained in detail below.

In this section, we first discuss the moisture management practices demonstrated and diffused by BA, and the challenges inherent in quantifying IAQ benefits from these practices. Then, we discuss BA's work on

[1] 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.

[2] 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.

ventilation and homes and the challenges inherent in quantifying both economic and IAQ impacts from ventilation practices.

MOISTURE MANAGEMENT PRACTICES DEMONSTRATED AND DIFFUSED BY BA

According to all building science experts interviewed, BA building science contractors, and in particular Building Science Corporation (BSC), pioneered the demonstration of several related moisture management practices, and BA and BSC guides helped to diffuse these practices throughout the residential new construction industry:

- **Bulk water management:** BSC and BAIHP teams conducted research and demonstration work to diagnose and avoid problems with bulk water management/rain water control, especially when increasing wall insulation. Best practices developed include changing the materials used for vapor and moisture barriers, using rain screens, specifying a certain area of space between building materials to facilitate drying, using moisture managed foundations, and using higher-tech products such as self-drying high R-value insulation. According to most experts interviewed, these practices are now standard practice in new residential construction, and BA deserves clear credit for demonstrating their efficacy and diffusing them throughout the industry.
- **Vapor retarder classification system:** As discussed in the "enabling factors" section below, BSC developed a new vapor retarder classification system to clear up market confusion about appropriate vapor barriers. As a result, IECC codes were updated in 2006 to allow paint and other "class III" vapor retarders to be used in certain climate zones and for certain uses, which also improved moisture management. According to experts, BA was in a unique position to advance this new classification system as DOE and BA are viewed by the industry as honest brokers. Various manufacturers of barriers materials tried to set up hurdles for competing materials to be accepted into code when the concept of a new vapor retarder classification system gained momentum, but BA's impartiality and demonstration of what worked succeeded in advancing a new, workable classification system.

MOISTURE, MOLD, AND INDOOR AIR QUALITY

Improper moisture control in buildings is a prerequisite for mold formation that occurs outside of one-time water damage events in the home (e.g., a bathtub overflow, a washing machine malfunctioning and leaking). The presence of mold in homes can lead to poor IAQ and resident health problems, depending on the type and severity of mold, and the pre-existing health of the individuals living in a home.

Unfortunately, according to experts interviewed, there is no dose-response relationship to mold. In other words, different people respond to the presence of mold in different ways; while some people suffer an allergic or asthmatic effect to a particular type of mold at a particular concentration, others do not. In addition, according to experts interviewed, one cannot predict whether and when a house with improper moisture control will lead to the development of particularly problematic strains and concentrations of mold. Given this, it is not possible to estimate health benefits that derive from BA's moisture management practices as part of this evaluation.

The most definitive study of the IAQ benefits of avoiding mold would require a rigorous experiment of mold growth patterns in a statistically-based national sample of homes with different building practices (some homes would have BA-diffused practices and some homes would have conventional practices). The study would need to include in-home environmental testing for mold, as well as occupant health questionnaires and potentially the provision of health record data from occupants. This study would need to have a control group of homes, and occupants living in homes, without mold-retarding practices, which poses ethical concerns. Due to the involvement of human subjects, this study would require federal Institutional Review Board (IRB) approval for experiments with human participants, as well as Information Collection Request (ICR) approval. As such, this is a cost-prohibitive study for BA to fund on its own, and no such study has been conducted to-date by others.

VENTILATION PRACTICES DEMONSTRATED AND DIFFUSED BY BA

BA funded research and demonstration projects on low-cost ventilation in production housing and worked to influence the development and adoption of ventilation requirements in ES Homes V 3.0 and ASHRAE 62.2. For example, according to two experts interviewed, BA research on central fan-integrated supply (CFIS) ventilation was important for gaining acceptance for this approach, and getting recognized as compliant with ASHRAE Standard 62.2. ASHRAE Standard 62.2 for residential buildings is generally referred to as the consensus standard of practice for the building industry with respect to ventilation and indoor air quality. While IECC does not specifically mention ASHRAE 62.2 by name, the ventilation requirements in the 2012 IECC are the same as those in 62.2, and moreover, in their adoption of IECC, states often cite 62.2 directly.[3]

While program staff and most of the experts interviewed for this study credit BA with advocating for the current ventilation requirements in ASHRAE 62.2, notably, a minority of experts indicated that DOE's role was more complicated than straight advocacy. First, three experts noted that there is major disagreement within the BA building science experts and teams about the appropriateness of the current ventilation requirements in 62.2, and specifically on the method for calculating a ventilation rate. Secondly, two experts indicated that BA would need to share credit with LBNL and other, third-party stakeholders for its passage. Thus, unlike the other advances discussed in this section, we cannot establish clear attribution for the ventilation requirements in the current version of ASHRAE 62.2 to BA.

VENTILATION AND INDOOR AIR QUALITY

Putting aside attribution issues discussed above, the IEc team also explored if we can quantitatively estimate the IAQ health benefits of increasing ventilation rates in new homes. Unfortunately, we cannot. There is limited literature on the health effects of ventilation in homes; there are too few studies to use a benefit transfer approach to this issue. The studies that are available have small sample sizes and most were not conducted in the U.S.[4] As confirmed by an LBNL IAQ expert, there are no widespread epidemiological studies on IAQ and ventilation rates in homes. In contrast, significant literature exists on ventilation rates in schools and work places,[5] but that literature is not transferrable to homes. Moreover, according to several experts interviewed, increasing ventilation rates does not have a standard relationship

[3] Interview with LNBL IAQ expert, January 2016.

[4] LBNL's summary of literature on ventilation rates in homes is available at: https://iaqscience.lbl.gov/vent-home. An additional study not included on this website is: Aubin et al., National Research Council Canada, "Effectiveness of Ventilation Interventions at Improving IAQ and Ventilation Rates in Canadian Homes with Asthmatic Children," presented at ISES Annual Meeting 2012.

[5] LBNL's summary of literature on ventilation in schools and work places is available at: https://iaqscience.lbl.gov/vent-summary.

to decreasing moisture or mold problems; for example, increasing a ventilation rate in a humid climate without de-humidifying the air does not help with moisture management.

Furthermore, a tradeoff exists between mechanical ventilation required by ASHRAE 62.2 and energy efficiency goals. Experts interviewed estimated that the ventilation requirements in the current ASHRAE 62.2 come at a cost of four Home Energy Rating System (HERS) Index points. Thus, any health benefit that the IEc team would be able to estimate would need to be offset with the cost of higher energy use.

Finally, it should be noted that only 21 states have adopted IECC 2012 or IECC 2015; previous versions of IECC do not reference ASHRAE 62.2 or require mechanical ventilation. Thus, in counting BA benefits, if we included ventilation, we would only be able to capture benefit data from these 21 states plus California, and for a maximum of three years (and fewer than three years for the majority of these 21 states that adopted IECC 2012 in 2014 or 2015).

APPENDIX B. SCOPING INTERVIEW GUIDES

INTERVIEW GUIDE FOR BUILDING EXPERTS PARTICIPATING IN BA

The U.S. Department of Energy contracted with Industrial Economics, Incorporated (IEc) to conduct an evaluation of the Building Technologies Office (BTO)'s investments in new residential efficiency program activities. A key focus is assessing the Building America program's influence on the market for new residential construction. Thank you for taking the time to answer the following questions, which will provide important insights for our evaluation.

Your responses will be kept confidential. IEc will report interview findings in aggregate; your comments will not be attributed to you as an individual or to your organization in IEc's discussions with DOE or in the evaluation report.

QUESTIONS ABOUT THE BUILDING AMERICA PROGRAM

1. What is your or your firm's relationship with Building America? If you were on a Building America team, which team(s) and during which years?
2. Please provide a brief description of your building science research, including how (if at all) this research has been affected (directly or indirectly) by the Building America program.
3. Please refer to the Building America Logic Model (Attachment A). IEc will walk through the diagram over the phone and requests feedback on the following questions based on your knowledge of the Building America program and the new residential construction market (answers can be provided after the interview if the interviewee would like more time to review the diagram):
    a. Do you think the boxes in the logic model accurately reflect the program's inputs, activities, outputs, and outcomes?
    b. Are the boxes shown in the right order?
    c. Are the connections between boxes shown correctly? Are there potentially other feedback loops?
    d. For which outputs and outcomes in the logic model do you think Building America has had the greatest influence?
    e. Are there areas shown in the logic model where Building America had less of an influence? If yes, please explain.

QUESTIONS ABOUT INDUSTRY-WIDE TRENDS IN RESIDENTIAL EFFICIENCY

4. With the exception of plug loads, energy use intensity (EUI) in new homes has been declining over the last 20 years. What factors are driving the decline in EUI in new homes?
    a. For each factor that you identified: To what extent, if any, did Building America influence it?

b. Other than Building America, what were the other influences on each factor that you identified?

c. For each factor that you identified:

i. Do you think this would have happened at all without Building America?

ii. If yes, do you think this would have happened *earlier, later,* or *at the same time* without Building America? For "earlier" or "later," can you estimate *how much* earlier or later?

5. Are you familiar with Building America's role in supporting the cost-effectiveness (or reducing the cost) of home energy efficiency measures? If yes:

a. Are you aware of work that Building America has conducted to reduce the cost of home energy efficiency measures? If yes, please describe.

b. Do you think trends in the cost of home energy efficiency measures over the last 20 years can be attributed to Building America? If yes, to what extent?

6. Are you familiar with Building American's role in supporting the development and adoption of the RESNET and the HERS rating system? If yes:

a. What do you understand that relationship to be?

b. Do you think the Home Energy Score data and trends can be attributed to Building America? If yes, to what extent?

QUESTIONS ABOUT BUILDING AMERICA'S ADVANCEMENT OF SPECIFIC TECHNOLOGIES AND PRACTICES

7. Please refer to the list of technologies and practices below. To the best of your knowledge, in which of these technologies/practices did Building America play a role in demonstrating and advancing in the marketplace? Which Building America team(s) worked on them and when?

a. Air leakage and infiltration levels

i. Thermal bypass air barriers/air sealing (Energy Star for Homes Thermal Bypass Checklist)

b. Duct leakage

i. Unvented, conditioned crawlspaces

ii. Unvented, conditioned attics

iii. Ducts in conditioned space

c. Enclosure requirements (insulation, fenestration U-factor and SHGC)

d. Removal of option to trade high-efficiency HVAC equipment for reductions in other requirements in the code

e. Efficient framing/advanced framing

i. Thermal bridging

f. Requirement that framing cavities may not be used as supply ducts or plenums

g. Moisture management

   i. Continuous insulation ratio

   ii. Ventilation

   iii. Vapor retarder classification system

h. Building science-based climate maps

i. Mechanical innovations:

   i. Hot water heating and distribution

   ii. Water heating/space heating combined systems

8. Are there other technologies/practices, not on this list that Building America helped to advance in the marketplace?

9. What other actors (outside of Building America) played a role in developing, demonstrating, and increasing the market adoption of these technologies/practices?

10. Which technologies/practices do you think Building America played the biggest role in mainstreaming into new residential construction?

11. Which technologies/practices do you think Building America played less of a role in mainstreaming into new residential construction?

12. Over the last 20 years, have you found in warmer climates that you can satisfy space heating with a water heater and eliminate a furnace?

    a. If yes, what (if any) was Building America's role?

13. To what extent have these technologies/practices influenced the housing retrofit market? Please explain.

14. Do you think that practices developed by Building America addressing moisture management led to decreases in mold problems in new homes over the last 20 years? Why or why not?

    If yes, please explain:

    a. Which practices?

    b. Which Building America team(s) worked on them and when?

    c. How often is a moisture problem bad enough to cause mold in new homes?

    d. Do you know of any way to estimate the percent of new homes where mold growth was avoided due to Building America?

15. Can you point us to any literature on cost reduction of callbacks from moisture management changes that Building America/BSC pioneered?

16. Can you point us to any literature on reduced litigation after moisture management changes?

17. Do you think that builder and homeowner insurance premiums were affected by the work that Building America did to manage moisture? If yes, please explain and point us to any relevant literature.

18. Are you familiar with Building America's role in supporting the development and adoption of the ASHRAE Standard 62.2: Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings? If yes:

    a. What do you understand that relationship to be?

    b. Do you think ASHRAE Standard 62.2 and improvements in home ventilation can be attributed to Building America? If yes, to what extent?

FINAL THOUGHTS

19. Who else should we be posing these questions to?

20. Are there any other thoughts or observations that you would like to share with us?

INTERVIEW GUIDE FOR BUILDING EXPERTS NOT PARTICIPATING IN BA

The U.S. Department of Energy contracted with Industrial Economics, Incorporated (IEc) to conduct an evaluation of the Building Technologies Office (BTO)'s investments in new residential efficiency program activities. A key focus is assessing the Building America program's influence on the market for new residential construction. Thank you for taking the time to answer the following questions, which will provide important insights for our evaluation.

Your responses will be kept confidential. IEc will report interview findings in aggregate; your comments will not be attributed to you as an individual or to your organization in IEc's discussions with DOE or in the evaluation report.

GENERAL QUESTIONS

1. Please provide a brief description of your building science research, in terms of the key topics or challenges you worked on.
    a. Has your work been affected (directly or indirectly) by the Building America program?
2. With the exception of plug loads, energy use intensity (EUI) in new homes has been declining over the last 20 years. What factors are driving the decline in EUI in new homes?
    a. For each factor that you identified: To what extent, if any, did Building America influence it?
    b. Other than Building America, what were the other influences on each factor that you identified?
    c. For each factor that you identified:
        i. Do you think this would have happened at all without Building America?
        ii. If yes, do you think this would have happened *earlier, later,* or *at the same time* without Building America? For "earlier" or "later," can you estimate *how much* earlier or later?
3. Are you familiar with Building America's role in supporting the cost-effectiveness (or reducing the cost) of home energy efficiency measures? If yes:
    a. Are you aware of work that Building America has conducted to reduce the cost of home energy efficiency measures? If yes, please describe.
    b. Do you think trends in the cost of home energy efficiency measures over the last 20 years can be attributed to Building America? If yes, to what extent?

QUESTIONS ABOUT BUILDING AMERICA'S ADVANCEMENT OF SPECIFIC TECHNOLOGIES AND PRACTICES

4. Please refer to the list of technologies and practices attached to this guide (Attachment B).

To the best of your knowledge, in which of these technologies/practices did Building America play a role in demonstrating and advancing in the marketplace? Which Building America team(s) worked on them and when?

a. Air leakage and infiltration levels

b. Thermal bypass air barriers/air sealing (Energy Star for Homes Thermal Bypass Checklist)
c. Duct leakage –
    i. Unvented, conditioned crawlspaces
    ii. Unvented, conditioned attic
    iii. Ducts in conditioned space
    iv. Requirement that framing cavities may not be used as supply ducts or plenums
d. Enclosure requirements (insulation, fenestration U-factor and SHGC)
e. Efficient framing/advanced framing
    i. Thermal bridging
f. Moisture management
    i. Continuous insulation ratio
    ii. Ventilation
    iii. Vapor retarder classification system
g. Building science-based climate maps
h. Mechanical innovations:
    i. Hot water heating and distribution
    ii. Water heating/space heating combined systems
i. Are there other technologies/practices, not on this list that Building America helped to advance in the marketplace?
j. What other actors (outside of Building America) played a role in developing, demonstrating, and increasing the market adoption of these technologies/practices?
k. To what extent have these technologies/practices influenced the housing retrofit market? Please explain.

5. Do you think that practices diffused by Building America reduced callbacks from moisture management problems in new construction?
    a. If yes, please explain.

FINAL THOUGHTS

6. Who else should we be posing these questions to?
7. Are there any other thoughts or observations that you would like to share with us?

APPENDIX C. DELPHI PANEL MATERIALS AND INTERVIEW GUIDE

INSTRUCTIONS:

This Delphi panel is being convened to elicit expert estimations of the portion of modeled residential energy savings that can be attributed to the U.S. Department of Energy's (DOE) Building America (BA) program. We are asking you to review the energy savings estimated by our modeling exercise, and to consider the role of the BA program versus rival factors in advancing market acceptance of selected energy technologies and practices. For this first phase of the process, please do the following:

1. Review the enclosed materials.
2. Compile any clarifying or technical questions you have about these materials by February 21st.
3. Send these questions to: nscherer@indecon.com

We will compile all clarifying and technical questions from the panel and share our responses with you before we conduct our first interview.

INTRODUCTION: PURPOSE OF EFFORT

Founded in 1994, DOE's BA program aims to help the U.S. building industry promote and construct homes that are better for business, homeowners, and the nation. 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, and bring innovations to market that improve residential building energy performance. After early years of working with custom home builders, BA focused intently on working with production builders, which dominate the new housing market, to take advantage of economies of scale and the opportunity to more readily and directly change standard industry practices.

In 2015, DOE's Building Technologies Office (BTO) initiated an evaluation to obtain a rigorous, methodologically sound, and defensible study of the impacts of selected BA activities designed to reduce energy consumption by improving the energy efficiency performance of **new** homes. The evaluation will assess the economic, energy, environmental, energy security, and knowledge impacts and overall cost-effectiveness of the selected activities. Quantifying the benefits and costs will enable DOE to improve program design and implementation and communicate program impact.

EVALUATION QUESTIONS AND ENERGY SAVINGS METHODOLOGY

This evaluation focuses primarily on the demonstration and market transformation activities conducted by the BA program. The evaluation will quantify the benefits and costs of DOE's support for selected new home construction technologies and practices demonstrated by the BA program, as well as assess spillover benefits from new homes to the housing retrofit market.

The evaluation is guided by four primary questions:

1. To what extent have selected BA activities produced energy savings by improving the energy efficiency of widely used model energy codes, above-code programs, and design and construction practices for new residential buildings?
2. What are the net benefits associated with the energy savings and other impacts of the selected BA activities?
3. Have BA activities directed at improving the efficiency of new residential buildings had spillover effects, such as improvements in the efficiency of existing homes?
4. What lessons learned can be applied to future programs with similar objectives?

The methodology uses a portfolio approach to analyze the benefits of the BA program. 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. From this portfolio, the IEc team selected four individual technologies/practices for detailed evaluation (the selection criteria and selection process are described below, in the section "Technologies and Practices Selected for Energy Savings Analysis – Identification of Key Practices"). The study will provide robust quantitative estimates of the benefits of the selected technologies and practices, and compare these benefits to the *total* DOE investment cost for the entire portfolio. 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 benefit.

The energy savings calculations for this evaluation focus on the selected technologies and practices and their adoption in the market. Per DOE guidance on implementing the portfolio approach, the IEc team chose a subset of technologies and practices that BA had worked toward diffusing throughout the market for new residential construction and that had, in fact, widely diffused. These technologies and practices were selected through discussions with program staff, review of program documents, and interviews with experts. Criteria for inclusion were that BA conducted work on the technology or practice; that there was uptake in the market (in Energy Star Homes and/or building codes); and that direct energy savings resulted. The IEc team conducted extensive energy modeling to estimate the energy impacts of these practices, as explained in Appendix A.

ATTRIBUTION APPROACH

An important aspect of the evaluation is to investigate what share of estimated benefits are fairly attributable to the BA program as opposed to alternative (or rival) causes. The evaluation uses a tiered approach to attribution:[6]

[6] Attribution is often called "additionality."

1. Original Technology Selection:

    a. Due Diligence File Review – The IEc team first looked for evidence that the specific energy-saving improvements selected for evaluation are integrated into energy codes and above-code programs and appear to be linked to BA program activities.

    b. Expert Interviews – We gave experts a long list of technologies and practices identified by BA staff as those that the program helped to advance. We asked experts to identify the practices which they agreed that BA helped to advance, as well as identify other factors that played a role in increasing the market adoption of the technologies and practices on the list. Experts noted the following rival factors:

        i. Utility energy efficiency incentive programs

        ii. Research carried out by national labs, and in particular Lawrence Berkeley National Laboratory (LBNL), but outside of the BA umbrella

        iii. Advocacy work of the Energy and Environmental Building Alliance

        iv. ASHRAE standards development (specific to ventilation practices)

        v. California regulation (specific to window requirements)

    We then asked experts to identify the practices which BA played the largest role in mainstreaming, compared to rival factors. Experts consistently identified insulation requirements, air tightness requirements, duct leakage requirements, and thermal bridging requirements as those where BA played the most substantial role.

    It is important to note that during these expert interviews, and in conjunction with a review of state regulation (CA Title 24), the IEc team probed the relationship between the BA program and the State of California, which had adopted stringent building energy codes earlier than the rest of the country. The IEc team's conclusion was that the role of BA in California is ambiguous and controversial given parallel state activities, and that the conservative approach is to assume that the BA program did not have enough verifiable impact on Title 24 and industry-wide impact on CA energy savings to include the state in the modeling and results. <u>As such, the State of California is excluded from the analysis of energy savings associated with BA.</u>

    c. Delphi Panel – The IEc team is using the Delphi panel of experts to review the energy modeling results for the four selected energy efficiency technologies/practices, consider other external factors that may have contributed to the results, and potentially downward adjust the results to reflect external factors.

2. Qualitative Methods

    a. Survey Responses – A survey is being conducted of 30 production builders that participated in the BA program, as well as a random sample of non-participating production builders. By comparing builders that did and did not participate in BA, we can examine to what extent BA directly influenced the adoption of technologies/practices by the two groups of builders.

b. Citation Analysis – The IEc team will use a citation analysis to further probe attribution. Because the BA program rarely generates patents or other intellectual property, the evaluation will employ a publication citation analysis to measure knowledge dissemination that can be traced back to BA publications and publications of BA teams.

Delphi Panel

The IEc team is convening a group of nine experts, which includes you, to review the 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 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. We will use the Delphi panel results to downward adjust, as applicable, total energy saving estimates to reflect the portion of energy savings that can be appropriately attributed to BA. Specifically, we plan to calculate the average practice-specific energy benefit apportionment across panelists, and downward adjust the benefit for each practice accordingly.

HISTORY AND DESCRIPTION OF THE BA PROGRAM

Founded in 1994, DOE's BA program aims to "help the U.S. building industry promote and construct homes that are better for business, homeowners, and the nation."[7] 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 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 assess all aspects of a project and make decisions quickly. Each team is led by a private-sector building science expert 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 facilitate market adoption by influencing 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 use and confirm the technical and economic feasibility of BA innovations, this results in greater market acceptance and deeper market penetration. Over time, the BA program aims for its innovations to become standard practice, and to be adopted into model building energy codes – e.g., the International Energy Conservation Code (IECC).

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

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

information and technical knowledge to promote and enable the industry's adoption of advanced building technologies and practices.

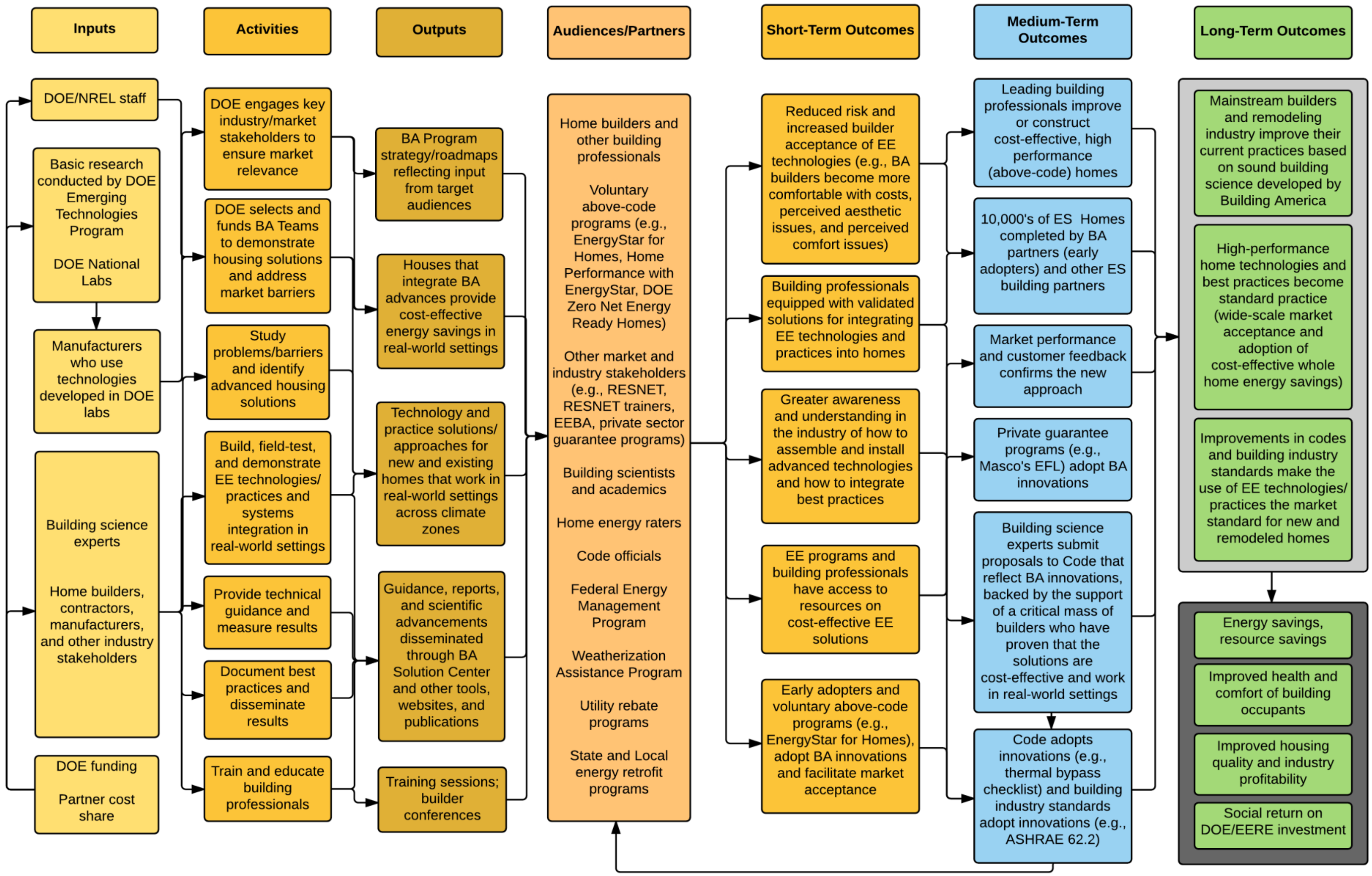
BA Program Logic Model

Figure 1 on the subsequent page presents a logic model for the BA program.[8] A logic model is a graphical representation of how a program works to achieve its goals. The logic model shows the key elements of the program and how these elements fit together. Components of the logic model include the following:

- **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 and manufacturers who use the research, building industry stakeholders (building science experts, contractors, etc.), and funding from DOE as well as partners' cost share.
- **Activities:** what the program does to achieve its goals. DOE engages key industry stakeholders and selects/funds cross-industry BA teams. The teams study problems/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/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/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/ 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 that are casually linked to the program, 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 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).

[8] 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.

FIGURE 1. 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.

- **Medium-term outcomes:** changes in market acceptance and behavior resulting from changes in knowledge and attitude. Medium-term outcomes include: construction or improvement of cost-effective, high-performance homes by leading building professionals; construction of Energy Star Homes by BA builders and other building partners; validation of new building approaches by market performance and customer feedback; and adoption of BA innovations in private guarantee programs (e.g., Masco's Environments for Living program). 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 remodeling industry improve their current practices based on sound building science developed/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/practices the market standard for new and remodeled homes. This in turn leads to: energy/resource savings, improved occupant health and comfort, improved housing quality and industry profitability, environmental effects, additions to the knowledge base, and social returns on DOE's investment.

The BA program operates within a broader technology and market context. Contextual factors include the following: 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.

The logic model also 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.

The logic model shows that 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 impacts in the short- or medium-term requires looking at interim metrics for R&D programs plus additional interim 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 that are the focus of this evaluation: consumption of energy and other resources, emission of air pollutants and greenhouse gases, and resulting return on investment and other long-term performance impact metrics.

TECHNOLOGIES AND PRACTICES SELECTED FOR ENERGY SAVINGS ANALYSIS

Identification of Key Practices

The energy savings calculations for this evaluation focus primarily on selected technologies and practices and their adoption in the market. These technologies and practices were selected through discussions with program staff, review of program documents, and interviews with experts. Criteria for inclusion were:

1. Clear relationship to activities conducted by BA;
2. Uptake in the market (in ES Homes or building codes); and
3. Direct energy savings.

Based on these three criteria, the IEc team selected the following four practices:

1. 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, the IECC required blower door testing to verify compliance with the air tightness requirements. ES began implementing the Thermal Bypass Checklist in 2006, mandating even tighter building envelopes.
2. Duct Leakage: IECC began mandating duct leakage testing for ducts outside conditioned space in 2009, and tightened the leakage requirement in 2012. ES has maintained strict duct leakage testing requirements since 2006.
3. 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, which does not have additional requirements for envelope insulation beyond existing code. Changes to window performance were not linked to BA in this study.
4. 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. ES has required advanced framing since 2012. The practice “Thermal Bridging” is relevant only in Climate Zones 4 – 8. This is because the basis for the continuous insulation ratio is to prevent wintertime interstitial condensation but also allow interstitial drying to the interior by employing a Class III interior vapor retarder.

The IEc team confirmed that BA worked on these technologies and practices before they were taken up by the market by reviewing historical program documents and collecting information from experts. Table 1 below shows the uptake of each of the chosen technologies and practices in ES Homes and building energy codes.

TABLE 1. TECHNOLOGY AND PRACTICE UPTAKE IN THE MARKET

TECHNOLOGY/PRACTICE	ES HOMES	IECC
Air leakage and infiltration requirements	2006 (v2) 2012 (v3)	2009 IECC 2012 IECC
Duct leakage requirements	2006 (v2) 2012 (v3)	2009 IECC 2012 IECC
Insulation requirements		2006 IECC 2009 IECC 2012 IECC
Thermal bridging requirements	2012 (v3)	2012 IECC (only certain climate zones)

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.[9] 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.[10] 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 reflected the input of the BA program and BA project experience, 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), 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. There are two main strategies to reduce

[9] 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

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

duct leakage: move ducts to a conditioned space or insulate the ducts. Moving ducts to a conditioned space can result in eight to 15 percent cost savings for air conditioning.[11] 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 meter 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.[12] 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 experts interviewed, BA worked on projects that demonstrated the feasibility of increased insulation requirements contained in the 2006, 2009 and 2012 IECC. Changes to insulation requirements in the 2006 IECC include:[13,14]

- 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,

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[11] 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

[12] http://energy.gov/energysaver/insulation

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

[14] 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.

- 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,
- 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:[15]

- 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:[16]

- 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.[17] 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,[18] which reduces the 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.[19] Continuous insulation has multiple benefits: reduced thermal bridging; better air tightness (if the rigid insulation used is taped or

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[15] 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

[16] Ibid.

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

[18] 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

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

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.[20] 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 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.

ENERGY MODELING

Approach

Our approach for estimating energy impacts of the BA program is to model the impacts of selected building technologies and practices. The impacts of those specific technologies and practices are 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.

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 technologies/practices: air leakage and infiltration requirements, duct leakage requirements, insulation requirements, and thermal bridging requirements. “Intervention” homes were modeled with those technologies/practices integrated, compared to “counterfactual” homes that would exist at that point in time without those technologies/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 technologies/practices that have been adopted.

To measure the incremental impact provided by the studied technologies/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.

[20] Ibid.

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 A.

- **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 2.

TABLE 2. DATE EACH PRACTICE BECAME MANDATORY IN CODES AND ENERGY STAR HOMES

STATE GROUPINGS	PRACTICE 1: TBC/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 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 terminology into modeling settings, mostly based on climate.
- **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 totals: per time period, per state, and nationwide.

Modeling Results

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 3. 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 3. TOTAL NATIONWIDE SITE ENERGY SAVINGS BASED ON MODELING STUDY (CUMULATIVE 2006-2015)

	TOTAL SAVINGS
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**

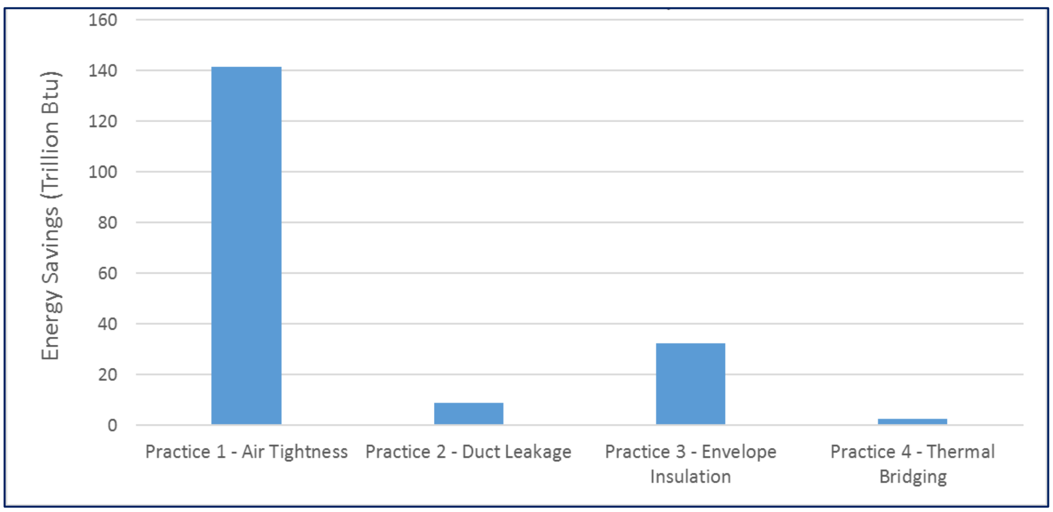
The energy savings from the four studied practices are summarized in Table 4 below.

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

TECHNOLOGY/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**

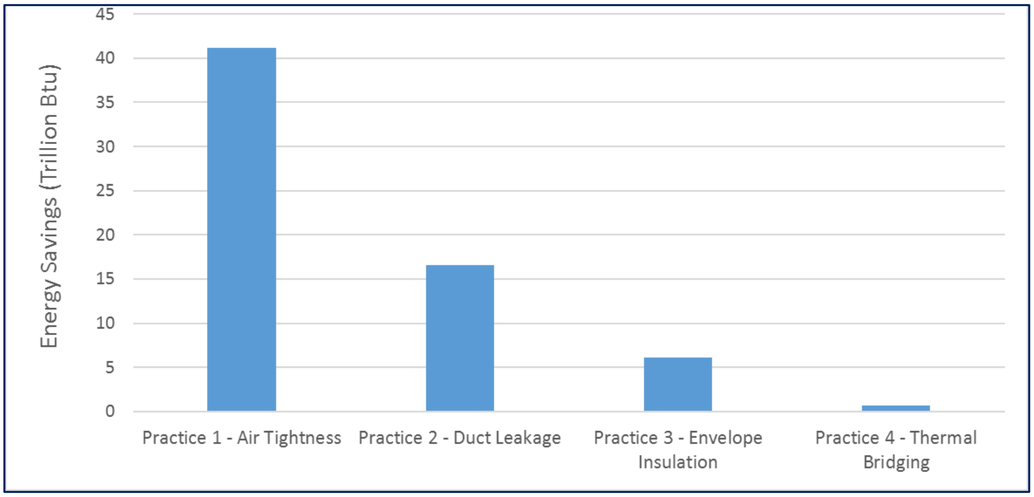
The breakdown of site energy savings for each of the four studied practices in code minimum homes is shown in Figure 2 below.

FIGURE 2. BREAKDOWN OF TOTAL NATIONWIDE SITE ENERGY SAVINGS BY INDIVIDUAL PRACTICE (CODE MINIMUM HOUSES)



As shown in Figure 3, 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.

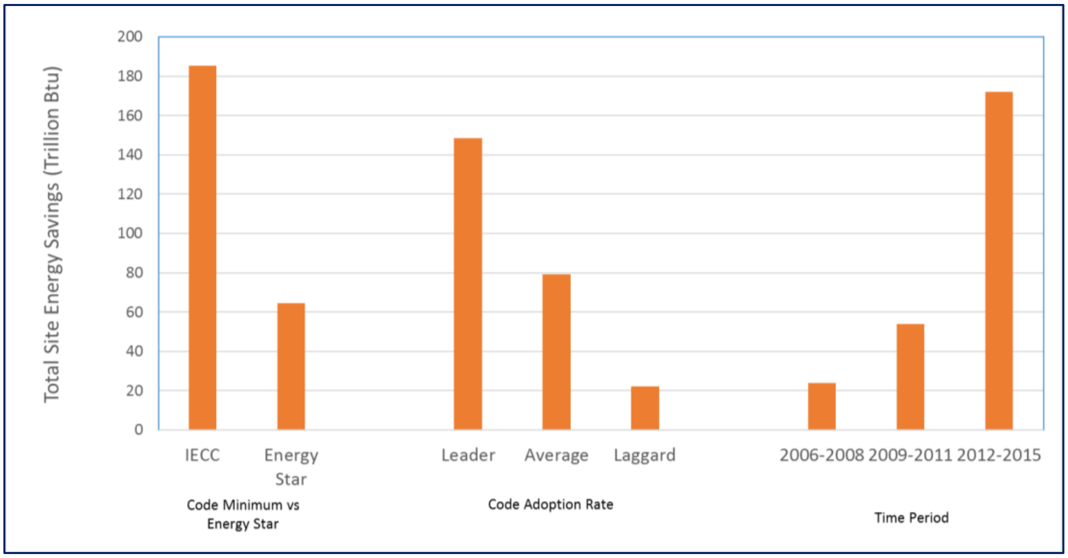
FIGURE 3. BREAKDOWN OF TOTAL NATIONWIDE SITE ENERGY SAVINGS BY INDIVIDUAL PRACTICE (ENERGY STAR HOUSES)



The IEc team disaggregated these interim results in several ways to provide insights into the largest contributors to energy savings. Figures 4-8 provide a variety of breakdowns of nationwide site energy savings, including by efficiency program (code vs. ES), code adoption rate, time period, state, and individual practice.

As shown in Figure 4, 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 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. BREAKDOWNS OF ESTIMATED INTERIM CUMULATIVE NATIONWIDE SITE ENERGY SAVINGS FOR THE FOUR PRACTICES BY PROGRAM, CODE ADOPTION RATE, AND TIME PERIOD



Figures 5 and 6 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 low construction rates and slower code adoption.

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

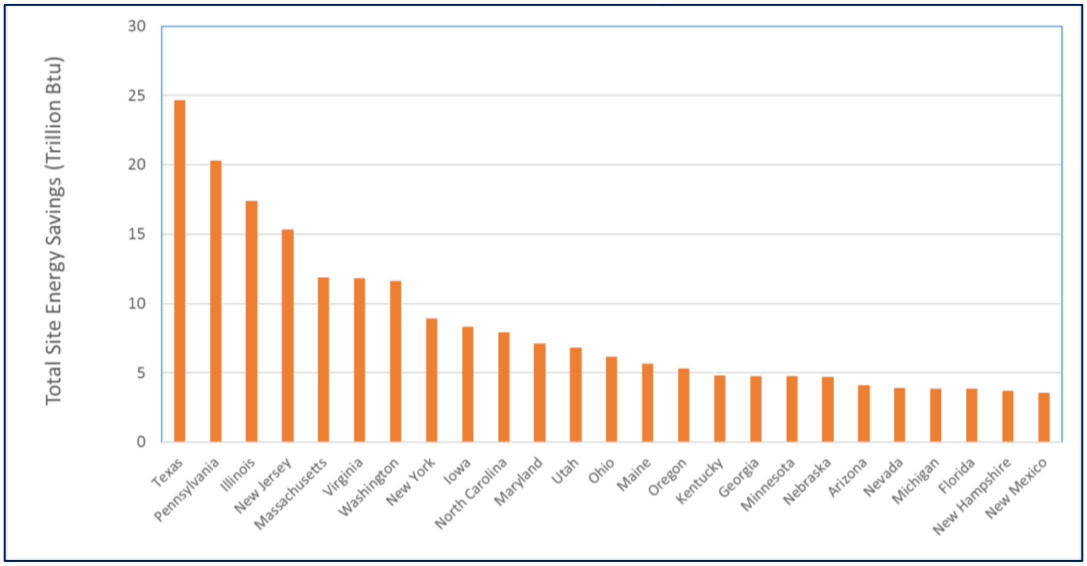
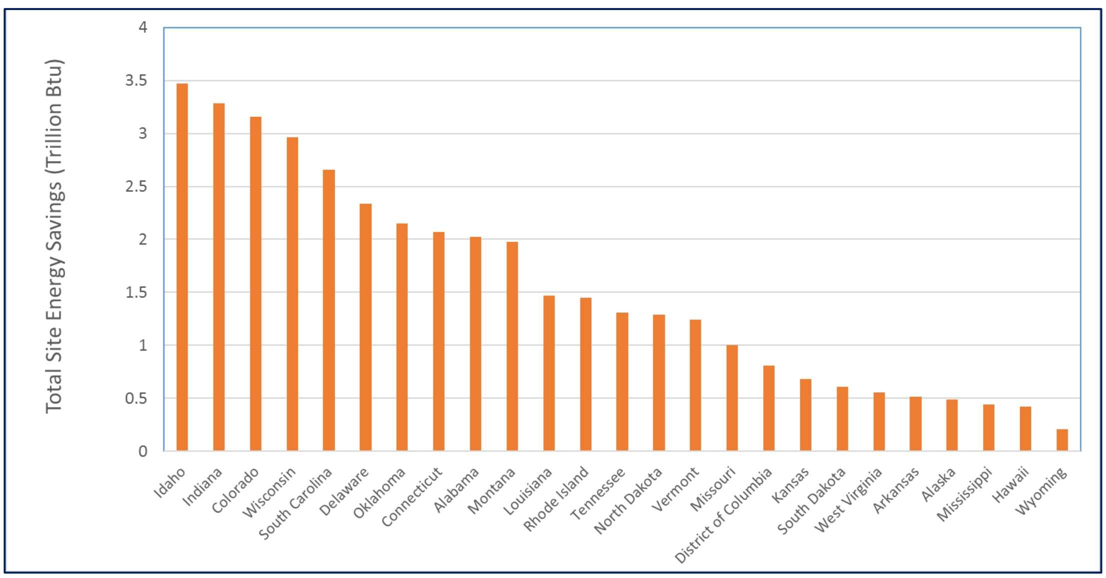


FIGURE 6.

EXCLUDING CALIFORNIA)



Figures 7 and 8 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 5-6 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 7. ESTIMATED INTERIM AVERAGE SITE ENERGY SAVINGS PER HOUSE FOR THE FOUR PRACTICES ORDERED BY STATE (25 MOST IMPACTED STATES, EXCLUDING CALIFORNIA)

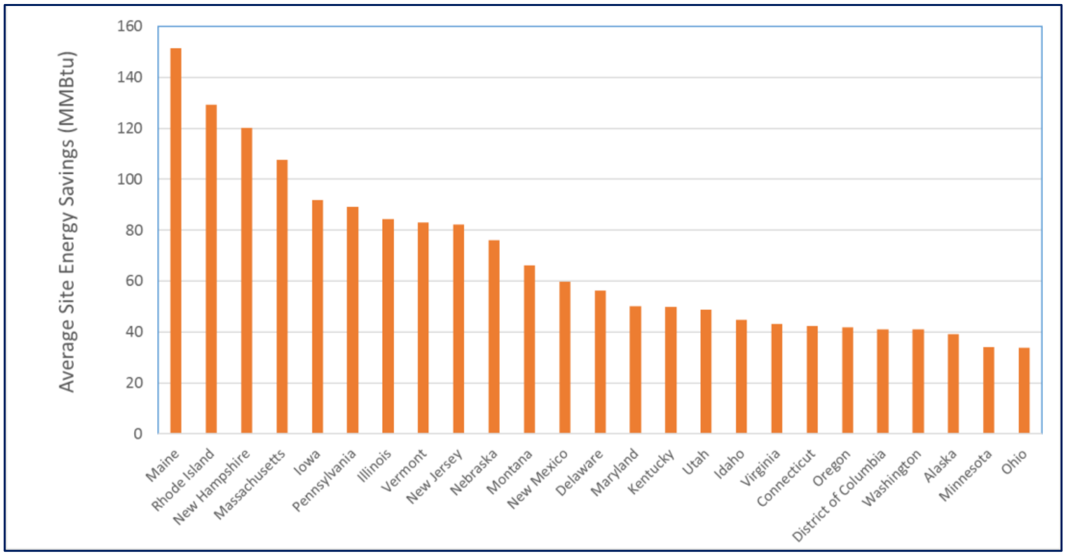
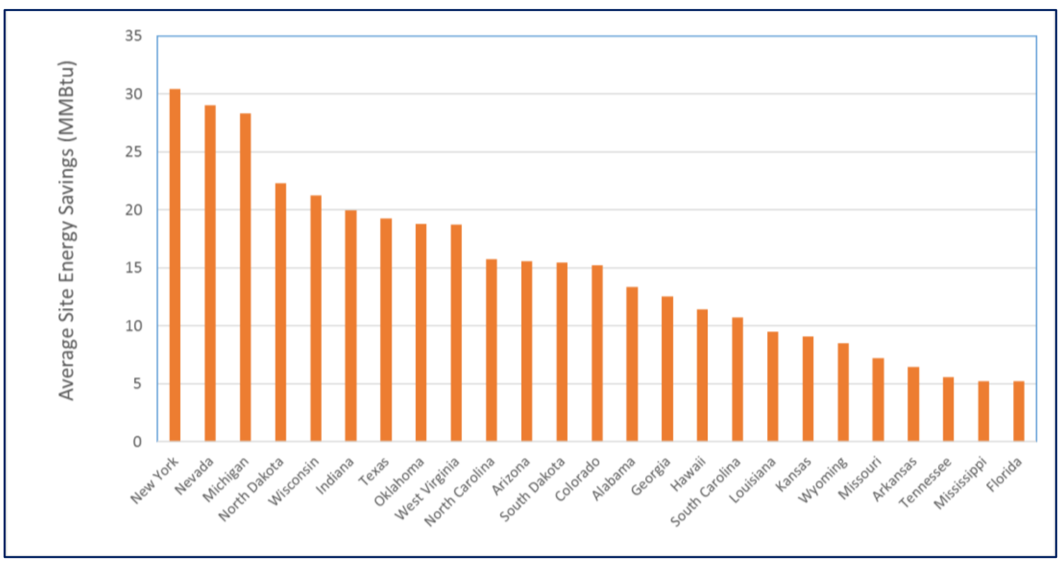


FIGURE 8. ESTIMATED INTERIM AVERAGE SITE ENERGY SAVINGS PER HOUSE FOR THE FOUR PRACTICES ORDERED BY STATE (25 LEAST IMPACTED STATES, EXCLUDING CALIFORNIA)



DELPHI PANEL INTERVIEW GUIDE[21]

INTRODUCTION

The materials provided discuss the activities of the Building America (BA) program in working to advance the following four selected practices in new production building construction in the U.S.:

1. *Air Tightness*: BA focused on increasing the stringency of air sealing and air barrier requirements, in particular to reduce thermal bypass issues.
2. *Duct Leakage:* 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.
3. *Envelope Insulation:* BA worked with builders to demonstrate the financial feasibility of increasing insulation required for the building envelope, including attics, walls, and foundations, chiefly by reducing the sizing of HVAC systems.
4. *Thermal Bridging:* There are multiple solutions to reduce thermal bridging, and the ones that BA worked on include advanced framing and using continuous insulation.

These four practices were selected for energy modeling as a subset of BA's practices because our preliminary research indicated that BA research, demonstration projects, and publications (including team publications) was a driver of acceptance of these practices within the market for new residential construction.

It is the role of the Delphi Panel to reflect on the role of BA relative to rival factors in increasing market acceptance for these practices. Rival factors may include naturally occurring market forces, other building science research programs, and other public policies. Rival factors identified by IEc during preliminary research for <u>all</u> practices that BA worked on (not specific to the four selected practices) include:

- Utility energy efficiency incentive programs
- Research carried out by national labs, and in particular LBNL, but outside of the BA umbrella
- Advocacy work of the Energy and Environmental Building Alliance

INTERVIEW QUESTIONS

Air Tightness

1. External to Building America, what, if any, other drivers do you think influenced the market acceptance of increased stringency of air sealing and air barrier requirements, in particular to reduce thermal bypass issues?
2. Without BA, would the market acceptance of air sealing and air barrier requirements have occurred at the same scale? Please explain.

[21] Interview guide including introduction will be read verbatim by interviewer.

3. Without BA, would the market acceptance of air sealing and air barrier requirements have occurred in the same timeframe? Please explain.

Duct Leakage

4. External to Building America, what, if any, other drivers do you think influenced the market acceptance of stricter duct leakage requirements?
5. Without BA, would the market acceptance of duct leakage requirements have occurred at the same scale? Please explain.
6. Without BA, would the market acceptance of duct leakage requirements have occurred in the same timeframe? Please explain.

Insulation

7. External to Building America, what, if any, other drivers do you think influenced the market acceptance of increased insulation requirements for the building envelope, including attics, walls, and foundations?
8. Without BA, would the market acceptance of increased insulation requirements have occurred at the same scale? Please explain.
9. Without BA, would the market acceptance of increased insulation requirements have occurred in the same timeframe? Please explain.

Thermal Bridging

10. External to Building America, what, if any, other drivers do you think influenced the market acceptance of continuous insulation requirements to reduce thermal bridging?
11. Without BA, would the market acceptance of continuous insulation requirements have occurred at the same scale? Please explain.
12. Without BA, would the market acceptance of continuous insulation requirements have occurred in the same timeframe? Please explain.

Energy Savings

As summarized in the results provided, our energy modeling estimates that the four studied building practices account for 250 trillion Btus saved, which is an approximately 6% reduction of the energy use in new homes built between 2006 and 2015 (excluding California).

The energy savings from each of the four practices is summarized below. **For each practice:**

13. What percent of the benefits of this practice do you attribute to BA? Please elaborate and provide your rationale.
14. What percent of the benefits of this practice do you attribute to other drivers? Please elaborate and provide your rationale.

In reflecting upon your response, please recall that this modeling exercise defined a counterfactual home as a code minimum or Energy Star home that would have existed during that same time frame if these four practices had not diffused into the marketplace. Although the counterfactuals reflect other changes in Energy Star and the energy code over time, they are static in the sense that we keep constant the assumption that the four practices being studied were not adopted during the 2006-2015 timeframe of the study.

PRACTICE	TOTAL ENERGY SAVINGS (2006 - 2015) (TRILLION BTU)	% ATTRIBUTABLE TO BA	% ATTRIBUTABLE TO OTHER DRIVERS	ELABORATION
Air leakage and infiltration requirements	182.5			
Duct leakage requirements	25.5			
Insulation requirements	38.6			
Thermal bridging requirements	3.2			

APPENDIX D. INTERVIEW GUIDES FOR HOMEBUILDERS

1. INTERVIEW GUIDE FOR BA BUILDERS WHO BUILD HOMES IN CALIFORNIA

OPENING STATEMENT

The U.S. Department of Energy contracted with Industrial Economics, Incorporated (IEc) to conduct an evaluation of the Building Technologies Office's (BTO's) investments in new residential efficiency program activities. A key focus is assessing the Building America program's influence on the adoption of energy efficiency practices in new residential construction. As part of this evaluation, we are interviewing builders who have worked with the Building America program, and those who have not, to help us understand Building America's role and influence in supporting the widespread market adoption of energy efficient building practices. Our conversation with you will provide important insights for our evaluation.

Please answer the following interview questions to the best of your ability. Please ask us to repeat any question if necessary.

Your participation in and the results of this interview will be kept confidential. IEc will report our findings in aggregate; your comments will not be attributed to you as an individual or to your organization in IEc's discussions with DOE or in the evaluation report.

This interview will take approximately 30 minutes.

BUILDER HISTORY

First, we will start with some questions about your company.

Q1. How many years has your company been in business?

1. Record response: _______
2. Don't know

Q2. How many years has your company worked in the new residential construction industry?

1. Record response: _______
2. Don't know

Q3. Does your company conduct home renovations in addition to building new homes?

1. Yes
2. No
3. Don't know

Q4. [If yes to Q3] What percent of your company's revenue comes from home renovations?

1. Record response: ________
2. Don't know

Q5. Our data show that your company works in [XX regions]. Is this correct?

1. Yes
2. No → we also work in these additional regions: _______
3. No → we do not work in these regions: _________
4. Don't know

Q6. Does your company build Energy Star homes?

1. Yes
2. No
3. [If yes] What year did your company start to build Energy Star homes?_______________

Q7. We understand that your company builds, on average, about [XX percent] of its homes in California. Is that right?

1. Yes
2. No
3. [If No] Can you tell me what percentage of the homes your company builds are in California?

BUILDING AMERICA INVOLVEMENT

Q8. During which years did your company work with the Department of Energy's Building America program? (Select all that apply)

1995	2001	2007	2013
1996	2002	2008	2014
1997	2003	2009	2015
1998	2004	2010	2016
1999	2005	2011	2017
2000	2006	2012	

Q9. Which Building America team(s) did/does your company work with? (check all that apply)

1. ARBI / Alliance for Residential Building Innovation (Davis Energy Group, DEG)
2. ARIES / Advanced Residential Integrated Energy Solutions (The Levy Partnership, Inc.)
3. BA-PIRC / Building America Partnership for Improved Residential Construction (Florida Solar Energy Center, FSEC, University of Central Florida) formerly Building America Industrialized Housing Partnership (BAIHP)
4. BARA / Building America Retrofit Alliance (Building Media Inc, BMI)

5. BEEHA / Building Energy Efficient Homes for America (U of Nebraska)
6. BIRA / Building Industry Research Alliance (ConSol)
7. BSC / Building Science Corporation
8. CARB / Consortium for Advanced Residential Buildings (Steven Winter Associates)
9. CSE / Fraunhofer Center for Sustainable Energy Systems
10. Dow / Habitat Cost Effective Energy Retrofit Program Team (Dow Chemical)
11. Gas Technology Institute
12. Hickory Consortium
13. Home Innovation Research Labs
14. IBACOS / Integrated Buildings and Construction Solutions Consortium
15. NELC / National Energy Leadership Corps (Penn St)
16. NREL / National Renewable Energy Laboratory
17. N-STAR / NorthernSTAR Energy Efficient Housing Research Partnership Team (University of Minnesota)
18. ORNL / Oak Ridge National Laboratory
19. PARR / Partnership for Advanced Residential Retrofit (Gas Technology Institute)
20. PHI / Partnership for Home Innovation (formerly National Association of Home Builders Research Center, NAHBRC-IP)
21. Other: ____
22. Don't know

Q10. Why did your company decide to work with the Building America program? (check all that apply)

1. Potential construction cost savings
2. Learn about whole home approaches to energy efficiency
3. Looking to better manage moisture in homes constructed
4. Looking to address quality issues other than moisture management
5. Assistance to obtain Energy Star certification
6. Other: _____
7. Other:______
8. Don't know

Q11. In your opinion, what were the main benefits your company received from working with the Building America program?

1. Construction cost savings

2. Learned about whole home approaches to energy efficiency
3. Better managed moisture in homes constructed
4. Addressed quality issues other than moisture management
5. Obtained Energy Star certification
6. Other: _____
7. Other:______
8. Don't know

ENERGY EFFICIENCY PRACTICE ADOPTION

For the next set of questions, I need to provide some more information on Building America first. Building America is a market diffusion program for building technologies/practices and whole house design approaches. While the focus of the program is on the house as a system and overall energy reductions with a group of technologies/practices, some energy efficiency practices demonstrated by Building America have been particularly successful in penetrating the new residential construction market. These are:

- Air leakage and infiltration requirements including requiring a specific performance level 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. BA-influenced requirements for air leakage and infiltration were initially reflected in Energy Star for Homes version 2.0 (2006) and the 2009 International Energy Conservation Code (IECC), as well as subsequent versions of the Energy Star Homes program and code.
- Duct leakage requirements including requiring a specific performance level (e.g., less than 4 cubic feet per meter 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). BA-influenced requirements for duct leakage were initially reflected in Energy Star for Homes version 2.0 (2006), and 2009 IECC, as well as subsequent versions of the program and code.
- Thermal bridging requirements including requiring specific placement of insulation or requiring continuous insulation. Thermal bridging requirements were initially reflected in Energy Star for Homes version 3 (2012), and 2012 IECC, as well as subsequent versions of the program and code.
- Increased insulation as initially reflected in 2006 IECC (and Energy Star for Homes refers to codes), as well as subsequent versions of the program and code.

For this next set of questions, please provide answers that apply to your company in general, across your company's divisions.

Q12. Are you aware of these practices? (Yes/No/Don't Know)

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012

4. Increased insulation requirements of IECC 2006

Q13. [If yes to Q12] How did you first hear about each of these practices?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q14. [If yes to Q12] Does your company use these practices? (Yes/No/Don't know)

If yes, why did you start using these practices?

If no, why not?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q15. [If yes to Q14] In what year did your company start using these practices in new residential construction?

1. Air leakage and infiltration requirements in 2009 IECC
2. Thermal bridging requirements of IECC 2012
3. Duct leakage requirements in 2009 IECC
4. Increased insulation requirements of IECC 2006

Q16. [If yes to Q14] Would you use these practices if they were not required by code? (Yes/No/Don't know)

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q17. [If yes to Q14] How did you learn to implement these practices?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q18. [If yes to Q14] Does your company use these practices as standard practice for new construction? (Yes/No/Don't Know)

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006

Q19. [If yes to Q18] In what year did your company start to use the practices as standard practice?

1. Air leakage and infiltration requirements in 2009 IECC_________
2. Duct leakage requirements in 2009 IECC__________
3. Thermal bridging requirements in IECC 2012__________
4. Increased insulation requirements of IECC 2006_______________

Q20. [If yes to Q14] How, if at all, have these practices changed net residential building costs over time? (Increased, decreased, stayed the same) *Why?*

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006

Q21. [If yes to Q14] Have you found that by adopting these practices, your HVAC equipment costs have changed? (e.g., saving costs by sizing a smaller system, or reducing the number of air handlers)? (Yes/No/Don't Know)

If yes, why? If no, why not?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006

Q22. Regarding HVAC, what is the typical square foot per ton that you are sizing today?_________

What was the square foot/ton that you were sizing in 2006?_________________________

For the next set of questions, please provide answers only for the homes your company builds in California.

Q23. What resources, if any, do you rely on to ensure your homes comply with CA Title 24 and/or CA ES Homes requirements?

Q24. Did you rely on any of the following Building America resources when designing homes to comply with CA Title 24 and/or CA ES Homes Requirements? [Yes/No/Don't Know]

1. EE construction approaches demonstrated by Building America projects
2. Guidance or resources developed by Building America or its teams

3. Case studies or other documentation on lessons learned from Building America demonstration projects

4. Others______________

Q25. [If Yes to at least one item in Q24] Did you realize any cost savings in complying with CA Title 24 and/or CA ES Homes by utilizing the [Building America resource]?

1. If yes, can you estimate the design cost savings (in $ per house) realized? Can you estimate the construction cost savings (in $ per square foot)?

BUILDING AMERICA RESOURCE	USED? (YES/NO)	AVERAGE $/HOUSE SAVINGS (DESIGN COSTS)	AVERAGE $/SQUARE FOOT (CONSTRUCTION COSTS)
EE construction approaches demonstrated by Building America projects			
Guidance or resources developed by Building America or its teams			
Case studies or other documentation of lessons learned from Building America demonstration projects			

Q26. [If yes to at least one item in Q24] Did [the Building America resource] help you comply with CA Title 24 or CA ES homes Requirements in other ways?

1. If yes, please elaborate.
2. If no, did you use any resources to help you comply? (Please list)

Q27. Did information gleaned from Building America resources and/or projects advance the uptake of the following energy efficiency practices by your other divisions outside of California? (Yes/No/Don't Know) *Please elaborate*.

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006

BUILDING AMERICA INFLUENCE ON INDUSTRY

Q28. Do you use any of the following Building America resources more than once per year? (check all that apply)

1. Case studies
2. Building America Solution Center
3. Best Practice Guides
4. Top innovation profiles

5. Window Replacement, Rehabilitation, and Repair Guide
6. Quality management System Guidelines
7. EEBA Builder's Guides
8. EEBA Water Management Guide
9. Attic Air Sealing Guidelines
10. National Residential Efficiency Measures Database
11. Building America House Simulation Protocol (HSP)
12. Building Energy Optimization Analysis Method (BEopt)
13. Domestic Hot Water Event Schedule Generator
14. Other resources developed by Building America building science experts
15. Other: ____
16. Other:________
17. None

Q29. Are there other, non-Building America resources you typically use to gather information to help you decide which energy efficiency technologies and practices to use in your buildings? For example, other DOE resources or Custom Builder's Magazines.

1. [For each resource reported] Do you use this resource more than once a year?

Q30. How do you typically hear about new energy efficiency technologies or practices?

Q31. What kinds of factors do you consider when deciding whether or not to start using a new energy efficiency technology or practice?

Q32. Are you aware of the BEopt modeling tool?

Q33. [If yes to Q32] Please rate the extent to which you agree with the following statement on a scale from 1 to 5, where 1 is strongly disagree and 5 is strongly agree: The BEopt modeling tool facilitates increased energy efficiency in new homes. *Please elaborate.*

Q34. Are you aware of the DOE climate maps?

Q35. [If yes to Q34] Please rate the extent to which you agree with the following statement on a scale from 1 to 5, where 1 is strongly disagree and 5 is strongly agree: The DOE climate maps facilitate increased energy efficiency in new homes. *Please elaborate*.

Q36. Are you aware of the vapor retarder classification system?

Q37. [If yes to Q36] Please rate the extent to which you agree with the following statement on a scale from 1 to 5, where 1 is strongly disagree and 5 is strongly agree: The vapor retarder classification system facilitates better moisture management in new homes. *Please elaborate.*

Q38. In your opinion, have the practices advanced by the Building America program spilled over into the renovation market? (Yes/No/Don't Know)

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006
5. Moisture management practices

If yes, are they commonly, sometimes, or rarely used in renovation market? Why?

PRACTICE	COMMON PRACTICE IN RENOVATION MARKET	USED SOMETIMES IN RENOVATION MARKET	RARELY USED IN RENOVATION MARKET	I DON'T KNOW
Air leakage and infiltration requirements in 2009 IECC				
Duct leakage requirements in 2009 IECC				
Thermal bridging requirements in IECC 2012				
Increased insulation requirements of IECC 2006				
Moisture management practices				

2. INTERVIEW GUIDE FOR BA BUILDERS OUTSIDE OF CALIFORNIA

OPENING STATEMENT

The U.S. Department of Energy contracted with Industrial Economics, Incorporated (IEc) to conduct an evaluation of the Building Technologies Office's (BTO's) investments in new residential efficiency program activities. A key focus is assessing the Building America program's influence on the adoption of energy efficiency practices in new residential construction. As part of this evaluation, we are interviewing builders who have worked with the Building America program, and those who have not, to help us understand Building America's role and influence in supporting the widespread market adoption of energy efficient building practices. Our conversation with you will provide important insights for our evaluation.

Please answer the following interview questions to the best of your ability. Please ask us to repeat any question if necessary.

Your participation in and the results of this interview will be kept confidential. IEc will report our findings in aggregate; your comments will not be attributed to you as an individual or to your organization in IEc's discussions with DOE or in the evaluation report.

This interview will take approximately 30 minutes.

BUILDER HISTORY

First, we will start with some questions about your company.

Q39. How many years has your company been in business?

1. Record response: _______
2. Don't know

Q40. How many years has your company worked in the new residential construction industry?

1. Record response: _______
2. Don't know

Q41. Does your company conduct home renovations in addition to building new homes?

1. Yes
2. No
3. Don't know

Q42. [If yes to Q3] What percent of your company's revenue comes from home renovations?

1. Record response: _______
2. Don't know

Q43. Our data show that your company works in [XX regions]. Is this correct?

1. Yes

2. No → we also work in these additional regions: ______
3. No → we do not work in these regions: ________
4. Don't know

Q44. Does your company build Energy Star homes?

1. Yes
2. No
3. [If yes] What year did your company start to build Energy Star homes?______________

BUILDING AMERICA INVOLVEMENT

Q45. During which years did your company work with the Department of Energy's Building America program? (Select all that apply)

1995	2001	2007	2013
1996	2002	2008	2014
1997	2003	2009	2015
1998	2004	2010	2016
1999	2005	2011	2017
2000	2006	2012	

Q46. Which Building America team(s) did/does your company work with? (Check all that apply)

1. ARBI / Alliance for Residential Building Innovation (Davis Energy Group, DEG)
2. ARIES / Advanced Residential Integrated Energy Solutions (The Levy Partnership, Inc.)
3. BA-PIRC / Building America Partnership for Improved Residential Construction (Florida Solar Energy Center, FSEC, University of Central Florida) formerly Building America Industrialized Housing Partnership (BAIHP)
4. BARA / Building America Retrofit Alliance (Building Media Inc, BMI)
5. BEEHA / Building Energy Efficient Homes for America (U of Nebraska)
6. BIRA / Building Industry Research Alliance (ConSol)
7. BSC / Building Science Corporation
8. CARB / Consortium for Advanced Residential Buildings (Steven Winter Associates)
9. CSE / Fraunhofer Center for Sustainable Energy Systems
10. Dow / Habitat Cost Effective Energy Retrofit Program Team (Dow Chemical)
11. Gas Technology Institute
12. Hickory Consortium
13. Home Innovation Research Labs

14. IBACOS / Integrated Buildings and Construction Solutions Consortium
15. NELC / National Energy Leadership Corps (Penn St)
16. NREL / National Renewable Energy Laboratory
17. N-STAR / NorthernSTAR Energy Efficient Housing Research Partnership Team (University of Minnesota)
18. ORNL / Oak Ridge National Laboratory
19. PARR / Partnership for Advanced Residential Retrofit (Gas Technology Institute)
20. PHI / Partnership for Home Innovation (formerly National Association of Home Builders Research Center, NAHBRC-IP)
21. Other: ____
22. Don't know

Q47. Why did your company decide to work with the Building America program? (check all that apply)

1. Potential construction cost savings
2. Learn about whole home approaches to energy efficiency
3. Looking to better manage moisture in homes constructed
4. Looking to address quality issues other than moisture management
5. Assistance to obtain Energy Star certification
6. Other: _____
7. Other:______
8. Don't know

Q48. In your opinion, what were the main benefits your company received from working with the Building America program?

1. Construction cost savings
2. Learned about whole home approaches to energy efficiency
3. Better managed moisture in homes constructed
4. Addressed quality issues other than moisture management
5. Obtained Energy Star certification
6. Other: _____
7. Other:______
8. Don't know

ENERGY EFFICIENCY PRACTICE ADOPTION

For the next set of questions, I need to provide some more information on Building America first. Building America is a market diffusion program for building technologies/practices and whole house design approaches. While the focus of the program is on the house as a system and overall energy reductions with a group of technologies/practices, some energy efficiency practices demonstrated by Building America have been particularly successful in penetrating the new residential construction market. These are:

- Air leakage and infiltration requirements including requiring a specific performance level 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. BA-influenced requirements for air leakage and infiltration were initially reflected in Energy Star for Homes version 2.0 (2006) and the 2009 International Energy Conservation Code (IECC), as well as subsequent versions of the Energy Star Homes program and code.
- Duct leakage requirements including requiring a specific performance level (e.g., less than 4 cubic feet per meter 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). BA-influenced requirements for duct leakage were initially reflected in Energy Star for Homes version 2.0 (2006), and 2009 IECC, as well as subsequent versions of the program and code.
- Thermal bridging requirements including requiring specific placement of insulation or requiring continuous insulation. Thermal bridging requirements were initially reflected in Energy Star for Homes version 3 (2012), and 2012 IECC, as well as subsequent versions of the program and code.
- Increased insulation as initially reflected in 2006 IECC (and Energy Star for Homes refers to codes), as well as subsequent versions of the program and code.

For this next set of questions, please provide answers that apply to your company in general, across your company's divisions.

Q49. Are you aware of these practices? (Yes/No/Don't Know)

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q50. [If yes to Q11] How did you first hear about each of these practices?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q51. [If yes to Q11] Does your company use these practices? (Yes/No/Don't know)

If yes, why did you start using these practices?

If no, why not?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q52. [If yes to Q13] In what year did your company start using these practices in new residential construction?

1. Air leakage and infiltration requirements in 2009 IECC
2. Thermal bridging requirements of IECC 2012
3. Duct leakage requirements in 2009 IECC
4. Increased insulation requirements of IECC 2006

Q53. [If yes to Q13] Would you use these practices if they were not required by code? (Yes/No/Don't know)

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q54. [If yes to Q13] How did you learn to implement these practices?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q55. [If yes to Q13] Does your company use these practices as standard practice for new construction? (Yes/No/Don't Know)

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006

Q56. [If yes to Q17] In what year did your company start to use the practices as standard practice?

1. Air leakage and infiltration requirements in 2009 IECC_________

2. Duct leakage requirements in 2009 IECC___________
3. Thermal bridging requirements in IECC 2012___________
4. Increased insulation requirements of IECC 2006________________

Q57. [If yes to Q13] How, if at all, have these practices changed net residential building costs over time? (Increased, decreased, stayed the same) *Why?*

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006

Q58. [If yes to Q13] Have you found that by adopting these practices, your HVAC equipment costs have changed? (e.g., saving costs by sizing a smaller system, or reducing the number of air handlers)? (Yes/No/Don't Know)

If yes, why? If no, why not?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006

Q59. Regarding HVAC, what is the typical square foot per ton that you are sizing today?__________

What was the square foot/ton that you were sizing in 2006?_________________________

BUILDING AMERICA INFLUENCE ON INDUSTRY

Q60. Do you use any of the following Building America resources more than once per year? (Check all that apply)

18. Case studies
19. Building America Solution Center
20. Best Practice Guides
21. Top innovation profiles
22. Window Replacement, Rehabilitation, and Repair Guide
23. Quality management System Guidelines
24. EEBA Builder's Guides
25. EEBA Water Management Guide
26. Attic Air Sealing Guidelines
27. National Residential Efficiency Measures Database

28. Building America House Simulation Protocol (HSP)
29. Building Energy Optimization Analysis Method (BEopt)
30. Domestic Hot Water Event Schedule Generator
31. Other resources developed by Building America building science experts
32. Other: ____
33. Other:________
34. None

Q61. Are there other, non-Building America resources you typically use to gather information to help you decide which energy efficiency technologies and practices to use in your buildings? For example, other DOE resources or Custom Builder's Magazines.

1. [For each resource reported] Do you use this resource more than once a year?

Q62. How do you typically hear about new energy efficiency technologies or practices?

Q63. What kinds of factors do you consider when deciding whether or not to start using a new energy efficiency technology or practice?

Q64. Are you aware of the BEopt modeling tool?

Q65. [If yes to Q26] Please rate the extent to which you agree with the following statement on a scale from 1 to 5, where 1 is strongly disagree and 5 is strongly agree: The BEopt modeling tool facilitates increased energy efficiency in new homes. *Please elaborate.*

Q66. Are you aware of the DOE climate maps?

Q67. [If yes to Q28] Please rate the extent to which you agree with the following statement on a scale from 1 to 5, where 1 is strongly disagree and 5 is strongly agree: The DOE climate maps facilitate increased energy efficiency in new homes. *Please elaborate*.

Q68. Are you aware of the vapor retarder classification system?

Q69. [If yes to Q30] Please rate the extent to which you agree with the following statement on a scale from 1 to 5, where 1 is strongly disagree and 5 is strongly agree: The vapor retarder classification system facilitates better moisture management in new homes. *Please elaborate.*

Q70. In your opinion, have the practices advanced by the Building America program spilled over into the renovation market? (Yes/No/Don't Know)

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006
5. Moisture management practices

If yes, are they commonly, sometimes, or rarely used in renovation market? Why?

PRACTICE	COMMON PRACTICE IN RENOVATION MARKET	USED SOMETIMES IN RENOVATION MARKET	RARELY USED IN RENOVATION MARKET	I DON'T KNOW
Air leakage and infiltration requirements in 2009 IECC				
Duct leakage requirements in 2009 IECC				
Thermal bridging requirements in IECC 2012				
Increased insulation requirements of IECC 2006				
Moisture management practices				

3. INTERVIEW GUIDE FOR NON-BA BUILDERS WHO BUILD HOMES IN CALIFORNIA

OPENING STATEMENT

The U.S. Department of Energy contracted with Industrial Economics, Incorporated (IEc) to conduct an evaluation of the Building Technologies Office's (BTO's) investments in new residential efficiency program activities. A key focus is assessing the Building America program's influence on the adoption of energy efficiency practices in new residential construction. As part of this evaluation, we are interviewing builders who have worked with the Building America program, and those who have not, to help us understand Building America's role and influence in supporting the widespread market adoption of energy efficient building practices. Our conversation with you will provide important insights for our evaluation.

Please answer the following interview questions to the best of your ability. Please ask us to repeat any question if necessary.

Your participation in and the results of this interview will be kept confidential. IEc will report our findings in aggregate; your comments will not be attributed to you as an individual or to your organization in IEc's discussions with DOE or in the evaluation report.

This interview will take approximately 30 minutes.

BUILDER HISTORY

First, we will start with some questions about your company.

Q71. How many years has your company been in business?

1. Record response: _______
2. Don't know

Q72. How many years has your company worked in the new residential construction industry?

1. Record response: _______
2. Don't know

Q73. Does your company conduct home renovations in addition to building new homes?

1. Yes
2. No
3. Don't know

Q74. [If yes to Q3] What percent of your company's revenue comes from home renovations?

1. Record response: _______
2. Don't know

Q75. Our data show that your company works in [XX regions]. Is this correct?

1. Yes

2. No → we also work in these additional regions: ______
3. No → we do not work in these regions: ________
4. Don't know

Q76. Does your company build Energy Star homes?

1. Yes
2. No
3. [If yes] What year did your company start to build Energy Star homes?______________

Q77. We understand that your company builds, on average, about [XX percent] of its homes in California. Is that right?

1. Yes
2. No
3. [If No] Can you tell me what percentage of the homes your company builds are in California?

BUILDING AMERICA INVOLVEMENT

Q78. Did your company ever have an opportunity to work with the Building America program (for example, was your company invited to participate on a team)?

1. Yes
2. No
3. Don't know

Q79. [If yes to Q8] Why did your company decide not to work with the Building America program?

1. Record response: ______
2. Don't know

ENERGY EFFICIENCY PRACTICE ADOPTION

For the next set of questions, I need to provide some more information on Building America first. Building America is a market diffusion program for building technologies/practices and whole house design approaches. While the focus of the program is on the house as a system and overall energy reductions with a group of technologies/practices, some energy efficiency practices demonstrated by Building America have been particularly successful in penetrating the new residential construction market. These are:

- Air leakage and infiltration requirements including requiring a specific performance level 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. BA-influenced requirements for air leakage and infiltration were initially reflected in Energy Star for Homes version 2.0 (2006) and the 2009 International Energy Conservation Code (IECC), as well as subsequent versions of the Energy Star Homes program and code.

- Duct leakage requirements including requiring a specific performance level (e.g., less than 4 cubic feet per meter 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). BA-influenced requirements for duct leakage were initially reflected in Energy Star for Homes version 2.0 (2006), and 2009 IECC, as well as subsequent versions of the program and code.
- Thermal bridging requirements including requiring specific placement of insulation or requiring continuous insulation. Thermal bridging requirements were initially reflected in Energy Star for Homes version 3 (2012), and 2012 IECC, as well as subsequent versions of the program and code.
- Increased insulation as initially reflected in 2006 IECC (and Energy Star for Homes refers to codes), as well as subsequent versions of the program and code.

For this next set of questions, please provide answers that apply to your company in general, across your company's divisions.

Q80. Are you aware of these practices? (Yes/No/Don't Know)

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q81. [If yes to Q10] How did you first hear about each of these practices?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q82. [If yes to Q10] Does your company use these practices? (Yes/No/Don't know)

If yes, why did you start using these practices?

If no, why not?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q83. [If yes to Q12] In what year did your company start using these practices in new residential construction?

1. Air leakage and infiltration requirements in 2009 IECC

2. Thermal bridging requirements of IECC 2012
3. Duct leakage requirements in 2009 IECC
4. Increased insulation requirements of IECC 2006

Q84. [If yes to Q12] Would you use these practices if they were not required by code? (Yes/No/Don't know)

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q85. [If yes to Q12] How did you learn to implement these practices?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q86. [If yes to Q12] Does your company use these practices as standard practice for new construction? (Yes/No/Don't Know)

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006

Q87. [If yes to Q16] In what year did your company start to use the practices as standard practice?

1. Air leakage and infiltration requirements in 2009 IECC_________
2. Duct leakage requirements in 2009 IECC__________
3. Thermal bridging requirements in IECC 2012__________
4. Increased insulation requirements of IECC 2006_______________

Q88. [If yes to Q12] How, if at all, have these practices changed net residential building costs over time? (Increased, decreased, stayed the same) *Why?*

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006

Q89. [If yes to Q12] Have you found that by adopting these practices, your HVAC equipment costs have changed? (e.g., saving costs by sizing a smaller system, or reducing the number of air handlers)? (Yes/No/Don't Know)

If yes, why? If no, why not?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006

Q90. Regarding HVAC, what is the typical square foot per ton that you are sizing today?_________

What was the square foot/ton that you were sizing in 2006?_________________________

For the next set of questions, please provide answers only for the homes your company builds in California.

Q91. What resources, if any, do you rely on to ensure your homes comply with CA Title 24 and/or CA ES Homes requirements?

Q92. Did you rely on any of the following Building America resources when designing homes to comply with CA Title 24 and/or CA ES Homes Requirements? [Yes/No/Don't Know]

1. EE construction approaches demonstrated by Building America projects
2. Guidance or resources developed by Building America or its teams
3. Case studies or other documentation on lessons learned from Building America demonstration projects
4. Others_______________

Q93. [If Yes to at least one item in Q22] Did you realize any cost savings in complying with CA Title 24 and/or CA ES Homes by utilizing the [Building America resource]?

1. If yes, can you estimate the design cost savings (in $ per house) realized? Can you estimate the construction cost savings (in $ per square foot)?

BUILDING AMERICA RESOURCE	USED? (YES/NO)	AVERAGE $/HOUSE SAVINGS (DESIGN COSTS)	AVERAGE $/SQUARE FOOT (CONSTRUCTION COSTS)
EE construction approaches demonstrated by Building America projects			
Guidance or resources developed by Building America or its teams			
Case studies or other documentation of lessons learned from Building America demonstration projects			

Q94. [If yes to at least one item in Q22] Did [the Building America resource] help you comply with CA Title 24 or CA ES homes Requirements in other ways?

1. If yes, please elaborate.
2. If no, did you use any resources to help you comply? (Please list)

Q95. Did information gleaned from Building America resources and/or projects advance the uptake of the following energy efficiency practices by your other divisions outside of California? (Yes/No/Don't Know) *Please elaborate*.

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006

4. INTERVIEW GUIDE FOR NON-BA BUILDERS OUTSIDE OF CALIFORNIA

OPENING STATEMENT

The U.S. Department of Energy contracted with Industrial Economics, Incorporated (IEc) to conduct an evaluation of the Building Technologies Office's (BTO's) investments in new residential efficiency program activities. A key focus is assessing the Building America program's influence on the adoption of energy efficiency practices in new residential construction. As part of this evaluation, we are interviewing builders who have worked with the Building America program, and those who have not, to help us understand Building America's role and influence in supporting the widespread market adoption of energy efficient building practices. Our conversation with you will provide important insights for our evaluation.

Please answer the following interview questions to the best of your ability. Please ask us to repeat any question if necessary.

Your participation in and the results of this interview will be kept confidential. IEc will report our findings in aggregate; your comments will not be attributed to you as an individual or to your organization in IEc's discussions with DOE or in the evaluation report.

This interview will take approximately 30 minutes.

BUILDER HISTORY

First, we will start with some questions about your company.

Q96. How many years has your company been in business?

1. Record response: _______
2. Don't know

Q97. How many years has your company worked in the new residential construction industry?

1. Record response: _______
2. Don't know

Q98. Does your company conduct home renovations in addition to building new homes?

1. Yes
2. No
3. Don't know

Q99. [If yes to Q3] What percent of your company's revenue comes from home renovations?

1. Record response: _______
2. Don't know

Q100. Our data show that your company works in [XX regions]. Is this correct?

1. Yes

2. No → we also work in these additional regions: ______
3. No → we do not work in these regions: ________
4. Don't know

Q101. Does your company build Energy Star homes?

1. Yes
2. No
3. [If yes] What year did your company start to build Energy Star homes?______________

BUILDING AMERICA INVOLVEMENT

Q102. Did your company ever have an opportunity to work with the Building America program (for example, was your company invited to participate on a team)?

1. Yes
2. No
3. Don't know

Q103. [If yes to Q7] Why did your company decide not to work with the Building America program?

1. Record response: ______
2. Don't know

ENERGY EFFICIENCY PRACTICE ADOPTION

For the next set of questions, I need to provide some more information on Building America first. Building America is a market diffusion program for building technologies/practices and whole house design approaches. While the focus of the program is on the house as a system and overall energy reductions with a group of technologies/practices, some energy efficiency practices demonstrated by Building America have been particularly successful in penetrating the new residential construction market. These are:

- Air leakage and infiltration requirements including requiring a specific performance level 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. BA-influenced requirements for air leakage and infiltration were initially reflected in Energy Star for Homes version 2.0 (2006) and the 2009 International Energy Conservation Code (IECC), as well as subsequent versions of the Energy Star Homes program and code.
- Duct leakage requirements including requiring a specific performance level (e.g., less than 4 cubic feet per meter 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). BA-influenced requirements for duct leakage were initially reflected in Energy Star for Homes version 2.0 (2006), and 2009 IECC, as well as subsequent versions of the program and code.
- Thermal bridging requirements including requiring specific placement of insulation or requiring continuous insulation. Thermal bridging requirements were initially reflected in Energy Star for

Homes version 3 (2012), and 2012 IECC, as well as subsequent versions of the program and code.

- Increased insulation as initially reflected in 2006 IECC (and Energy Star for Homes refers to codes), as well as subsequent versions of the program and code.

For this next set of questions, please provide answers that apply to your company in general, across your company's divisions.

Q104. Are you aware of these practices? (Yes/No/Don't Know)

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q105. [If yes to Q9] How did you first hear about each of these practices?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q106. [If yes to Q9] Does your company use these practices? (Yes/No/Don't know)

If yes, why did you start using these practices?

If no, why not?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q107. [If yes to Q11] In what year did your company start using these practices in new residential construction?

1. Air leakage and infiltration requirements in 2009 IECC
2. Thermal bridging requirements of IECC 2012
3. Duct leakage requirements in 2009 IECC
4. Increased insulation requirements of IECC 2006

Q108. [If yes to Q11] Would you use these practices if they were not required by code? (Yes/No/Don't know)

1. Air leakage and infiltration requirements in 2009 IECC

2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q109. [If yes to Q11] How did you learn to implement these practices?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements of IECC 2012
4. Increased insulation requirements of IECC 2006

Q110. [If yes to Q11] Does your company use these practices as standard practice for new construction? (Yes/No/Don't Know)

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006

Q111. [If yes to Q15] In what year did your company start to use the practices as standard practice?

1. Air leakage and infiltration requirements in 2009 IECC_________
2. Duct leakage requirements in 2009 IECC__________
3. Thermal bridging requirements in IECC 2012__________
4. Increased insulation requirements of IECC 2006_______________

Q112. [If yes to Q11] How, if at all, have these practices changed net residential building costs over time? (Increased, decreased, stayed the same) *Why?*

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006

Q113. [If yes to Q11] Have you found that by adopting these practices, your HVAC equipment costs have changed? (e.g., saving costs by sizing a smaller system, or reducing the number of air handlers)? (Yes/No/Don't Know)

If yes, why? If no, why not?

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012

4. Increased insulation requirements of IECC 2006

Q114. Regarding HVAC, what is the typical square foot per ton that you are sizing today?_________

What was the square foot/ton that you were sizing in 2006?_________________________

BUILDING AMERICA INFLUENCE ON INDUSTRY

Q115. Do you use any of the following Building America resources more than once per year? (check all that apply)

35. Case studies
36. Building America Solution Center
37. Best Practice Guides
38. Top innovation profiles
39. Window Replacement, Rehabilitation, and Repair Guide
40. Quality management System Guidelines
41. EEBA Builder's Guides
42. EEBA Water Management Guide
43. Attic Air Sealing Guidelines
44. National Residential Efficiency Measures Database
45. Building America House Simulation Protocol (HSP)
46. Building Energy Optimization Analysis Method (BEopt)
47. Domestic Hot Water Event Schedule Generator
48. Other resources developed by Building America building science experts
49. Other: ____
50. Other:________
51. None

Q116. Are there other, non-Building America resources you typically use to gather information to help you decide which energy efficiency technologies and practices to use in your buildings? For example, other DOE resources or Custom Builder's Magazines.

1. [For each resource reported] Do you use this resource more than once a year?

Q117. How do you typically hear about new energy efficiency technologies or practices?

Q118. What kinds of factors do you consider when deciding whether or not to start using a new energy efficiency technology or practice?

Q119. As far as you know, have you received any information about building construction practices from builders, building science experts, or other individuals that have worked with Building America? If yes, please elaborate.

1. If yes, did you apply this information to your building practices?

    i. If yes, how?

Q120. Are you aware of the BEopt modeling tool?

Q121. [If yes to Q25] Please rate the extent to which you agree with the following statement on a scale from 1 to 5, where 1 is strongly disagree and 5 is strongly agree: The BEopt modeling tool facilitates increased energy efficiency in new homes. *Please elaborate.*

Q122. Are you aware of the DOE climate maps?

Q123. [If yes to Q27] Please rate the extent to which you agree with the following statement on a scale from 1 to 5, where 1 is strongly disagree and 5 is strongly agree: The DOE climate maps facilitate increased energy efficiency in new homes. *Please elaborate*.

Q124. Are you aware of the vapor retarder classification system?

Q125. [If yes to Q29] Please rate the extent to which you agree with the following statement on a scale from 1 to 5, where 1 is strongly disagree and 5 is strongly agree: The vapor retarder classification system facilitates better moisture management in new homes. *Please elaborate.*

Q126. In your opinion, have the practices advanced by the Building America program spilled over into the renovation market? (Yes/No/Don't Know)

1. Air leakage and infiltration requirements in 2009 IECC
2. Duct leakage requirements in 2009 IECC
3. Thermal bridging requirements in IECC 2012
4. Increased insulation requirements of IECC 2006
5. Moisture management practices

If yes, are they commonly, sometimes, or rarely used in renovation market? Why?

PRACTICE	COMMON PRACTICE IN RENOVATION MARKET	USED SOMETIMES IN RENOVATION MARKET	RARELY USED IN RENOVATION MARKET	I DON'T KNOW
Air leakage and infiltration requirements in 2009 IECC				
Duct leakage requirements in 2009 IECC				
Thermal bridging requirements in IECC 2012				
Increased insulation requirements of IECC 2006				
Moisture management practices				

APPENDIX E. CODES PROGRAM EXPERT INTERVIEW GUIDE

The U.S. Department of Energy (DOE) contracted with Industrial Economics, Incorporated (IEc) to conduct an evaluation of Building Technologies Office investments in new residential efficiency activities. One evaluation objective is to understand the contribution of DOE's Building Energy Codes Program (BECP) to the development of progressively more energy efficient codes. Thank you for taking the time to answer the following questions, which will provide important insights for our evaluation.

Please answer the questions based on your experience and professional judgment. It is not necessary to conduct any research prior to the interview.

Your responses will be kept confidential. IEc will report interview findings in aggregate; your comments will not be attributed to you as an individual or to your organization in IEc's discussions with DOE or in the evaluation report.

1. Please tell us about your role in developing, analyzing, or implementing building energy code.
2. What is your experience or understanding of DOE/BECP's role in the codes process?
3. Please refer to the diagrams on the next page. The diagrams are based on an analysis of approved code proposals that resulted in significant changes in the 2009 and 2012 residential IECC Code. The diagrams are organized by proponent – DOE, Building Quality (BQ), Energy Efficient Codes Coalition (EECC), and other – and by type of change: air leakage, duct leakage, insulation and fenestration, other systems, and lighting.
    a. Did DOE/BECP play a role in getting these changes into code? If yes, what role did they play?
    b. What role did other actors (outside of DOE/BECP) play in getting these changes into the code? How did their role compare to that of DOE/BECP?
    c. Do you think that these changes would have happened at all without DOE/BECP's participation in the codes process?
    d. If yes, do you think that those changes would have happened *earlier, later*, or *at the same time* without DOE/BECP's participation? For specific code changes that would have happened "earlier" or "later", can you estimate *how much* earlier or later?
4. Are there other major categories of energy-saving changes, not mentioned above, that DOE/BECP helped get into code?
    a. If yes, please identify the change and describe DOE/BECP's role.
    b. What role did other actors (outside of DOE/BECP) play in getting these changes into code? How does their role compare to the role played by DOE/BECP?
    c. Do you think that these changes would have happened without DOE/BECP's participation?

d. If yes, do you think that these would have happened *earlier, later*, or *at the same time* without DOE/BECP's participation? For specific technologies/practices that would have been added to the code "earlier" or "later", can you estimate *how much* earlier or later?

5. Overall, how do you think the residential IECC code in 2009 and 2012 would have been different if DOE/BECP had not been involved?

6. Who else should we be posing these questions to?

Are there any other thoughts or observations that you would like to share with us?

APPENDIX F. ENERGY MODELING APPROACH AND OUTPUTS

ENERGY MODELING APPROACH

As discussed previously in this evaluation plan, the IEc team recommends quantifying the estimated impact BA has had on energy consumption/savings in new homes through energy modeling. In developing the protocol to guide the energy modeling, a balance must be struck between the improved accuracy resulting from increasing the number of parameters affecting energy consumption/savings deployed in the modeling, and the cost and complexity resulting from increasing the number of parameters.

The IEc team has worked through the protocol and selection of what we feel is the most appropriate energy modeling program, BEopt. BEopt was developed with partial funding from BA for multiple purposes, including standardization of energy savings analysis across BA teams. BEopt has a built-in reference home consistent with IECC 2009, which can be leveraged to create other reference homes for this study, and make 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,[22] 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 leading building scientists, with the sole objective of providing realistic and accurate energy savings estimates for houses constructed as part of BA. These assumptions are documented and justified in detail in the HSP. Note that the IEc team will document any and all parameters that require changing from default settings. Moreover, we will conduct a sensitivity analysis to explore the effects of key modeling assumptions, as detailed later in this Appendix.

An interplay exists between the implementation of the protocol and actually conducting the modeling; it is likely that as we model, we will need to adjust the protocol to maximize the accuracy of the energy modeling results. One way to do this is to conduct sensitivity analyses around parameters that we discover may or may not be determinant. The ease and breadth of sensitivity analysis within BEopt is one of the reasons the team selected it for this energy modeling task. Other reasons for selecting BEopt are:

- *Existence of an energy modeling simulation protocol*: The 2014 BA House Simulation Protocols establish an extensive and rigorous set of parameters from which to build our protocol, and this protocol – while not exclusive to BEopt – is thoroughly integrated into BEopt. The protocol works with the B10 Benchmark, an automatically generated reference case setting within the BEopt modeling program. The B10 Benchmark was developed for objective analysis of energy savings relative to the minimum requirements of the 2009 International Energy Conservation Code

[22] 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

(IECC), while adding additional detail in key areas such as lighting, hot water use, appliances, and miscellaneous electric loads, which are not addressed in detail by the IECC but are important drivers of energy use in new homes. The 2009 IECC reference home for this study can be validated against the automated B10 Benchmark to assure minimal code compliance and to verify that the energy savings projected from the reference home is near zero. Additionally other required reference cases (IECC 2006, Energy Star, etc.) can be created relatively quickly by modifying the relevant features of the IECC 2009 reference case. This streamlines what would otherwise be a time-intensive process of establishing counterfactual homes in the modeling process.

- *Keeping our energy modeling bias-free:* While it is possible to set up any modeling program with settings that favor certain outcomes over others—and then bury these settings in the modeling results – adherence to the 2014 BA House Simulation Protocols along with transparent documentation of any necessary divergence from this protocol means we can trust the energy modeling results. All modeling input and output files will be reviewed by IEc and provided to DOE in order to ensure bias-free modeling, data processing, and results.
- *Superior choice compared to other energy modeling programs*: As a subhourly modeling program set up to allow for design/parametric/optimization processes using the powerful EnergyPlus simulation engine, there is very little that BEopt cannot analyze. BEopt provides a broad range of standard building characteristics that can be easily selected through a user-friendly interface, as well as an Option Editor capability that allows an infinite number of additional building attributes and energy efficiency measures to be included in the analysis when necessary for more precise results.

  A program such as EnergyGauge is tuned to residential building simulation and includes code-compliance analysis, but EnergyGauge has changed in response to changes in BEopt, so there is little to be gained by using Energy Gauge instead of BEopt. In addition, EnergyGauge uses the somewhat older DOE-2.1E simulation engine, which has been largely superseded by EnergyPlus, the simulation engine used within BEopt.

  And finally a program such as REMRate—another industry standard for the residential building industry—does not have nearly the capabilities as BEopt. Also, it has changed over time in response to BEopt changes. BEopt is the clear driver for the most up-to-date energy modeling for the residential building industry.

GENERAL MODELING APPROACH

As discussed in Chapter 3, the energy modeling approach for this project is to select four technologies/practices that we are confident BA can take credit for diffusing in the marketplace, and model a BA-influenced home with those technologies/practices integrated, compared to a counterfactual home that would exist at that point in time without BA. Specifically, we define the BA home or innovation home as a home that meets the applicable statewide code or Energy Star requirements during a specific timeframe, including any BA technologies/practices that have been adopted. We define the counterfactual home as a code minimum or Energy Star home that would have existed during that same timeframe if BA had not diffused these technologies/practices into the marketplace. IEc has already conducted extensive research to identify technologies/practices that BA can take credit for diffusing, and has selected four that are clearly attributable to BA:

1. ES Thermal Bypass Checklist/Air Leakage Requirements
2. Duct Leakage Requirements
3. Enclosure Requirements
4. Thermal Bridging Requirements.

The technology "Thermal Bridging Requirements" is assumed to be relevant only in Climate Zones 4 – 8. This is because the basis for the continuous insulation ratio is to prevent wintertime interstitial condensation but also allow interstitial drying to the interior by employing a Class III interior vapor retarder.

Because BA technologies/practices came online at different points of time, a temporal analysis is necessary. In addition, states uptake energy codes on their own cycles, which means that some state-by-state analysis is in order. Finally, the energy savings for BA practices will be strongly affected by climate zone, necessitating analysis in multiple locations around the U.S.

The IEc Team's specific approach is discussed in eight steps below.

Step 1: Aggregation of Time Periods and States

To scope the modeling effort into a manageable and affordable task, years and states were clustered into logical groupings.

- **Time Periods:** IEc's research on technology/practice uptake indicates that technologies/practices are taken up by either Energy Star Homes or Codes on a roughly three-year cycle. Looking at when different BA-driven technologies/practices started to be required by ES Homes and IECC, ,[23] we can group years as follows: 2012-2015, 2009-2011, and 2006-2008.
- **States:** We grouped states into three categories: leaders, average, and laggards. Leaders are states that adopt the IECC code within three years; average states are one cycle behind; and laggard states are two cycles behind. In some cases, states have varied in their actual code adoption behavior over time, and the IEc team needed to make judgment calls regarding their assignment. Six states still have no mandatory code, but we recommend grouping these six states in with laggards, because market forces would likely push energy efficiency levels in all states to at least the minimal level consistent with laggard states, and because this is a conservative assumption to the alternative of assuming that no energy code is used in these states. The IEc team evaluated (by industry survey and Title 24 content and content changes over time) the relationship between Title 24 and the BA program in California over time. The IEc team conclusion is that the conservative approach is to assume that the BA program did not have enough independent and verifiable impact on Title 24 and industry-wide impact on CA energy savings to include in the modeling and results.

These groupings are reflected in the overall crosswalk of states, modeling scenarios, time periods, nominal codes, and applicability of BA practices, as shown in Exhibit E-1. The "yes" results under

[23] IEc has determined that the linkages between BA and California's Title 24 are not sufficiently strong to justify crediting BA with energy savings in California through either code improvements or construction of Energy Star homes.

Practices means that the BA practice is applicable and modeling will be conducted; the "no" results under Practices means that the BA practice is not applicable in the scenario, and therefore modeling will not be conducted.

Step 2: Sensitivity Analysis

Before locking in the range of simulations that must be run for this project, it will be necessary to perform sensitivity analysis to verify that certain variables can either be neglected or accounted for using simple adjustment factors. At a minimum, the following variables will be examined using a simple BEopt model of a 2000 ft^2 detached single-family home in Washington, DC, as the baseline:

1. Location within a climate region (five locations in Hot-Humid, five in Hot-Dry/Mixed-Dry, five in Mixed-Humid, five in Cold/Very Cold, and five in Marine)
2. Primary heating fuel (natural gas furnace vs air source heat pump) in three locations
3. Foundation type (basement vs crawlspace vs slab-on-grade) in three locations
4. House floor area (1000, 2000, 3000 ft^2) with number of floors held constant in three locations
5. Number of floors (1, 2, 3) with floor area held constant in three locations
6. Attached single-family (2 sides) vs detached single-family (0 sides) vs multi-family (4 sides) in three locations
7. Cooling system SEER (10, 13, 14) in three locations
8. Heating system AFUE (78, 80, 90) in three locations
9. Another 10-15 variables will be identified and screened based on their likely impact on energy savings for the BA practices, and the availability of empirical market penetration data that can be used to calculate weighting factors. For the most impactful variables, regression analysis will be used to develop reasonable energy savings adjustment factors, which will be applied to the modeled results during post-processing. Uncertainty analysis will be performed to determine whether the adjustment factors are sufficiently accurate. Of particular concern is the extrapolation of energy savings across locations within each climate region based on heating/cooling degree days or other weather variables. The subtleties of weather effects on energy use in residential buildings are notoriously difficult to approximate, but it may be possible if each adjustment factor applies only within a given climate region. If the results indicate that uncertainty is too large, and the effects of these variables cannot be estimated using adjustment factors, additional modeling using BEopt may be necessary to accurately quantify their impact.

Exhibit E-1. Crosswalk of States, Modeling Scenarios, Time Periods, Nominal Codes, And Applicability Of BA Practices

STATE CODE ADOPTION CATEGORY	EFFICIENCY LEVEL	TIME PERIOD	NOMINAL CODE	PRACTICE 1: TBC/AIR	PRACTICE 2: DUCTS	PRACTICE 3: ENCLOSURE	PRACTICE 4: THERMAL BRIDGING
Leaders	Counter-factual Code Home	2012-2015	IECC 2012	N	N	N	N
		2009-2011	IECC 2009	N	N	N	N
		2006-2008	IECC 2006	N	N	N	N
	BA Influenced Code	2012-2015	IECC 2012	Y	Y	Y	Y
		2009-2011	IECC 2009	Y	Y	Y	N
		2006-2008	IECC 2006	N	N	Y	N
	Counter-factual Energy Star	2012-2015	ES Version 3	N	N	N	N
		2009-2011	ES Version 2	N	N	N	N
		2006-2008	ES Version 2	N	N	N	N
	BA Influenced Energy Star	2012-2015	ES Version 3	Y	Y	Y	Y
		2009-2011	ES Version 2	Y	Y	Y	N
		2006-2008	ES Version 2	Y	Y	Y	N
Average	Counter-factual Code Home	2012-2015	IECC 2009	N	N	N	N
		2009-2011	IECC 2006	N	N	N	N
		2006-2008	IECC 2003	N	N	N	N
	BA Influenced Code	2012-2015	IECC 2009	Y	Y	Y	N
		2009-2011	IECC 2006	N	N	Y	N
		2006-2008	IECC 2003	N	N	N	N
	Counter-factual Energy Star	2012-2015	ES Version 3	N	N	N	N
		2009-2011	ES Version 2	N	N	N	N
		2006-2008	ES Version 2	N	N	N	N
	BA Influenced Energy Star	2012-2015	ES Version 3	Y	Y	Y	Y
		2009-2011	ES Version 2	Y	Y	Y	N
		2006-2008	ES Version 2	Y	Y	Y	N
Laggards	Counter-factual Code Home	2012-2015	IECC 2006	N	N	N	N
		2009-2011	IECC 2003	N	N	N	N
		2006-2008	IECC 2000	N	N	N	N
	BA Influenced Code	2012-2015	IECC 2006	N	N	Y	N
		2009-2011	IECC 2003	N	N	N	N

STATE CODE ADOPTION CATEGORY	EFFICIENCY LEVEL	TIME PERIOD	NOMINAL CODE	PRACTICE 1: TBC/AIR	PRACTICE 2: DUCTS	PRACTICE 3: ENCLOSURE	PRACTICE 4: THERMAL BRIDGING
		2006-2008	IECC 2000	N	N	N	N
	Counter-factual Energy Star	2012-2015	ES Version 3	N	N	N	N
		2009-2011	ES Version 2	N	N	N	N
		2006-2008	ES Version 2	N	N	N	N
	BA Influenced Energy Star	2012-2015	ES Version 3	Y	Y	Y	Y
		2009-2011	ES Version 2	Y	Y	Y	N
		2006-2008	ES Version 2	Y	Y	Y	N

Step 3: Select Locations

The IEc team will choose representative cities in each of five major climate regions for the simulation studies using BEopt.

1. Cold/Very Cold/Subarctic
2. Mixed Humid
3. Hot Humid
4. Hot-Dry/Mixed-Dry
5. Marine

The city must be relatively average for that climate region in terms of heating degree days, cooling degree days, and annual precipitation. It should also reflect a relatively active home construction market. The specific choice is not critical, because adjustments will be made for other locations within the climate zone. However, we will select cities where the insulation requirements were not significantly affected by the changes to IECC climate zone boundaries in the 2004 IECC Supplement.

Step 4: Convert General Practices to Specific Attributes

Each of the four BA practices selected for analysis must be converted from generalized code or ES terminology into specific changes in building attributes that can be modeled using BEopt. These attributes may be climate-dependent in some cases. The specific attributes associated with each practice will be based on scientific studies and expert consensus whenever possible. In some cases, judgment from the modeling team may be required. Treatment of requirements versus options are critical, because we need to assume that the BA-influenced home used the technology/practice in all cases.

In addition, the requirements of the IECC (2012, 2009, 2006, 2003, and 2000) and the Energy Star program (Version 2.0 and 3.0) must be translated into specific options within BEopt. When possible, the simplest version of the prescriptive path will be used, with any gaps filled in using the reference home for the performance path, followed by the B10 Benchmark default assumptions as implemented by BEopt.

A set of proposed assumptions with justification will be provided to DOE for review and discussion before modeling commences, as a separate deliverable from this evaluation plan.

Step 5: Create A Detailed Matrix Of Scenarios For Modeling

A complete matrix of simulation runs will be developed to ensure all important scenarios are included. At present, pending the results of the sensitivity analysis, it is expected that 120 unique BEopt runs will be required (5 climate zones X 7 reference codes X 6 efficiency levels – 90 duplicate or irrelevant cases). The preliminary matrix of BEopt runs is shown in Exhibit E-3 below. This matrix documents the minimum number of BEopt runs necessary to provide complete results for all scenarios listed in Exhibit F-1, including the various time periods and code adoption rates. In some instances, two cases are identical from a modeling standpoint, and only one run is necessary.

The IEc team will ultimately develop a much more expanded matrix of analytical results for all state/climate region combinations, which will include key outputs needed for nationwide roll-up of energy savings by fuel-type and BA practice. This matrix will be the basis for extrapolating energy savings beyond the BEopt models using the adjustment factors developed as part of the sensitivity studies.

Exhibit E-2. Matrix of Beopt Simulations for Each Location, with Individual Measure Attribution

NOMINAL CODE	EFFICIENCY LEVEL	PRACTICE 1: TBC/AIR	PRACTICE 2: DUCTS	PRACTICE 3: ENCLOSURE	PRACTICE 4: BRIDGING
IECC 2012	Reference Home	N	N	N	N
	BA Influenced Code	Y	Y	Y	N
	Practice 1	Y	N	N	N
	Practice 2	N	Y	N	N
	Practice 3	N	N	Y	N
	Practice 4	N	N	N	Y
IECC 2009	Reference Home	N	N	N	N
	BA Influenced Code	Y	Y	Y	N
	Practice 1	Y	N	N	N
	Practice 2	N	Y	N	N
	Practice 3	N	N	Y	N
	Practice 4	N	N	N	Y
IECC 2006	Reference Home	N	N	N	N
	BA Influenced Code	N	N	Y	N
	Practice 1	Y	N	N	N
	Practice 2	N	Y	N	N
	Practice 3	N	N	Y	N
	Practice 4	N	N	N	Y
IECC 2003	Reference Home / BA Influenced Code	N	N	N	N
IECC 2000	Reference Home / BA Influenced Code	N	N	N	N
Energy Star 2.0	Reference Energy Star Home	N	N	N	N
	BA Influenced Energy Star	Y	Y	Y	N
Energy Star 3.0	Reference Energy Star Home	N	N	N	N
	BA Influenced Energy Star	Y	Y	Y	Y

Step 6: Develop Batch Run Capability

The standard BEopt interface includes extensive parametric run capability, but it does not extend to climate zones and reference case attributes. Depending on the final matrix of BEopt runs and the complexity of creating models for each nominal code and BA practice, the IEc team may write a Python script to generate BEopt input XML files and apply building and climate attributes in a methodical way. This Python script would minimize manual entry time, minimize errors, and ensure that changes can be made in a consistent manner to all models when necessary. BEopt provides example Python scripts that would serve as a starting point. The Python script would also run the full matrix of cases in a single batch run. However, creating a script may be more complex than necessary for this project if the changes from one modeling run to the next are simple and straightforward, and the changes can be implemented using the existing batch and parametric run capabilities of BEopt. A final decision on this issue will be made once Steps 4 and 5 are complete.

Step 7: Run All Simulations

Once all of the BEopt input files have been generated, they can be run in a series of batch runs if the BEopt interface is used, or a single batch run if a script is used. Because each run takes approximately 60 seconds in BEopt, it would take approximately 2.5 hours to run the full matrix of cases in a single batch. If the BEopt interface is used, it would probably take about 6 hours to run all cases. The counterfactual reference case (Reference Home) will be one of the six efficiency levels for each location/nominal code combination, and therefore no reference case will be defined in BEopt and energy consumption (not energy savings) will be the relevant output. Another Python script may be developed to parse the relevant data so it can be loaded into a spreadsheet, which will then calculate energy savings and expand the results to other locations.

Step 8: Postprocessing

A post processing spreadsheet will further process the modeling output by applying adjustment factors generated as part of the sensitivity studies to expand the dataset beyond the original 150 runs to all state/climate combinations (78 not including California) and all time periods. Weighting factors will be applied when analyzing energy use across each state, to reflect the correct mix of house sizes, foundation types, and heating fuels. The spreadsheet will also perform the detailed energy savings calculations, which can then be rolled up on a nationwide scale based on the number of housing starts and ES market penetration, as applicable, in each state during the relevant time period. Exhibit E-3 presents the summary table shell for displaying energy modeling results.

Finally, the IEc team will downward adjust aggregate energy savings by applying a code non-compliance factor, using the same methodology developed by PNNL for its recent evaluation of DOE's Building Energy Code program. Additional downward adjustments for attribution may be made subsequently by the Delphi Panel.

Exhibit E-3. Energy Modeling Results Summary Table Shell

STATE	CODE-MINIMUM ANNUAL WEIGHTED AVERAGE ENERGY PER HOUSE (2006-2008)				CODE-MINIMUM ANNUAL WEIGHTED AVERAGE ENERGY PER HOUSE (2009-2011)				CODE-MINIMUM ANNUAL WEIGHTED AVERAGE ENERGY PER HOUSE (2012-2015)				ENERGY STAR ANNUAL WEIGHTED AVERAGE ENERGY PER HOUSE (2006-2015)				ALL HOUSES
	TOTAL ENERGY SAVINGS ELECTRICITY + GAS (GJ)	BA INFLUENCED HOMES ELECTRICITY + GAS (GJ)	COUNTERFACTUAL HOMES ELECTRICITY + GAS (GJ)		TOTAL ENERGY SAVINGS ELECTRICITY + GAS (GJ)	BA INFLUENCED HOMES ELECTRICITY + GAS (GJ)	COUNTERFACTUAL HOMES ELECTRICITY + GAS (GJ)		TOTAL ENERGY SAVINGS ELECTRICITY + GAS (GJ)	BA INFLUENCED HOMES ELECTRICITY + GAS (GJ)	COUNTERFACTUAL HOMES ELECTRICITY + GAS (GJ)		TOTAL ENERGY SAVINGS ELECTRICITY + GAS (GJ)	BA INFLUENCED HOMES ELECTRICITY + GAS (GJ)	COUNTERFACTUAL HOMES ELECTRICITY + GAS (GJ)		TOTAL ENERGY SAVINGS ELECTRICITY + GAS (GJ)
Alabama																	
Alaska																	
Arizona																	
Arkansas																	
California																	
Colorado																	
Connecticut																	
Delaware																	
Florida																	
Georgia																	
Hawaii																	
Idaho																	
Illinois																	
Indiana																	
Iowa																	
Kansas																	
Kentucky																	
Louisiana																	
Maine																	
Maryland																	
Massachusetts																	
Michigan																	
Minnesota																	
Mississippi																	
Missouri																	
Montana																	
Nebraska																	
Nevada																	
New Hampshire																	
New Jersey																	

STATE	CODE-MINIMUM ANNUAL WEIGHTED AVERAGE ENERGY PER HOUSE (2006-2008)				CODE-MINIMUM ANNUAL WEIGHTED AVERAGE ENERGY PER HOUSE (2009-2011)				CODE-MINIMUM ANNUAL WEIGHTED AVERAGE ENERGY PER HOUSE (2012-2015)				ENERGY STAR ANNUAL WEIGHTED AVERAGE ENERGY PER HOUSE (2006-2015)				ALL HOUSES
	TOTAL ENERGY SAVINGS ELECTRICITY + GAS (GJ)	BA INFLUENCED HOMES ELECTRICITY + GAS (GJ)	COUNTERFACTUAL HOMES ELECTRICITY + GAS (GJ)		TOTAL ENERGY SAVINGS ELECTRICITY + GAS (GJ)	BA INFLUENCED HOMES ELECTRICITY + GAS (GJ)	COUNTERFACTUAL HOMES ELECTRICITY + GAS (GJ)		TOTAL ENERGY SAVINGS ELECTRICITY + GAS (GJ)	BA INFLUENCED HOMES ELECTRICITY + GAS (GJ)	COUNTERFACTUAL HOMES ELECTRICITY + GAS (GJ)		TOTAL ENERGY SAVINGS ELECTRICITY + GAS (GJ)	BA INFLUENCED HOMES ELECTRICITY + GAS (GJ)	COUNTERFACTUAL HOMES ELECTRICITY + GAS (GJ)		TOTAL ENERGY SAVINGS ELECTRICITY + GAS (GJ)
New Mexico																	
New York																	
North Carolina																	
North Dakota																	
Ohio																	
Oklahoma																	
Oregon																	
Pennsylvania																	
Rhode Island																	
South Carolina																	
South Dakota																	
Tennessee																	
Texas																	
Utah																	
Vermont																	
Virginia																	
Washington																	
West Virginia																	
Wisconsin																	
Wyoming																	
TOTAL																	

CRITICAL ASSUMPTIONS

The modeling process will require making several key assumptions to remain practical and affordable within the available budget for the overall evaluation. These assumptions were described at each step in the modeling process above, and are summarized below:

- Variations in energy use due to basic house characteristics such as floor area, foundation type, and primary heating fuel can be accurately estimated using adjustment factors instead of additional BEopt modeling runs relative to the 150 cases listed in Exhibit F-3.
- Energy savings within climate regions can be normalized reasonably well using heating and cooling degree days or other weather variables.
- States without state-wide building codes (there are six) can be added to the "Laggard" group in terms of code categorization/adoption, because market forces would encourage a base level of efficiency even in the absence of an energy code.

STRENGTHS AND WEAKNESSES OF MODELING APPROACH

The IEc team believes that the strengths of the recommended modeling approach outweigh the weaknesses of it, and that this approach will produce accurate and reliable estimates of home energy savings attributable to BA.

Specific strengths include:

- Leverages a well-established modeling program (BEopt) with standardized, technically justified operating conditions and modeling assumptions.
- Limits the range of modeling runs to a manageable level.
- Allows changes to be made to a single script file instead of modifying hundreds of models through the BEopt interface.
- Creates transparency in the assumptions and results that can be vetted by all collaborators in the project to ensure objectivity.

Specific weaknesses include:

- Many simplifications and approximations must be made to constrain the number of simulation runs.
- May require the creation of a potentially complex script to manage the batch runs.
- Even with simplifications, the amount of data that must be processed remains very large.

ENERGY MODELING OUTPUTS

EXECUTIVE SUMMARY

In 2015, in response to requests from internal and external stakeholders, BTO initiated an evaluation to obtain a rigorous, methodologically sound, and defensible study of the impacts of some key BTO investments designed to reduce energy consumption by improving the energy efficiency performance of **new** homes. The evaluation will assess the economic, energy, and environmental impacts and cost-effectiveness of selected activities, as well as their contributions to the knowledge base. Quantifying the benefits and costs will allow BTO to improve program design and execution and communicate program impact. In addition, the evaluation will explore process and strategy questions that can inform BTO's program planning and budgeting activities.

This evaluation focuses on the research and development, systems integration and demonstration, and market transformation activities conducted by the BA program, and, to some extent, model code development activities conducted by BECP.[24] The evaluation will quantify the benefits and costs of DOE's support for selected new home construction technologies and practices demonstrated by the BA program, as well as assess spillover benefits from new homes to the housing retrofit market.

The largest scale benefit to be quantified by this evaluation is the estimation of energy savings from construction practices that Building America advanced in the marketplace. The IEc team including Building Green and Hendron Energy Consulting Services, estimated energy consumption in new homes by modeling four key practices advanced by Building America: requirements for insulation, air infiltration, duct leakage, thermal bridging that were integrated into Energy Star Homes and ultimately IECC model building energy codes.

This report summarizes the technical approach for the modeling task, along with key results and interpretations of these results in the context of the overall BA evaluation effort. Critical assumptions and data sources used in the process are documented wherever relevant. Finally, important limitations of the modeling results and overall conclusions are also discussed.

[24] The evaluation addresses only those elements of these programs that are directed at improving the efficiency of new residential construction. It does not address the impacts on new residential construction of BTO's Emerging Technologies or Appliance and Equipment Standards programs, or the impacts of those elements of the Building Energy Codes Program directed at supporting state adoption and implementation of building codes. The following Residential Buildings Integration activities are also outside the scope of the evaluation, as they have been or are currently being covered by separate evaluations: Solar Decathlon, Home Energy Score, and the Better Buildings Neighborhood Program.

The IEc team conducted a rigorous 8-step energy modeling analysis of these practices and 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). This estimated interim result will be further analyzed using Delphi panel analysis—based on balanced input from leading industry experts—to assign appropriate attribution of the estimated savings.

Preliminary actions for the energy modeling analysis included:

- Identification of four BA builder practices deployed through the Environmental Protection Agency (EPA) Energy Star (ES) Program and the International Energy Conservation Code (IECC) model residential energy code, which could be reasonably and strongly associated with BA program efforts: building enclosure air tightness, HVAC duct tightness, building enclosure insulation levels, and thermal bridging.
- Selection of the best-suited energy modeling program: BEopt, a sub-hourly residential software driven by Energy Plus (a leading energy analytical engine), including a House Simulation Protocol that proved very useful as modeling guidelines.

The IEc team then used eight analysis steps to provide a fair estimate of energy savings, given available data and resources.

- ***Step 1: Aggregate by time periods and states*** – Develop reasonable groupings based largely on building code cycles and code adoption rates.
- ***Step 2: Select locations*** – Identify representative cities based on 5 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 BA practices as expressed in building code and ES terminology into modeling settings, mostly based on climate.
- ***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 totals: per time period, per state, and nationwide.

This report provides transparent and thorough documentation and explanation of the processes required to develop reasonable and fair interim estimates of site energy savings, given the inherent complexity of the task.[25] A Delphi Panel will consider attribution factors and produce a final estimate of energy savings. The IEc team will then estimate the economic and environmental impacts of these savings, including avoided social cost of carbon and health impacts from avoided electricity generation. The IEc team will also explore other areas of program benefit, including other areas of cost savings, knowledge benefits, and energy security benefits. The evaluation will collect qualitative evidence of program attribution from production builders, via survey, to understand the differences in rate and timing of adoption of these technologies among builders that participated in BA and those that did not. The survey will also: explore moisture management as a potential economic benefit of BA; probe if BA helped California builders come into compliance with state-specific energy codes; and explore spillover to non-participants and to the retrofit market. The IEc team is using a citation analysis, in addition to the survey, to capture knowledge benefits.

INTRODUCTION

In support of the evaluation of the impact of the U.S. Department of Energy's Building America (BA) Program, the Industrial Economics, Incorporated (IEc) team, including Building Green and Hendron Energy Consulting Services, estimated energy consumption in new homes by modeling four energy efficiency construction practices, herein referred to in this report as "BA practices." The energy modeling focused on the impact of these four BA practices as they were deployed via model energy codes and the Energy Star (ES) Program. We conducted the modeling using a range of housing attributes in several locations throughout the U.S., with adjustment factors applied to the results to extend their usefulness to the broad range of housing characteristics and weather conditions present in different parts of the country. We rolled up the results nationwide using state-level weighting factors and data for actual housing starts over the period 2006-2015. These interim estimated nationwide energy savings provide one element of the overall benefits of BA to U.S. homeowners and the nation as a whole, which will be a focal point of the overall BA evaluation led by IEc.[26]

This report summarizes the technical approach for the modeling task, along with key results and interpretations of these results in the context of the overall BA evaluation effort. Critical assumptions and data sources used in the process are documented wherever relevant. Finally, important limitations of the modeling results and overall conclusions are also discussed.

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[25] The use of site energy instead of source energy for modeling output allows the calculation of either energy cost savings or source energy savings in future stages of the overall BA impact evaluation.

[26] Evaluation Plan for Building America and Selected Building Energy Codes Program Activities. 2016. Industrial Economics, Incorporated. Cambridge, MA.

TECHNICAL APPROACH

Identification of Key BA Practices

The energy modeling approach selected for this project focused on four technologies/practices that the IEc team is confident BA can take substantial credit for diffusing in the marketplace. We modeled BA-influenced homes with those technologies/practices integrated, compared to counterfactual homes that would exist at that point in time without BA. Specifically, we defined each BA-influenced home as a home that meets the applicable statewide code or ES requirements during a specific timeframe, including any BA technologies/practices that have been adopted. To measure the incremental impact provided by BA, we defined the corresponding counterfactual home as a code minimum or ES home that would have existed during that same timeframe if BA had not diffused these technologies/practices into the marketplace. The IEc team conducted extensive research to identify technologies/practices that BA can take credit for diffusing, and selected four that are largely attributable to BA:

5. 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 3 ACH50 through stricter prescriptive requirements for air sealing. In addition, beginning in 2012, the IECC required blower door testing to verify compliance with the air tightness requirements. ES began implementing the Thermal Bypass Checklist in 2006, mandating even tighter building envelopes.
6. Duct Leakage: IECC began mandating duct leakage testing for ducts outside conditioned space in 2009, and tightened the leakage requirement in 2012. ES has maintained strict duct leakage testing requirements since 2006.
7. 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, which does not have additional requirements for envelope insulation beyond existing code. Changes to window performance were not attributed to BA in this study.
8. 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. ES has required advanced framing since 2012.

The timetable for adoption of the four BA practices is summarized in Table 1. The practice “Thermal Bridging” is relevant only in Climate Zones 4 – 8. This is because the basis for the continuous insulation ratio is to prevent wintertime interstitial condensation but also allow interstitial drying to the interior by employing a Class III interior vapor retarder.

Table 1. Uptake of BA Practices in the Market

TECHNOLOGY/PRACTICE	ES HOMES	IECC
Air tightness	2006 (v2) 2012 (v3)	2006 IECC 2009 IECC 2012 IECC
Duct leakage	2006 (v2) 2012 (v3)	2009 IECC 2012 IECC
Envelope insulation	2006 (v2) 2012 (v3)	2006 IECC 2009 IECC 2012 IECC
Thermal bridging	2012 (v3)	2012 IECC (only certain climate zones)

Because BA 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. Finally, the energy savings for BA practices are strongly affected by climate zone, necessitating analysis in representative climate regions around the U.S.

For each BA practice, the IEc team established "counterfactual" cases for both code compliant and ES homes. For code minimum homes, the counterfactual input was simply the value required by the IECC in the cycle preceding the introduction of the BA practice. For example, the counterfactual air tightness was the value specified in the performance path reference home in IECC 2003, while the duct leakage was consistent with the performance path in IECC 2006. The counterfactual practice for ES was consistent with the counterfactual version of the IECC in place at the time. Continuing enhancements to the counterfactual inputs over time due to market forces or inevitable technical advancements were not included in this analysis. Instead, a Delphi Panel will consider these effects and the issue of overall attribution. For building attributes other than those associated with the four BA Practices, we used the same requirements of the code or ES for both the counterfactual and BA-influenced cases.

Selection of Energy Modeling Software

The IEc team selected BEopt as the most appropriate energy modeling program for this study. BEopt was developed with partial funding from BA for multiple purposes, including standardization of energy savings analysis across BA teams. BEopt has a built-in reference home consistent with IECC 2009, which was leveraged to create other baseline homes for this study, making the modeling process more efficient by streamlining the process of developing both BA-influenced and counterfactual models. Also, by establishing consistent operating conditions and typical building attributes in accordance with the BA House Simulation Protocols (HSP),[27] using BEopt prevents "gamesmanship" in the modeling process, which could exaggerate energy savings through manipulation of hidden variables in the energy models.

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[27] 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

During the implementation of the protocol established in the Evaluation Plan, occasional adjustments were necessary to maximize the accuracy of the energy modeling results within the prescribed budget. We conducted sensitivity analyses around a variety of modeling parameters to identify those that had the biggest quantifiable impact on site energy use. The ease and breadth of sensitivity analysis capabilities within BEopt was one of the reasons the team selected it for this energy modeling task. Other reasons for selecting BEopt were:

- *Existence of an energy modeling simulation protocol*: The HSP established an extensive and rigorous set of parameters from which to build our protocol, and this protocol – while not exclusive to BEopt – has been thoroughly integrated into BEopt. The protocol works with the B10 Benchmark, an automatically generated reference case within the BEopt modeling program. The B10 Benchmark was developed for objective analysis of energy savings relative to the minimum requirements of the 2009 International Energy Conservation Code (IECC), while adding additional detail in key areas such as lighting, hot water use, appliances, and miscellaneous electric loads, which are not addressed in detail by the IECC but are important drivers of energy use in new homes. We validated the 2009 IECC reference home for this study against the automated B10 Benchmark to ensure minimal code compliance and to verify that the energy savings projected from the reference home is near zero. Additionally, other required reference cases (IECC 2006, ES, etc.) could be created relatively quickly by modifying the relevant features of the IECC 2009 reference case. This streamlined what would otherwise be a time-intensive process of establishing counterfactual homes in the modeling process.
- *Ensuring bias-free energy modeling :* While it is possible to set up any modeling program with settings that favor certain outcomes over others—and then bury these settings in the modeling results – adherence to the HSP along with transparent documentation of any necessary divergence from this protocol provides bias-free energy modeling results. All modeling input assumptions and output data were reviewed by IEc and have been provided to DOE in order to ensure transparent modeling, data processing, and results.
- *Superior input choice compared to other energy modeling programs*: As a subhourly modeling program set up to allow for design/parametric/optimization processes using the powerful EnergyPlus simulation engine, there is very little that BEopt cannot analyze. BEopt provides a broad range of standard building characteristics that could be easily selected through a user-friendly interface, as well as an Option Editor capability that allowed an infinite number of additional building attributes and energy efficiency measures to be included in the analysis when necessary for more precise results.

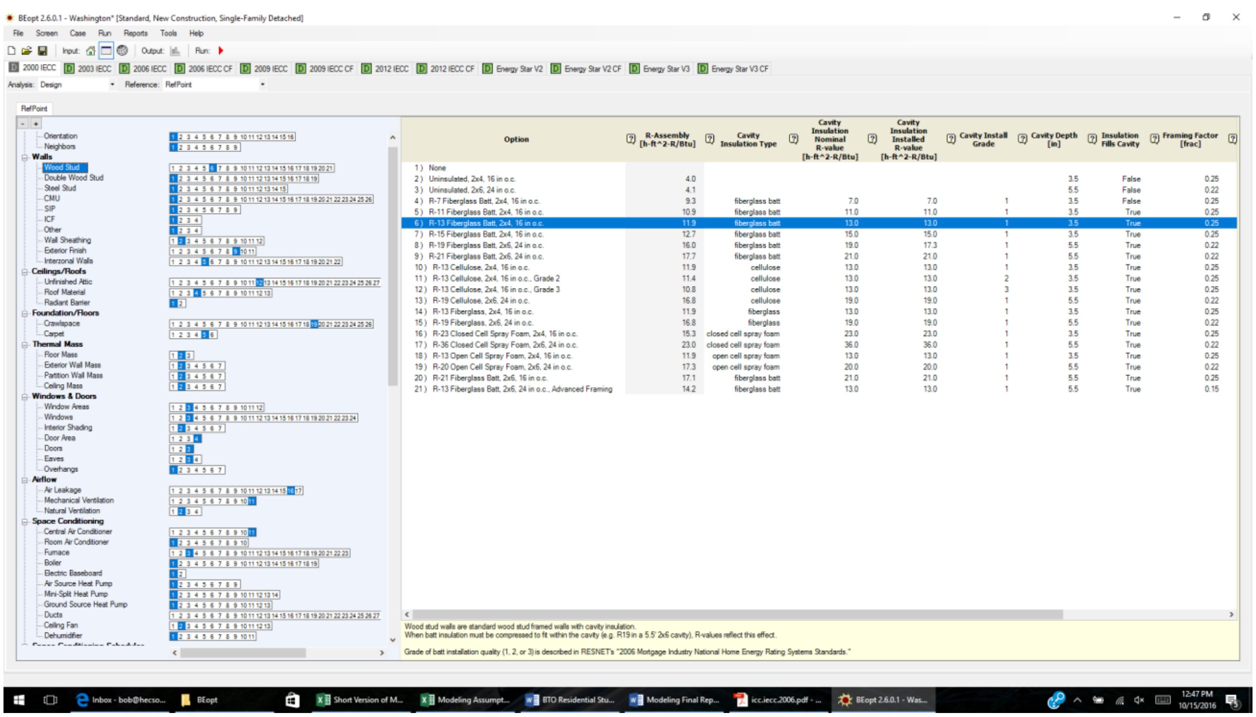
  A program such as EnergyGauge is tuned to residential building simulation and includes code-compliance analysis, but EnergyGauge has changed in response to changes in BEopt, so there was little to be gained by using Energy Gauge instead of BEopt. In addition, EnergyGauge used the somewhat older DOE-2.1E simulation engine, which has been largely superseded by EnergyPlus, the simulation engine used within BEopt.

  And finally, a program such as REMRate—another industry standard for the residential building industry—does not have nearly the capabilities BEopt has. BEopt was the clear best option for the most up-to-date energy modeling for the residential building industry.

The National Renewable Energy Laboratory (NREL) established the standard assumptions built into BEopt through a consensus process of leading building scientists, with the sole objective being to estimate realistic and accurate energy savings for houses constructed as part of BA. These assumptions are documented and justified in detail in the HSP. This report documents the small number of parameters where changes from the BEopt default settings were warranted in the context of the current BA program impact evaluation.

A screen capture of BEopt is shown in Figure 1.

Figure 1. Screen Capture of BEopt Modeling Software Input Screen



Steps in the Modeling Process

In developing the protocol to implement the energy modeling, we struck a balance between the improved accuracy resulting from increasing the number of parameters affecting energy consumption/savings deployed in the modeling, and the cost and complexity resulting from increasing the number of parameters. As a result, much of the initial phase of the modeling effort focused on:

- Developing representative baseline models in a range of climates;
- Identifying the building attributes that should either be included in the matrix of modeling runs or addressed in post-processing using adjustment factors; and,
- Rolling up the results nationwide using state-specific weighting factors and construction statistics.

The IEc team's specific approach included eight steps. Each step is briefly described in Table 2. More complete descriptions, including analytical techniques and results, are included in the remaining sections of this report.

Table 2. Steps in the Modeling Process

STEP	DESCRIPTION
Step 1: Aggregate Time Periods and States	The complexity of modeling all state energy codes as they evolved over a 10-year evaluation period necessitated simplification by assigning similar calendar years and code adoption rates into a manageable number of categories.
Step 2: Select Locations	Representative cities were selected in each climate region for direct modeling, and within each state/climate combination for extrapolation of results nationwide.
Step 3: Convert General Practices to Specific Attributes	The four BA practices were defined in more specific terms that could be used as direct modeling inputs.
Step 4: Establish Model Settings	The various versions of the IECC from 2000-2012 and ES Versions 2 and 3 were translated into BEopt modeling inputs.
Step 5: Sensitivity Analysis	The effects of numerous building attributes were analyzed to determine which should reasonably be modeled directly, which could be approximated using adjustment factors, and which could be neglected.
Step 6: Create A Detailed Matrix of Scenarios for Modeling	The final set of modeling runs was established, balancing accuracy with budget constraints.
Step 7: Run All Simulations	The full matrix of modeling runs was performed using BEopt.
Step 8: Post-processing	Data from the BEopt output files were imported into a post-processing spreadsheet, which then applied adjustment factors and rolled up results statewide and nationwide for each time period.

The steps in Table 2 include the following minor changes to the original modeling steps described in the Evaluation Plan:

- We conducted the sensitivity analysis later in the process, to ensure that basic modeling inputs were firmly established before parametric analysis was applied. We revisited he modeling inputs after the sensitivity analysis was completed to ensure the accuracy of inputs that were found to have a large impact on analysis results.
- We added "Establish Model Settings" as an explicit step, distinct from converting the BA practices into specific building attributes.
- We dropped "Develop Batch Run Capability" from the plan, because it proved both unnecessary and impractical. The BEopt user interface allowed multiple cases to be performed in a single run, which minimized the amount of manual intervention required for the modeling effort. In addition, the inability to convert code requirements into a logical algorithm made batch runs impractical.

Finally, the standard CSV output format for BEopt would have been lost, making it more difficult to link the output data to the post-processing spreadsheet.

PROCESSING RESULTS

Step 1: Aggregation of Time Periods and States

To scope the modeling effort into a manageable and affordable task, the IEc team clustered years and states into logical groupings.

- **Time Periods:** IEc's research on technology/practice uptake indicated that technologies/practices were taken up by either ES Homes or the IECC on a roughly three-year cycle. Looking at when different BA-driven practices were first required by ES Homes and IECC,[28] years were grouped as follows: 2006-2008, 2009-2011, and 2012-2015. We used these time periods to establish energy savings for the first year following construction, and we assumed that the same level of energy savings carried forward in subsequent years of the analysis period (2006-2015). We will address energy savings in future years (2016 and later) in the overall report prepared by IEc.
- **States:** We grouped states into three adoption rate categories: leaders, average, and laggards. Leaders are states that adopt the IECC code within three years; average states are one cycle behind; and laggard states are two cycles behind. This categorization is summarized in Table 3. In some cases, states have varied in their actual code adoption behavior over time, and the IEc team needed to make judgment calls regarding their assignment. Six states still have no mandatory code, but these six states were grouped in with laggards, because market forces would likely push energy efficiency levels in all states to at least the minimal level consistent with laggard states. The IEc team evaluated (by industry survey and Title 24 content changes over time) the relationship between Title 24 and the BA program in California. Our conclusion was that the impact of BA in California is ambiguous and controversial given parallel state activities, and that the conservative approach is to assume that the BA program did not have enough verifiable impact on Title 24 and industry-wide impact on CA energy savings to include in the modeling and results.

Table 3. Assignment of States into Three Code Adoption Rate Categories

Alabama	Average	Missouri	Laggard
Alaska	Laggard	Montana	Leader
Arizona	Laggard	Nebraska	Leader
Arkansas	Laggard	Nevada	Average
California	N/A	New Hampshire	Leader
Colorado	Laggard	New Jersey	Leader

[28] IEc has determined that the linkages between BA and California's Title 24 are not sufficiently strong to justify crediting BA with energy savings in California through either code improvements or construction of Energy Star homes.

Connecticut	Average	New Mexico	Leader
Delaware	Leader	New York	Average
District of Columbia	Leader	North Carolina	Average
Florida	Average	North Dakota	Laggard
Georgia	Average	Ohio	Average
Hawaii	Average	Oklahoma	Laggard
Idaho	Leader	Oregon	Leader
Illinois	Leader	Pennsylvania	Leader
Indiana	Laggard	Rhode Island	Leader
Iowa	Leader	South Carolina	Average
Kansas	Laggard	South Dakota	Laggard
Kentucky	Leader	Tennessee	Laggard
Louisiana	Average	Texas	Average
Maine	Leader	Utah	Leader
Maryland	Leader	Vermont	Average
Massachusetts	Leader	Virginia	Leader
Michigan	Average	Washington	Leader
Minnesota	Average	West Virginia	Average
Mississippi	Laggard		

The year when each of the four BA practices became mandatory in each state depends on both the date they were first mandated in the IECC, and the date that version of the IECC was adopted. For ES homes, only the date of implementation in ES is relevant, because ES is a voluntary program that doesn't require state-level adoption. Table 4 summarizes the relevant dates when the BA practices became mandatory for code-minimum and ES homes, and consequently the year when our analysis began tallying energy savings for the measure. As discussed earlier, the counterfactual models do not include the BA practices.

The groupings are reflected in the overall matrix of states, modeling scenarios, time periods, nominal codes, and applicability of BA practices, as shown in Table 5. The "Y" results under Practices mean that the BA practice is applicable and modeling will be conducted; the "N" results under Practices means that the BA practice is not applicable in the scenario, and therefore modeling was not conducted. The assignment of states into adoption rate categories (as shown in Table 3) is one driver of the matrix of modeling runs, but does not represent the full matrix, which must also include climatic differences within states.

Table 4. Date Each BA Practice Became Mandatory in Codes and ES

	PRACTICE 1: TBC/AIR	PRACTICE 2: DUCTS	PRACTICE 3: ENCLOSURE	PRACTICE 4: THERMAL BRIDGING
	Year Required in Code			
Leaders BA-Influenced	2009	2009	2006	2012
Leaders Counterfactual	-	-	-	-
Average BA-Influenced	2012	2012	2009	-
Average Counterfactual	-	-	-	-
Laggards BA-Influenced	-	-	2012	-
Laggards Counterfactual	-	-	-	-
	Year Required in Energy Star			
BA Influenced Energy Star	2006	2006	2006	2012
Counter-factual Energy Star	-	-	-	-

Table . Matrix of States, Modeling Scenarios, Time Periods, Nominal Codes, and Applicability of BA Practices

STATE CODE ADOPTION CATEGORY	EFFICIENCY LEVEL	TIME PERIOD	NOMINAL CODE	PRACTICE 1: TBC/AIR	PRACTICE 2: DUCTS	PRACTICE 3: ENCLOSURE	PRACTICE 4: THERMAL BRIDGING
Leaders	Counter-factual Code Home	2012-2015	IECC 2012	N	N	N	N
		2009-2011	IECC 2009	N	N	N	N
		2006-2008	IECC 2006	N	N	N	N
	BA Influenced Code	2012-2015	IECC 2012	Y	Y	Y	Y
		2009-2011	IECC 2009	Y	Y	Y	N
		2006-2008	IECC 2006	N	N	Y	N
	Counter-factual ES	2012-2015	ES Version 3	N	N	N	N
		2009-2011	ES Version 2	N	N	N	N
		2006-2008	ES Version 2	N	N	N	N
	BA Influenced ES	2012-2015	ES Version 3	Y	Y	Y	Y
		2009-2011	ES Version 2	Y	Y	Y	N
		2006-2008	ES Version 2	Y	Y	Y	N
Average	Counter-factual Code Home	2012-2015	IECC 2009	N	N	N	N
		2009-2011	IECC 2006	N	N	N	N
		2006-2008	IECC 2003	N	N	N	N
	BA Influenced Code	2012-2015	IECC 2009	Y	Y	Y	N
		2009-2011	IECC 2006	N	N	Y	N
		2006-2008	IECC 2003	N	N	N	N
	Counter-factual ES	2012-2015	ES Version 3	N	N	N	N
		2009-2011	ES Version 2	N	N	N	N
		2006-2008	ES Version 2	N	N	N	N
	BA Influenced ES	2012-2015	ES Version 3	Y	Y	Y	Y
		2009-2011	ES Version 2	Y	Y	Y	N
		2006-2008	ES Version 2	Y	Y	Y	N
Laggards	Counter-factual Code Home	2012-2015	IECC 2006	N	N	N	N
		2009-2011	IECC 2003	N	N	N	N
		2006-2008	IECC 2000	N	N	N	N
	BA Influenced Code	2012-2015	IECC 2006	N	N	Y	N
		2009-2011	IECC 2003	N	N	N	N
		2006-2008	IECC 2000	N	N	N	N
	Counter-factual ES	2012-2015	ES Version 3	N	N	N	N
		2009-2011	ES Version 2	N	N	N	N
		2006-2008	ES Version 2	N	N	N	N
	BA Influenced ES	2012-2015	ES Version 3	Y	Y	Y	Y
		2009-2011	ES Version 2	Y	Y	Y	N
		2006-2008	ES Version 2	Y	Y	Y	N

Step 2: Select Locations

The IEc team focused on the following five major climate regions for the modeling analysis:

1. Cold/Very Cold/Subarctic
2. Mixed Humid
3. Hot Humid
4. Hot-Dry/Mixed-Dry
5. Marine

We drew the climate regions from the eight defined for the BA program[29] by combining the three coldest regions and the two dry regions to keep the modeling scope more manageable.

We selected a representative city for each climate region, which would then be used as the baseline for energy modeling in future steps. Decision criteria included:

- The city must be relatively average for that climate region in terms of heating degree days (HDD), cooling degree days (CDD), and annual precipitation.
- It should also reflect a relatively active home construction market, and it should not be significantly affected by the changes to IECC climate zone boundaries in the 2004 IECC Supplement.

The specific choice of city was not critical, because adjustments were later made for other locations within the climate zone, but the adjustments are more accurate if the reference city is typical and does not have extreme weather conditions.

Table 6 highlights the representative cities in green (Houston, Detroit, Washington, El Paso, and Portland), along with four secondary cities (in yellow) that were used in the sensitivity analysis. We chose the secondary cities from among the 10 largest cities to provide a diversity of weather conditions, providing a more robust set of adjustment factors.

[29] http://energy.gov/eere/buildings/climate-zones

Table 6. Locations Selected for Energy Analysis (Green indicates baseline city for modeling, yellow indicates secondary city for sensitivity analysis)

Climate Region	City***	State	HDD**	CDD**	Precipitation (in)*
Hot Humid	Houston (Bush)	TX	1371	3059	49.7
	San Antonio (Int. Airport)	TX	1418	3157	32.3
	Dallas (Love Field)	TX	2058	2944	37.4
	Austin (Bergstrom)	TX	1671	2962	32.2
	Jacksonville (Int. Airport)	FL	1327	2632	52.4
	Fort Worth (Alliance)	TX	2363	2668	37.4
	Miami (Int. Airport)	FL	126	4537	61.9
	New Orleans (Int. Airport)	LA	1444	2626	62.5
	Honolulu (Int. Airport)	HI	0	4679	17.1
	Tampa (Int. Airport)	FL	527	3563	46.3
	Average of 10 largest cities		1231	3283	42.9
Cold/Very Cold/Subarctic	Chicago (Midway)	IL	5872	1034	39.1
	Indianapolis (Int. Airport)	IN	5272	1087	42.4
	Columbus (OSU)	OH	5255	1015	39.0
	Denver (DIA)	CO	5959	777	14.3
	Detroit (Metro)	MI	6103	807	33.5
	Boston (Logan)	MA	5596	750	43.8
	Milwaukee (Mitchell)	WI	6684	690	34.8
	Colorado Springs (Municipal)	CO	6160	459	16.5
	Omaha (Eppley)	NE	6025	1132	30.6
	Minneapolis (Int. Airport)	MN	7472	765	30.6
	Average of 10 largest cities		6040	852	32.5
Mixed Humid	New York (JFK)	NY	4843	984	42.8
	Philadelphia (Int. Airport)	PA	4512	1332	41.5
	Charlotte (Douglas)	NC	3065	1713	41.6
	Washington (Reagan)	DC	3996	1555	43.5
	Memphis (Int. Airport)	TN	2898	2253	53.7

Climate Region	City***	State	HDD**	CDD**	Precipitation (in)*
	Nashville (Int. Airport)	TN	3518	1729	47.3
	Oklahoma City (Will Rogers)	OK	3438	1950	36.5
	Baltimore (BWI)	MD	4552	1261	41.9
	Louisville (Int. Airport)	KY	4109	1572	44.9
	Kansas City (Int. Airport)	MO	5012	1372	38.9
	Average of 10 largest cities		3994	1572	43.3
Hot-Dry/Mixed-Dry	Los Angeles (Int. Airport)	CA	1295	582	12.8
	Phoenix (Sky Harbor)	AZ	923	4626	8.0
	San Diego (Int. Airport)	CA	1197	673	10.3
	El Paso (Int. Airport)	TX	2383	2379	8.8
	Las Vegas (McCarran)	NV	2015	3486	4.2
	Albuquerque (Int. Airport)	NM	3994	1370	9.5
	Tucson (Int. Airport)	AZ	1416	3273	11.6
	Fresno (Yosemite)	CA	2266	2097	11.5
	Sacramento (Metro)	CA	2425	1390	21.2
	Long Beach (Daugherty)	CA	1190	1062	12.3
	Average of 10 largest cities		1910	2094	11.0
Marine	San Jose	CA	2131	1077	14.9
	San Francisco (Int. Airport)	CA	2689	144	23.7
	Seattle (Boeing)	WA	4320	264	39.9
	Portland (Int. Airport)	OR	4214	433	36.0
	Oakland (Int. Airport)	CA	2637	155	20.8
	Fremont (Hayward)	CA	2572	288	16.7
	Tacoma (Narrows)	WA	5288	123	43.0
	Oxnard (Ventura/Camarillo)	CA	1872	374	14.6
	Santa Rosa (Sonoma)	CA	3047	375	36.3
	Vancouver (Pearson)	WA	4415	374	39.1
	Salem	OR	4533	313	39.7
	Average of 10 largest cities		3559	284	31.0

* Source: NOAA National Climatic Data Center (1981-2010 averages). http://www.ncdc.noaa.gov/cdo-web/datatools/normals

** Source: ASHRAE Fundamentals 2013 (Data from 1982-2006)

*** Specific airport or other location for city weather data is indicated in parentheses

Step 3: Convert General Practices to Specific Attributes

The IEc team converted each of the four BA practices selected for analysis from generalized code or ES terminology into specific changes in building attributes. These attributes were climate-dependent in most cases. In some cases, we utilized scientific studies and expert consensus when the code or ES was ambiguous about the practical implementation of a practice. We included the practice in the BA-influenced home only when the practice was mandated either directly in the prescriptive path of the code, or indirectly through the performance path. If the practice was optional, we did not include it. This was a conservative assumption that has the effect of underestimating the interim energy savings benefits of these practices.

The final specifications for the BA practices in the context of the Washington DC model are summarized in Table 7, as an example. Some of the specific values differ for other models depending on the geographic location and foundation type, but the pattern is the same. The analysis focused on homes with central space conditioning systems, which are typical of new homes constructed within the timeframe of this study.

Table 7. Specific Modifications to BEopt Models when BA Practices are applied (Washington Example)

BA PRACTICE	COUNTER-FACTUAL (2006-2015)	IECC 2006	IECC 2009	IECC 2012	ES V2	ES V3
Air tightness	11.4 ACH50	7.5 ACH50	7 ACH50	3 ACH50	6 ACH50	5 ACH50
Duct leakage	30%[30]	30%	12 cfm/100 ft^2	4 cfm/100 ft^2	4 cfm/100 ft^2	4 cfm/100 ft^2
Envelope insulation	Wall: R-13 Sheathing: R-0 Attic: R-38 Floor: R-19	Wall: R-13 Sheathing: R-5 Attic: R-38 Floor: R-19	Wall: R-21 Sheathing: R-0 Attic: R-38 Floor: R-19	Wall: R-13 Sheathing: R-5 Attic: R-49 Floor: R-19	Wall: R-13 Sheathing: R-5 Attic: R-38 Floor: R-19	Wall: R-13 Sheathing: R-5 Attic: R-38 Floor: R-19
Thermal bridging	2x4 16" o.c. 25% framing[31]	2x4 16" o.c. 25% framing	2x6 16" o.c. 25% framing	2x6 24" o.c. 15% framing[32]	2x4 16" o.c. 25% framing	2x6 24" o.c. 15% framing

[30] Approximation that roughly matches the 0.80 distribution loss factor specified in the performance path.
[31] 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
[32] Joseph Lstiburek. 2010. BSI-030: Advanced Framing. Building Science Corporation. buildingscience.com/documents/insights/bsi-030-advanced-framing

We based the counterfactual air tightness values in the 11-14 ACH50 range (depending on location) on the IECC 2000/2003 performance path reference home, which specifies 0.57xW where W is a climate-dependent weather factor from ASHRAE Standard 136. However, the interpretation of the 2006 IECC proved challenging because the performance path reference for air infiltration was reduced significantly to a specific leakage area of 0.00036 (~7.5 ACH50). This value presented a challenge because there wasn't a corresponding increase in stringency for infiltration in the prescriptive path to justify a lower infiltration rate. After discussions with the Pacific Northwest National Laboratory (PNNL) and a review of the 2006 code change proposals, it appeared that the change was made to be more consistent with empirical air leakage data that had become available at the time. During evaluation scoping interviews conducted by IEc, building science experts indicated that BA greatly contributed to demonstrating the feasibility of reducing air infiltration in new homes, leading to the change to the 2006 IECC performance path. Therefore, we included the reduction from 11-14 ACH50 to 7.5 ACH50 as part of the savings associated with the air infiltration practice, instead of only counting the savings associated with the introduction of the Thermal Bypass Checklist (TBC) and mandatory blower door testing in the 2009 IECC. In a later step of this evaluation, the Delphi panel will have an opportunity to adjust the results if they do not feel that BA should be credited with all or most of the benefits associated with the increased stringency of the air infiltration requirements in the 2006 IECC or later versions.

One additional analytical challenge was the duct leakage requirement via testing in the 2009 IECC (12 cfm/100 ft^2), which was an improvement in hot climates, but was actually a bit weaker than the counterfactual case in cold and marine climates. The reason is that the counterfactual duct leakage (30% of total airflow, or a distribution loss factor of approximately 0.80) scaled with the fan size, which in turn scaled with the cooling load, while the 2009 IECC duct leakage was a constant CFM number regardless of the fan size, scaling only with floor area.[33] This reflects an anomaly in how the code specified duct leakage in 2009, not an intentional loosening of the code requirements.

Finally, we interpreted advanced framing to include 2x6 studs instead of 2x4, even when the cavity insulation requirement was R-13. The reason for this interpretation is that the shift to 24" spacing necessitates deeper studs for structural integrity.

Step 4: Establish Model Settings

The IEc team translated the requirements of the IECC (2012, 2009, 2006, 2003, and 2000) and the ES Program (Version 2.0 and 3.0) into specific options within BEopt to establish the baseline models. We determined the specific values using the following order of prioritization:

- The simplest version of the prescriptive path
- The reference home for the performance path
- BA HSP default specifications as implemented by BEopt

The key model attributes used in BEopt are broken into three sets. Table 8 provides the baseline envelope specifications, which were fixed regardless of the version of the IECC or ES. Table 9 provides baseline equipment specifications, again fixed for all models. Table 10 provides key variable specifications for the Washington DC case as an example, which changed depending on the relevant version of the IECC or ES.

[33] In Portland for example, 12 cfm/100 ft^2 resulted in a duct leakage rate of 240 cubic feet per minute (cfm) for the 2000 ft^2 baseline home, which was actually bigger than 30% of total airflow, which was about 145 cfm. In Houston, 12 cfm/100 ft^2 (240 cfm) was smaller than 30% of total airflow (~347 cfm).

Model attributes related to the four BA practices are not included in the tables, because they were already addressed in Step 3. The full set of model attributes, including less critical specifications and all five locations, is available in spreadsheet form upon request.

Table 8. Key Baseline Model Attributes (Envelope)

	Detroit	**Washington**	**Houston**	**El Paso**	**Portland**
Conditioned Area (ft^2)	2000	2000	2000	2000	2000
Dimensions (ft)	40x50	40x50	40x50	40x50	40x50
Foundation Type	Unconditioned Basement	Vented Crawlspace	Slab-on-Grade	Slab-on-Grade	Vented Crawlspace
Number of Bedrooms	3	3	3	3	3
Number of Bathrooms	2	2	2	2	2
Number of Stories	1	1	1	1	1
Wall Height (ft)	8	8	8	8	8
Crawlspace Height (ft)	n/a	4	n/a	n/a	4
Terrain	Suburban	Suburban	Suburban	Suburban	Suburban
Attached Garage Area (ft^2)	225	225	225	225	225
Attached Housing Units	None	None	None	None	None
Orientation	North	North	North	North	North
Neighbors	None	None	None	None	None
Wall Type	Wood Stud	Wood Stud	Wood Stud	Wood Stud	Wood Stud
Wall Insulation Type	Fiberglass Batt	Fiberglass Batt	Fiberglass Batt	Fiberglass Batt	Fiberglass Batt
Wall Exterior Finish Material	Vinyl	Vinyl	Vinyl	Vinyl	Vinyl
Ceiling Insulation Type	Cellulose	Cellulose	Cellulose	Cellulose	Cellulose
Attic Venting	Vented	Vented	Vented	Vented	Vented
Roofing Material	Asphalt shingles	Asphalt shingles	Asphalt shingles	Asphalt shingles	Asphalt shingles
Roofing Color	White/cool	White/cool	White/cool	White/cool	White/cool
Radiant Barrier	None	None	None	None	None
Basement Wall Insulation Material	XPS	N/A	N/A	N/A	N/A
Basement Wall Insulation Height	Whole wall	N/A	N/A	N/A	N/A
Basement Wall Construction	Concrete	N/A	N/A	N/A	N/A
Floor Insulation Material	N/A	Fiberglass Batt	N/A	N/A	Fiberglass Batt
Window Distribution	Uniform	Uniform	Uniform	Uniform	Uniform
Window to Wall Ratio	0.15	0.15	0.15	0.15	0.15
Interior Shading - All Year	0.7	0.7	0.7	0.7	0.7
Eaves	2 ft	2 ft	2 ft	2 ft	2 ft
Overhangs	None	None	None	None	None

Table 9. Key Baseline Model Attributes (Equipment)

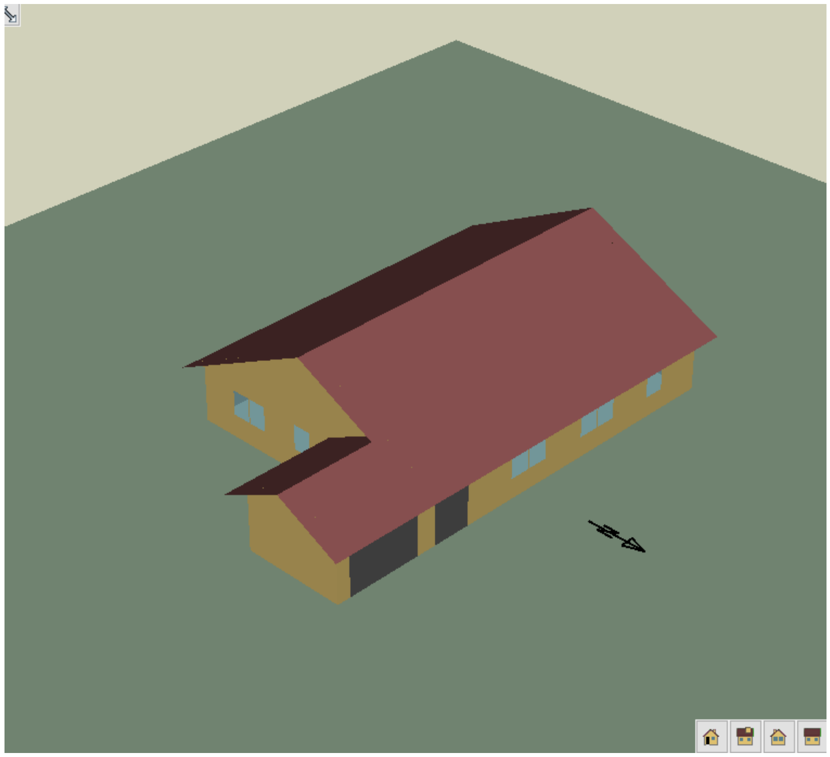
	Detroit	Washington	Houston	El Paso	Portland
Cooling System	Central A/C	Central A/C	Central A/C	Central A/C	Central A/C
Cooling Airflow	386.1 cfm/ton	386.1 cfm/ton	386.1 cfm/ton	386.1 cfm/ton	386.1 cfm/ton
Heating System	Gas Furnace	Gas Furnace	Gas Furnace	Gas Furnace	Gas Furnace
Natural Ventilation	All Year	All Year	All Year	All Year	All Year
Fraction Supply Duct Leakage	0.667	0.667	0.667	0.667	0.667
Fraction Return Duct Leakage	0.33	0.33	0.33	0.33	0.33
Duct Location	Basement	Crawlspace	Unfinished Attic	Unfinished Attic	Crawlspace
Duct Area	400 ft^2 Supply, 240 ft^2 Return	540 ft^2 Supply, 200 ft^2 Return	540 ft^2 Supply, 200 ft^2 Return	540 ft^2 Supply, 200 ft^2 Return	540 ft^2 Supply, 200 ft^2 Return
Dehumidifier	None	None	None	None	None
Cooling Set Point	76°F	76°F	76°F	76°F	76°F
Cooling Setup	0°F	0°F	0°F	0°F	0°F
Heating Set Point	71°F	71°F	71°F	71°F	71°F
Heating Setback	0°F	0°F	0°F	0°F	0°F
Water Heater Fuel	Gas	Gas	Gas	Gas	Gas
Hot Water Distribution Type	Trunk/Branch	Trunk/Branch	Trunk/Branch	Trunk/Branch	Trunk/Branch
Percent Plug-in Incandescent	0.66	0.66	0.66	0.66	0.66
Lighting Percent Plug-in CFL	0.34	0.34	0.34	0.34	0.34
Refrigerator Type	Top Freezer	Top Freezer	Top Freezer	Top Freezer	Top Freezer
Range Type	Electric	Electric	Electric	Electric	Electric
Daily Clothes Washer Hot Water Use	10 gal	10 gal	10 gal	10 gal	10 gal
Clothes Dryer Type	Electric	Electric	Electric	Electric	Electric
Hot Water Usage	BA HSP	BA HSP	BA HSP	BA HSP	BA HSP
Schedules	BA HSP	BA HSP	BA HSP	BA HSP	BA HSP
Miscellaneous Electric Loads	2206 kWh/yr	2206 kWh/yr	2206 kWh/yr	2206 kWh/yr	2206 kWh/yr
Site Generation	None	None	None	None	None

Table 10. Key Code-Dependent Model Attributes (Washington Example)

	IECC 2000/2003	IECC 2006	IECC 2009	IECC 2012	Energy Star V2	Energy Star V3
Climate Zone	10B	4A	4A	4A	4A	4A
Window Glazing	Clear, Double Pane	Low-E, Double Pane	Low-E, Double Pane	Low-E, Double Pane	Low-E, Double Pane	Low-E, Double Pane
Window Framing	Vinyl	Vinyl	Vinyl	Vinyl	Vinyl	Insul. Vinyl
Window Fill	Air	Air	Argon	Argon	Air	Air
Window U-value	0.49	0.38	0.35	0.34	0.38	0.29
Window SHGC	0.56	0.44	0.44	0.3	0.44	0.31
Mechanical Ventilation Type	Continuous Exhaust	Continuous Exhaust	Continuous Exhaust	Continuous Exhaust	Continuous Exhaust	Continuous Exhaust
Ventilation Rate	50 cfm	50 cfm	50 cfm	50 cfm	50 cfm	50 cfm
Ventilation Power	25 W	22.5 W	22.5 W	17.8 W	22.5 W	22.5 W
Cooling Efficiency	SEER 13, EER 11.1	SEER 13, EER 11.1	SEER 13, EER 11.1	SEER 13, EER 11.1	SEER 13, EER 11.1	SEER 13, EER 11.1
Cooling Capacity	500 ft2/ton	Manual J	Manual J	Manual J	Manual J	Manual J
Rated Supply Fan Power	0.55 W/cfm	0.55 W/cfm	0.364 W/cfm	0.364 W/cfm	0.55 W/cfm	0.364 W/cfm
Heating Efficiency	0.78 AFUE	0.78 AFUE	0.78 AFUE	0.78 AFUE	0.90 AFUE	0.90 AFUE
Duct Insulation (Nominal)	R-8	R-8	R-6	R-6	R-6	R-6
Ceiling Fans	BA HSP	BA HSP	BA HSP	BA HSP	BA HSP	High Eff.
Water Heater Annual Efficiency	0.59 EF	0.59 EF	0.59 EF	0.59 EF	0.67 EF	0.67 EF
Refrigerator Efficiency	17.6 EF	17.6 EF	17.6 EF	17.6 EF	21.9 EF	21.9 EF
Annual Refrigerator Energy	434 kWh	434 kWh	434 kWh	434 kWh	348 kWh	348 kWh
Annual Dishwasher Energy	111 kWh	111 kWh	111 kWh	111 kWh	111 kWh	83 kWh
Daily Dishwasher Hot Water Use	3.1 gal	3.1 gal	3.1 gal	3.1 gal	3.1 gal	1.7 gal
Annual Clothes Washer Energy	387 kWh	387 kWh	387 kWh	387 kWh	123 kWh	387 kWh
Hot Water Distribution Insulation	R-2	R-0	R-0	R-3	R-0	R-0
Lighting Percent Hardwired Incandescent	66%	66%	66%	25%	40%	20%
Lighting Percent Hardwired CFL	34%	34%	34%	75%	60%	80%

A graphical illustration of the baseline geometry, including building shape, window and door locations, orientation, attached garage, and roof type, for the Washington DC model is shown in Figure 2.

Figure 2. Baseline Geometry as Represented in BEopt (Washington Example)



There was a small number of important building attributes that IECC, ES, and the BA HSP did not address sufficiently. We defined these attributes as follows:

- Certain physical attributes that are considered “blind” in the IECC and ES. These include features such as floor area, foundation type, heating fuel, and window area (when below 18% of floor area). We selected typical values for the baseline analysis using engineering judgment. We included most of these attributes in the sensitivity analysis under Step 5 in order to correctly adjust for the diversity of physical home characteristics in each state.
- Older versions of the BA Benchmark (representing mid-90s construction) used 0.55 W/cfm for the central air handler. The more recent BA HSP, which is intended to be consistent with 2010 code-minimum construction and 2009 typical practices, uses 0.364 W/cfm. Consequently, to be consistent with common practice at the time, we used 0.55 W/cfm for codes prior to IECC 2009, and 0.364 W/cfm thereafter.
- For ES Version 2 Builder Option Packages, a choice of 5 ES Qualified pieces of equipment is required. For this analysis, we chose two light fixtures, refrigerator, clothes washer, and water heater.
- Equipment sizing according to Manual J was not specifically encouraged until IECC 2006. For IECC 2000-2003, we assumed 500 ft^2/ton as a common rule of thumb.[34]

[34] Robin K. Vieira, Danny S. Parker, Jon F. Klongerbo, Jeffrey K. Sonne, and Jo Ellen Cummings. 1996. "How Contractors Really Size Air Conditioning Systems." 1996 ACEEE Summer Study on Energy Efficiency in Buildings. (http://www.fsec.ucf.edu/en/publications/html/FSEC-PF-289-95/)

- Maximum window U-value and SHGC requirements in the IECC and ES do not always correspond with realistic window combinations. Therefore, we selected the least expensive window option in BEopt that met both requirements to better represent how actual houses would be constructed.
- Equipment efficiencies are mandated through federal equipment standards, not energy codes. For the baseline, the efficiencies applicable in 2009 were used in our models. We addressed adjustments for earlier and later equipment standards, which apply to all states regardless of the version of the IECC in place at the time, as part of the sensitivity analysis.

Step 5: Sensitivity Analysis

The IEc team employed several simplifications to constrain the BEopt modeling effort so that it could be accomplished within the time and resources available under the budget for the BA evaluation. At the same time, these simplifications could introduce uncertainties into the energy savings calculations if they were inaccurate or oversimplified. To strike a reasonable balance, we used a consistent process to determine the baseline model attributes, (as discussed in Steps 3 and 4) and introduced a sensitivity analysis process for verifying the attributes that are the most variable across locations, and have the most impact on energy savings estimates.

Many features of a house are either "blind" in the codes and ES (i.e. they are the same in the reference home as they are in the proposed home, such as house size and shape), or they are not defined at all (e.g., dehumidification, furnace efficiency). These features could have a significant effect on nationwide interim energy savings estimates for this project, and were the focus of the sensitivity analysis conducted for this study.

The following steps describe the process used for selecting parameters for the sensitivity analysis. While generally consistent with our original sensitivity analysis plan, this approach included a broader screening process to determine the variables of the most importance, instead of simply relying on engineering judgment to filter out those for which adjustment factors would be developed. The addition of this screening step improved the process by increasing confidence in the model attributes and results.

- **Variable Identification:** Based on experience and consensus within the energy modeling team, we identified 26 variables for an initial sensitivity screening process. These variables included those judged most likely to have a significant impact on nationwide energy savings for the four BA practices. This set of variables focuses primarily on functional and design features of new homes, and did not include energy efficiency measures that are already included in the analysis based on their presence in the IECC and ES.

- **Screening:** We performed initial screening of the 26 variables to determine their impact and viability as part of this study. If a variable met all four of the following criteria, it was analyzed further using BEopt, and adjustment factors were developed:

  Criterion #1. There must be empirical data available over time to allow the application of weighting factors to the energy savings. For example, the IEc team was unable to find a study showing how often crawlspaces are vented, so even if this variable has an impact on energy savings, there was no way to apply the results of the analysis without guessing. National studies such as the Residential Energy Consumption Survey (RECS) and the U.S. Census were the preferred sources of empirical data, but other authoritative sources were used when available. The data must be pre-compiled in a useful format. It is beyond the resources of this study to filter and compile raw data from RECS or the U.S. Census.

Criterion #2. If empirical data were available, the percentage of houses that deviated from the baseline attribute must exceed 10% in at least one climate region, based on the best available reference identified under Criterion #1. Market shares below 10% are unlikely to have a significant influence on nationwide energy savings.

Criterion #3. The energy savings impact must be at least 5% compared to the baseline savings (i.e. 105 MMBtu vs 100 MMBtu, not 10.5% savings compared to 10% savings). To make this determination, we analyzed two or three values of each variable using BEopt in the context of the 2012 IECC version of the Washington DC model, both BA influenced and counterfactual. Because the 2012 IECC included all four BA practices, and the Washington model included significant loads for both heating and cooling, this model gave us the best indication of potential impact nationwide.

Criterion #4. Either the savings must be non-linear relative to the baseline value, or the values must have been non-continuous (number of stories, foundation type). If the savings were linear, the choice of an average baseline value should give reasonably accurate results for total energy savings.

- **Adjustment Factors:** For those building attributes that met all four criteria, we developed adjustment factors for energy savings and weighting factors for market share, to allow state-by-state roll-up of energy savings over time. We calculated adjustment factors using multiple BEopt runs in several climate regions, and adjusted both total energy and energy savings separately for electricity and gas. We derived weighting factors from the literature, primarily the U.S. Census and RECS.

These three screening steps are discussed in more detail below.

Variable Identification

Table 11 summarizes the preliminary list of 26 building attributes included as variables to be screened as part of the sensitivity analysis, along with a brief rationale for attributes that were likely to affect the energy savings results. The IEc team developed the list based on the experience and judgment of the modeling team.

Table 11. Building Attributes Considered as Part of the Sensitivity Analysis

Building Attribute	Reason for Including in Sensitivity Analysis
Location within Climate Region	Heating and cooling loads vary greatly even within a climate region. Since all of the BA practices affect heating and cooling, the savings impact is likely to be large.
Primary Heating Fuel	There is a large split between gas or fuel oil furnaces and air source heat pumps, especially in warmer climates. Site energy use tends to be much smaller for heat pumps, while source energy use is comparable.
Foundation Type	The location of ducts and their thermal environment is heavily dependent on the type of foundation used for the house.
Above Grade Floor Area	Heating and cooling load is directly related to the volume of conditioned space.
Number of Stories	Taller buildings tend to have higher natural infiltration rates for the same leakage area, longer duct runs, and higher window-to-floor area ratios.
A/C efficiency	Direct effect on cooling energy.
Furnace efficiency	Direct effect on heating energy.
Heat pump efficiency	Direct effect on both heating and cooling energy.
Attached units	Attached units tend to reduce the heating and cooling loads, because there is less area exposed to outdoor conditions.
Window to wall ratio	Greater window areas tend to increase both heating and cooling loads, unless part of a passive solar design.
House shape/aspect ratio	Square buildings have the least exposed surface area for the same floor area. More complex shapes tend to have higher envelope loads.
Window distribution	A higher percentage of south-facing windows can result in higher solar heat gains in the winter, reducing the heating load.
Concrete wall construction vs wood frame	Concrete walls can store heat more effectively than wood, reducing heating and cooling loads where there is a large diurnal temperature swing. In addition, the insulation required by code can be very different.
Fraction supply vs return leakage	Supply duct leakage has a larger effect on energy use than leakage in return ducts, because supply air is conditioned.
Roof absorptivity	Lower absorptivity roofs such as white tiles can reduce attic temperatures in the summer, creating a more benign environment for ducts.
Number of bedrooms	Bedrooms are used as a surrogate for occupancy, which affects internal gains and ventilation requirements.
Finished/conditioned basement	Conditioned basements are a more benign environment for ducts, but also increase the volume that must be conditioned.
Unvented crawlspace	Unvented crawlspaces are insulated at the walls, and generally result in milder

	environments for ducts. Heating loads can be higher or lower.
Natural ventilation schedule	More active use of windows in beneficial weather can reduce cooling loads during the summer.
Orientation	Orientation can affect solar heat gains, and consequently heating and cooling loads.
Eave length	Longer eaves can provide beneficial shading during the summer, reducing cooling loads.
Close neighbors (urban)	Nearby houses can provide shading and reduce infiltration rate by providing shielding of wind.
Presence of whole house dehumidification	Dehumidifiers add some space conditioning load while making the house more comfortable.
Tuck-under vs attached garage	Tuck-under garages increase the thermal boundary of the house and complicate insulation.
Fireplace(s)/no fireplace	Wood fireplaces can displace the use of fossil fuels, while potentially increasing air infiltration.
Skylights/no skylights	Skylights can reduce cooling loads and displace electric lighting, but may also increase heating loads.

Screening

The IEc team applied the four screening criteria to all 26 sensitivity variables to identify the ones requiring modeling in additional locations and the use of adjustment factors and weighting factors during nationwide roll-up of interim energy savings. The detailed results are shown in Table 12, and a quick summary is provided in Table 13.

Table 12. Sensitivity Screening Details

Sensitivity Variable	**Criterion 1 Empirical Data Available**	**Criterion 2* >10% Deviation from Baseline**	**Criterion 3** >5% Energy Savings Difference**	**Criterion 4 Non-linear or Non-continuous**
Location within Climate Region	"Cost-Effectiveness Analysis of the Residential Provisions of the 2015 IECC." Pacific Northwest National Laboratory.	>80%	24%	Non-continuous
Primary Heating Fuel	Electric/Gas: "American FactFinder." U.S. Census Bureau. Fuel Oil: "Characteristics of New Housing." U.S. Census Bureau.	4%-92% (electric); 0%-10% (fuel oil)	65%	Non-continuous
Foundation Type	"Cost-Effectiveness Analysis of the Residential Provisions of the 2015 IECC." Pacific Northwest National Laboratory.	20%-50%	44%	Non-continuous
Above Grade Floor Area	"Characteristics of New Housing." U.S. Census Bureau.	72%-76%	44%	Linear
Number of Stories	"2009 DOE Residential Energy Consumption Survey." U.S. Department of Energy	15%-40%	60%	Non-linear
A/C efficiency	Code of Federal Regulations, Title 10, Part 430, Subpart C.	15%	2.2%	
Furnace efficiency	Code of Federal Regulations, Title 10, Part 430, Subpart C.	20%	12%	Linear
Heat pump efficiency	Code of Federal Regulations, Title 10, Part 430, Subpart C.	20%	36%	Non-linear
Attached units	"American FactFinder." U.S. Census Bureau.	18%-88%	26%	Non-continuous
Window to wall ratio	No reference found.			
House shape/aspect ratio	No reference found.			
Window distribution	No reference found.			

Sensitivity Variable	Criterion 1 Empirical Data Available	Criterion 2* >10% Deviation from Baseline	Criterion 3** >5% Energy Savings Difference	Criterion 4 Non-linear or Non-continuous
Concrete wall construction vs wood frame	"Characteristics of New Housing." U.S. Census Bureau.	0%-13%	22%	Non-continuous
Fraction supply vs return leakage	No reference found.			
Roof absorptivity	"2009 DOE Residential Energy Consumption Survey." U.S. Department of Energy	1%-23%	1.6%	
Number of bedrooms	"Characteristics of New Housing." U.S. Census Bureau.	45%-60%	4.3%	
Finished/conditioned basement	"Cost-Effectiveness Analysis of the Residential Provisions of the 2015 IECC." Pacific Northwest National Laboratory.	20%-75%	13%	Non-continuous
Unvented crawlspace	No reference found.			
Natural ventilation schedule	No reference found.			
Orientation	Estimated 25% in each cardinal orientation.	25%	3.9%	
Eave length	No reference found.			
Close neighbors (urban)	"2009 DOE Residential Energy Consumption Survey." U.S. Department of Energy	57%	6.7%	Non-continuous
Presence of whole house dehumidification	"2009 DOE Residential Energy Consumption Survey." U.S. Department of Energy	2%-24%	0.1%	
Tuck-under vs attached garage	No reference found.			
Fireplace(s)/no fireplace	"2009 DOE Residential Energy Consumption Survey." U.S. Department of Energy	1%-2%		
Skylights/no skylights	No reference found.			

* Range of deviation for states or climate regions.

** Maximum deviation from baseline energy savings for alternative attributes.

Table 13. Sensitivity Screening Results Summary

Green Cell: Meets all four criteria.
Pink Cell: Fails one or more criteria.

Sensitivity Variable	Criterion 1	Criterion 2	Criterion 3	Criterion 4
Location within Climate Region	✓	✓	✓	✓
Primary Heating Fuel	✓	✓	✓	✓
Foundation Type	✓	✓	✓	✓
Above Grade Floor Area*	✓	✓	✓	X
Number of Stories	✓	✓	✓	✓
A/C efficiency	✓	✓	X	
Furnace efficiency**	✓	✓	✓	X
Heat pump efficiency	✓	✓	✓	✓
Attached units	✓	✓	✓	✓
Window to wall ratio	X			
House shape/aspect ratio	X			
Window distribution	X			
Concrete wall construction vs wood frame	✓	✓	✓	✓
Fraction supply vs return leakage	X			
Roof absorptivity	✓	✓	X	
Number of bedrooms	✓	✓	X	
Finished/conditioned basement	✓	✓	✓	✓
Unvented crawlspace	X			
Natural ventilation schedule	X			
Orientation	✓	✓	X	
Eave length	X			
Close neighbors	✓	✓	✓	✓
Presence of whole house dehumidification	✓	✓	X	
Tuck-under vs attached garage	X			

Fireplace(s)/no fireplace	✓	X		
Skylights/no skylights	X			

* Adjustment factors are needed to convert the baseline energy savings to that of the regional average floor area. Only the average floor area is needed within each region, not the distribution of floor area, because the effect on energy savings is linear.

** Adjustment factors are needed to adjust energy savings based on equipment standard changes, but it is assumed that minimally efficient furnaces dominate the market for new construction.

The modeled site energy savings impacts used as the basis for Criterion 3 are shown in graphical form in Figures 3-7.

Figure 3. Sensitivity Analysis Part 1

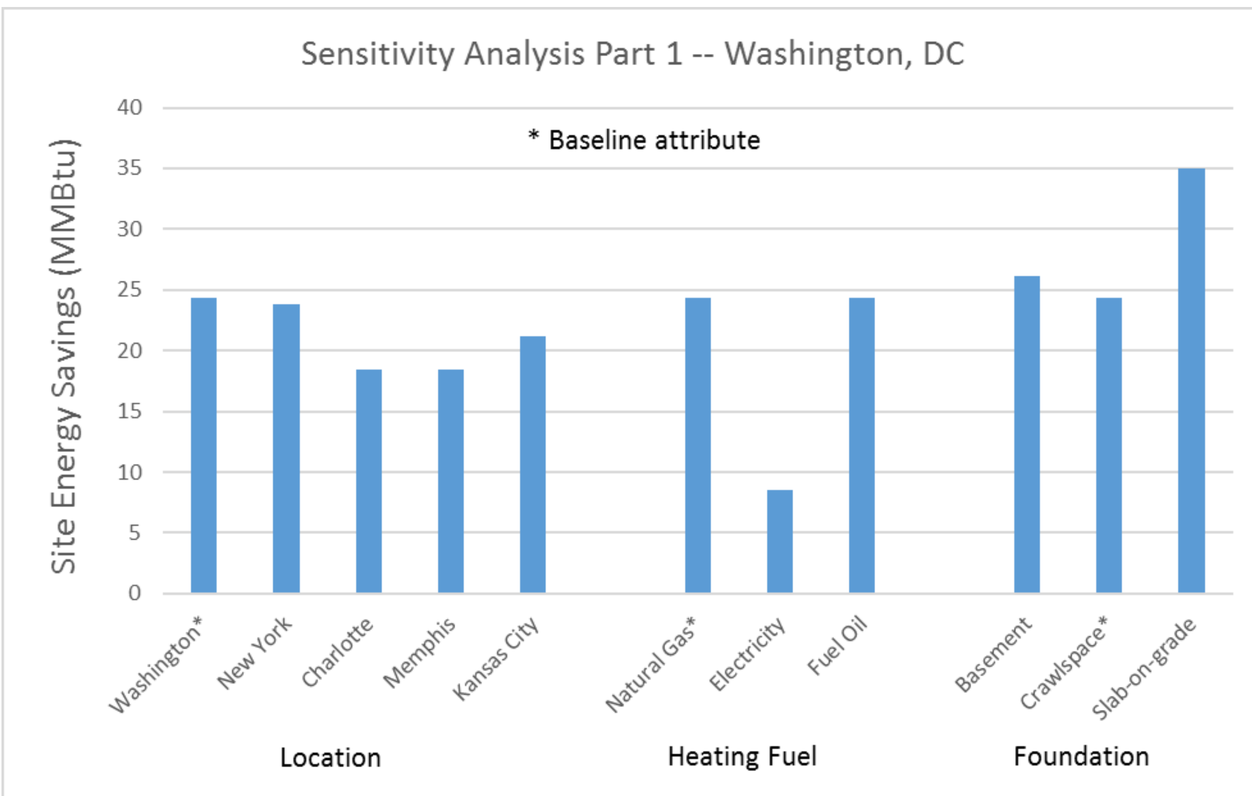


Figure 4. Sensitivity Analysis Part 2

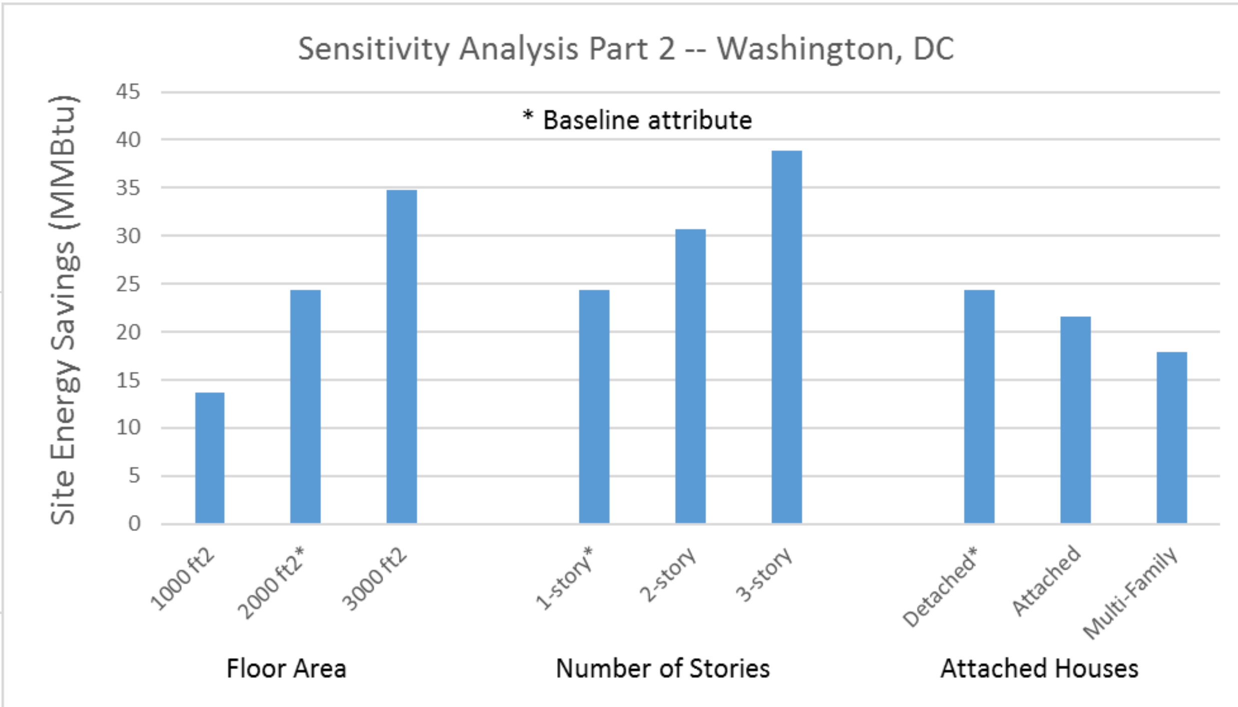
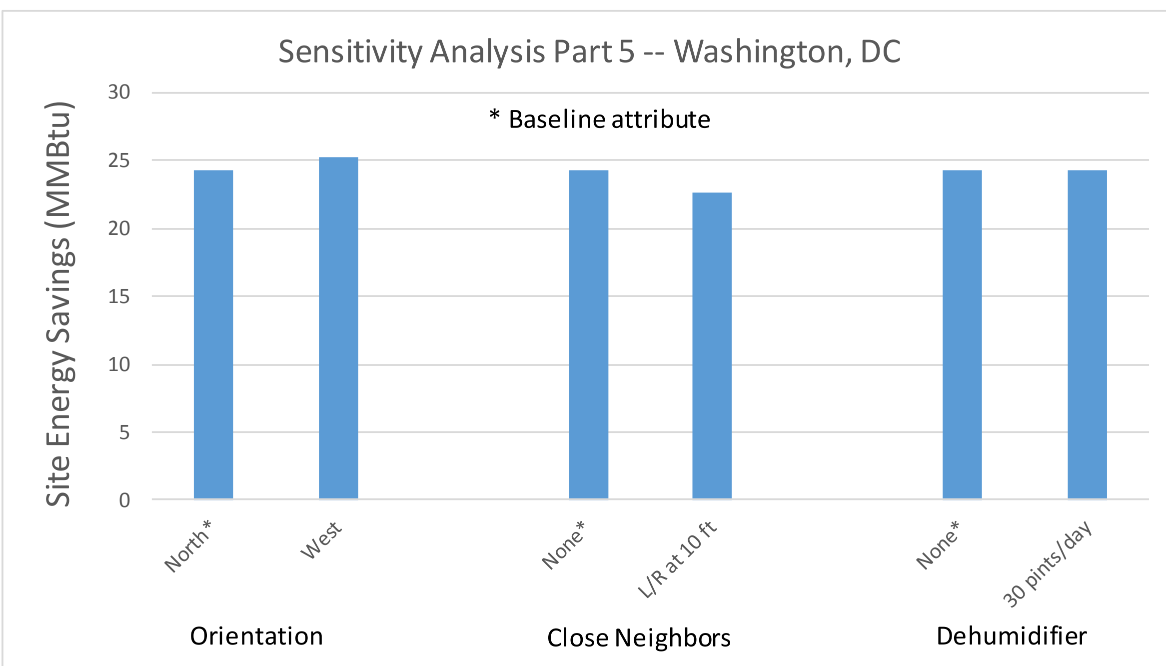


Figure 7. Sensitivity Analysis Part 5



Adjustment Factors

For those sensitivity variables meeting all four criteria, we developed adjustment factors to modify the baseline energy use and savings to make them more fully representative of the new housing stock. Most of the variables required four basic adjustments to create accurate results:

1. BA-influenced total electricity multiplier
2. BA-influenced total other fuel multiplier (gas/fuel oil)
3. Electricity savings multiplier
4. Other fuel savings multiplier

In some cases, we averaged these four multipliers across three locations (Chicago, Washington, and Houston) when the values were fairly similar. In other cases, we used three separate sets of multipliers depending on climate region, with Marine combined with Mixed-Humid, and Hot-Dry/Mixed-Dry combined with Hot-Humid. An example set of adjustment factors is shown in Table 14.

Table 14. Adjustment Factors for Foundation Type

Location	Foundation Type	Electricity Savings Multiplier	Other Fuel Savings Multiplier	BA-Influenced Electricity Multiplier	BA-Influenced Other Fuel Multiplier
Detroit	Unconditioned Basement*	1.00	1.00	1.00	1.00
	Conditioned Basement	0.66	0.91	1.29	1.01
	Crawlspace	0.95	0.75	1.03	1.04
	Slab-on-grade	1.62	1.22	1.00	1.01
Washington	Unconditioned Basement	0.96	1.08	0.96	0.98
	Conditioned Basement	0.70	0.95	1.24	1.01
	Crawlspace*	1.00	1.00	1.00	1.00
	Slab-on-grade	1.25	1.45	0.97	0.94
Houston	Unconditioned Basement	0.71	0.87	1.00	1.08
	Conditioned Basement	0.40	0.69	1.28	1.20
	Crawlspace	0.80	0.83	1.02	1.04
	Slab-on-grade*	1.00	1.00	1.00	1.00

* Baseline model characteristic

An additional level of detail was required for geographic location within a climate region, because multiple weather characteristics influenced energy savings. We generated curve fits relative to each baseline location using the linear regression function in Microsoft Excel. As a result, adjustments to energy use are based on the deviation of weather conditions from the baseline location, not a simple multiplier.

Finally, we developed weighting factors using the references identified in Table 12. Whenever possible, we calculated these factors separately for every state and climate region combination. In some cases, the empirical data were not sufficiently refined, and state groupings were necessary.

Special Case: Mechanical Ventilation

The IEc team did not include whole house mechanical ventilation in the sensitivity screening process because while ventilation is sometimes viewed as an energy efficiency measure linked to tighter building envelopes, it is actually a health and comfort measure that increases energy use. Historically, both the IECC and ES have been ambiguous about recommending mechanical ventilation—even when the envelope is tight—creating some difficulty in determining whether ventilation is commonly implemented in code-compliant and ES homes. Consequently, there was some question about whether mechanical ventilation should be included in the counterfactual BEopt models for this project. As ventilation systems have become more common in recent years, it is clearer that ASHRAE Standard 62.2 ventilation rates are recommended for all new houses. A closer examination of the options for modeling mechanical ventilation in the context of this project was needed to determine the most appropriate approach.

First, we examined the approaches for modeling ventilation in the reference home for several programs:

- IECC 2012: For the performance path, no ventilation unless present in the proposed design. It does not appear that ventilation is mandatory in the prescriptive path, but when it is provided, the ventilation rate must be at least 60 cfm. There is no specified ventilation rate for the reference home in the performance path, but ventilation fan energy is defined in a format similar to ASHRAE 62.2.
- Home Energy Rating System (HERS): No ventilation unless present in the proposed design. There are no minimum requirements for the proposed design, primarily because HERS is a rating program, not a certification program. Again, no ventilation rate is specified.
- ES Version 3: Uses the HERS guidelines for modeling, but ventilation according to ASHRAE 62.2 - 2010 is mandatory for the proposed home. No ventilation rate for the reference home is provided.
- BA HSP: For the reference home (Benchmark), ventilation rate should be as required by ASHRAE 62.2 - 2010. This was our approach for all BA-influenced cases.

All of these codes and programs except BA avoided a clear rule for the reference home ventilation rate, but given the passionate debates that surrounded ventilation in the high performance building industry, perhaps it is not surprising. The rules for most programs could be reasonably interpreted as implying either the same rate as the proposed design, or the minimum required by ASHRAE 62.2. However, it is clear that all of the programs include mechanical ventilation in the reference home when present in the proposed design.

Time-series data on the installation of mechanical ventilation in new homes were not available to alleviate this confusion. Thus, for the modeling effort used in this project, we considered three viable approaches to modeling mechanical ventilation:

1. Use 0.35 ACH natural infiltration as the cut-off point for mechanical ventilation, based on IECC 2000-2009, where no savings due to infiltration reduction was allowed below 0.35 ACH. The ventilation rate in the models would be as specified by ASHRAE 62.2-2010. The logic behind this approach is that below an infiltration rate of 0.35 ACH, mechanical ventilation would be needed to ensure health and comfort. An additional justification for this cut-off point is that ASHRAE 62.2-2010 uses a 2 cfm/100 ft^2 infiltration credit, which when combined with the required ventilation rate results in a total ACH of about 0.35 ACH. However, this approach has the potential for penalizing BA when infiltration is reduced from just above 0.35 ACH to just below, because the ventilation rate (50 cfm, or 0.15 ACH for the baseline models) increases the space conditioning load more than the tighter building envelope reduces it.

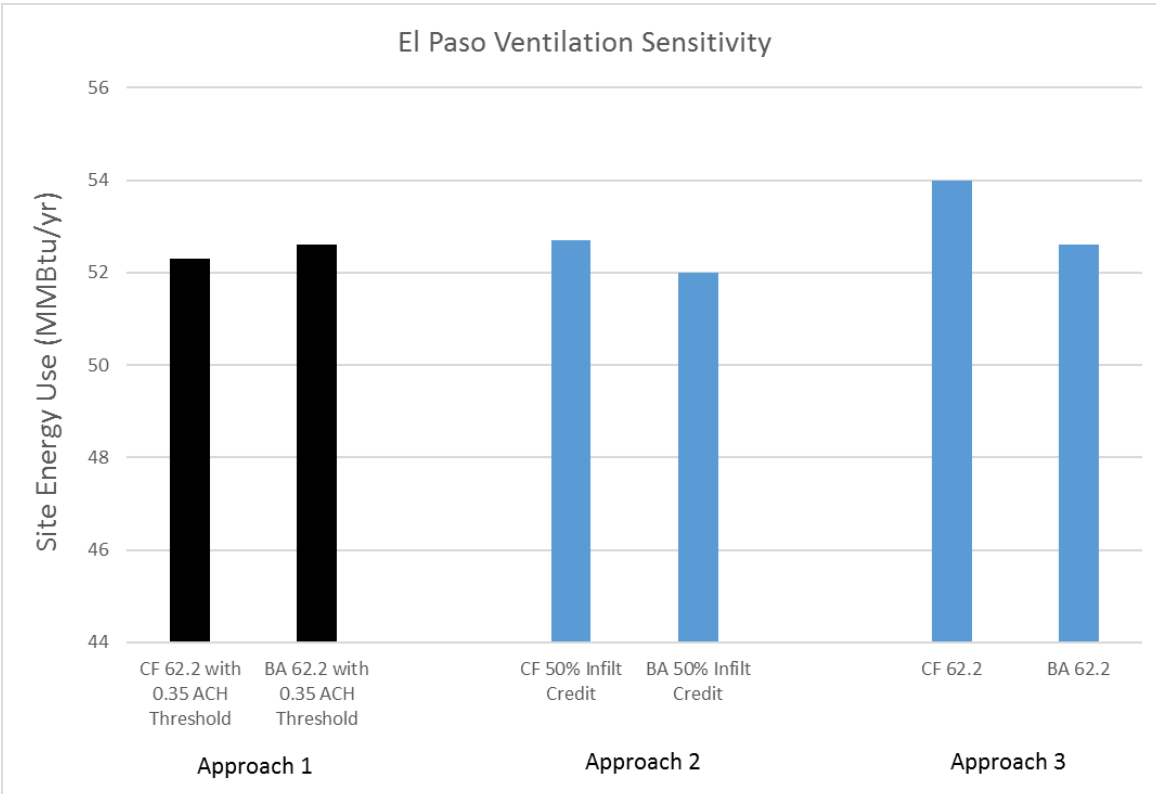
2. Include mechanical ventilation only at the level necessary to increase the annual average ACH to about 0.35 using the same 50% credit used in ASHRAE 62.2-2010 when an existing home is leakier than the allotted 2 cfm/100 ft^2. For consistency, we would increase the ventilation rate in the models for houses tighter than 2 cfm/100 ft^2. (It should be noted that ASHRAE 62.2-2010 only allows for a lower ventilation rate for existing houses that are leakier than the allotted 2 cfm/100 ft^2. The credit cannot be applied to new houses, but it is unclear how this distinction is technically justified.) Applying this approach to our project would eliminate the potential problem of an abrupt increase in energy use for ventilation when infiltration drops below 0.35 ACH. However, it would create some additional modeling difficulties, because a large number of new BEopt options for ventilation rate would need to be added and assigned to the various cases.

3. Include mechanical ventilation in all cases. Many building scientists argue that infiltration should never be relied upon to provide adequate fresh air, because there will be periods of mild weather with minimal infiltration even in leaky houses. There are also issues of the path traveled by outside air entering through infiltration, and whether it is truly fresh air by the time it enters the living space. The most recent version of ASHRAE 62.2 (2013) eliminated the infiltration credit and increased the ventilation rate, suggesting that a minimum amount of mechanical ventilation is required for all houses regardless of natural infiltration.

The modeling results associated with these three approaches, as applied to the 2006 IECC baseline in El Paso, are shown in Figure 8, as an example. We chose this scenario because reduced infiltration (BA

Practice 1) is the only difference between the BA influenced and counterfactual cases, and the reduction in infiltration rate is relatively small. The data points shaded in black represent Approach 1, where the ventilation energy penalty outweighs the infiltration reduction.

Figure 8. Ventilation sensitivity analysis in El Paso.



The IEc team decided to proceed with Approach 3, based on the simplification that all BA-influenced and counterfactual homes are ventilated in accordance with the guidelines in ASHRAE 62.2-2010. There are two primary reasons for this recommendation:

1. It is consistent with the established approach to determine modeling attributes, first using the IECC prescriptive path, then the IECC performance path reference home, and finally the reference home from the BA HSP. Because the IECC does not specify a minimum ventilation rate in either the prescriptive or performance path until 2012, the HSP methodology would be the next place to look. The HSP specifies that the reference home should have mechanical ventilation meeting the requirements of ASHRAE 62.2-2010.

2. ASHRAE does not qualify the ventilation rates for new homes based on the natural infiltration rate. The logic is that even leaky homes will have long periods of low infiltration during mild

weather, and it is important to introduce a base level of fresh air to ensure health and comfort. Because ASHRAE 62.2 was published in 2003, before the period of interest for our study, it is assumed that most builders of code-compliant houses adopted its recommendations as good practice for new home construction prior to the start of our evaluation period (2006-2015).

Sensitivity Analysis Results

The sensitivity analysis yielded nine variables for which variations across states and climate regions required adjustment during post-processing of the modeling results in order to accurately roll up energy savings for BA impacts nationwide. It did not appear that an expanded matrix of modeling runs was necessary to provide greater accuracy, if the following three assumptions could be made:

1. The adjustment factors would not vary significantly if code versions other than IECC 2012 were used.
2. The energy savings for each of the four BA practices are affected in approximately the same way by the sensitivity variables.
3. The sensitivity variables are reasonably independent in terms of their impact on energy savings. Although there are some interactive effects between building attributes, it would be impractical to model all combinations in all climates for each version of the code or ES.

Because most of the important drivers of space conditioning load were either included in the four BA practices or in the nine sensitivity variables, and because there were no other energy impacts of the BA practices beyond space conditioning, it seemed reasonable to accept the three assumptions and proceed to the nationwide energy savings analysis with confidence in the results.

Step 6: Create A Detailed Matrix Of Scenarios For Modeling

The IEc team developed a complete matrix of simulation runs to ensure all important scenarios were included in the analysis. In the end, 130 unique BEopt runs were required for the primary set of cases to be rolled up nationwide (5 climate zones X 7 reference codes X 6 combinations of BA practices – 80 duplicate or irrelevant cases). An additional 79 runs were needed for the sensitivity analysis, as discussed under Step 5. The final matrix of primary BEopt runs is shown in Table 15, with irrelevant and redundant cases highlighted in gray. This matrix documents the minimum number of BEopt runs necessary to provide complete results for all scenarios listed in Table 5, including the various time periods and code adoption rates. In some instances, two cases were identical from a modeling standpoint, and only one run was run using BEopt, even though both cases are needed in the final roll-up.

Table 15. Matrix of BEopt Simulations for Each Location, with Individual Measure Attribution

NOMINAL CODE	EFFICIENCY LEVEL	CHICAGO	WASHINGTON	HOUSTON	EL PASO	PORTLAND
IECC 2012	Counterfactual Home	✓	✓	✓	✓	✓
	BA Influenced Code	✓	✓	✓	✓	✓
	Practice 1	✓	✓	✓	✓	✓
	Practice 2	✓	✓	✓	✓	✓
	Practice 3	✓	✓	✓	✓	✓
	Practice 4	✓	✓	✓	✓	✓
IECC 2009	Counterfactual Home	✓	✓	✓	✓	✓
	BA Influenced Code	✓	✓	✓	✓	✓
	Practice 1	✓	✓	✓	✓	✓
	Practice 2	✓	✓	✓	✓	✓
	Practice 3		✓	✓		✓
IECC 2006	Counterfactual Home	✓	✓	✓	✓	✓
	BA Influenced Code	✓	✓	✓	✓	✓
	Practice 1		✓	✓		✓
	Practice 3		✓	✓		✓
IECC 2003	Counterfactual Home / BA Influenced Code	✓	✓	✓	✓	✓
IECC 2000	Counterfactual Home / BA Influenced Code	✓	✓	✓	✓	✓
Energy Star 2.0	Counterfactual ES Home	✓	✓	✓	✓	✓
	BA Influenced ES	✓	✓	✓	✓	✓
	Practice 1	✓	✓	✓	✓	✓
	Practice 2	✓	✓	✓	✓	✓
	Practice 3		✓	✓		✓
Energy Star 3.0	Counterfactual ES Home	✓	✓	✓	✓	✓
	BA Influenced ES	✓	✓	✓	✓	✓
	Practice 1	✓	✓	✓	✓	✓
	Practice 2	✓	✓	✓	✓	✓
	Practice 3		✓	✓		✓
	Practice 4	✓	✓	✓	✓	✓

Step 7: Run All Simulations

The IEc team generated and ran all the BEopt input files in a series of batch runs using the BEopt interface. All BEopt input and output files are available for review.

The key results of the baseline modeling runs for the five primary locations are summarized in Figures 9-13. All results are expressed in terms of site energy, which provides the flexibility to calculate either source energy or energy cost during later stages of the BA impact evaluation process.

Figure 9. Modeling Results for the Detroit Baseline Cases

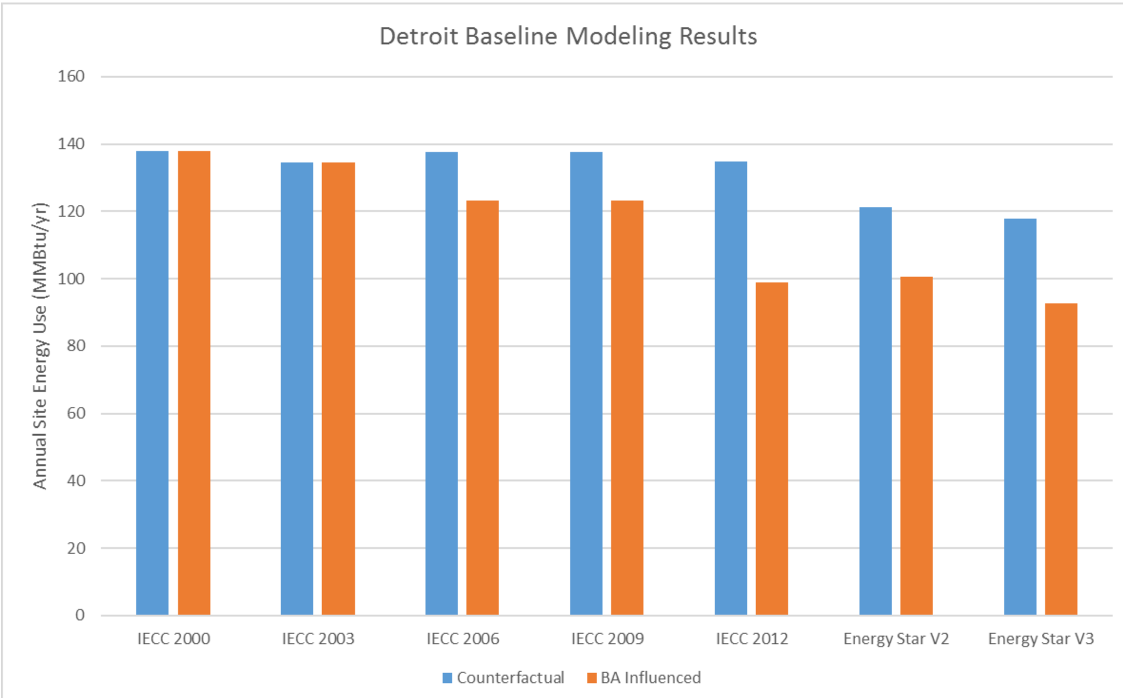


Figure 10. Modeling Results for the Washington DC Baseline Cases

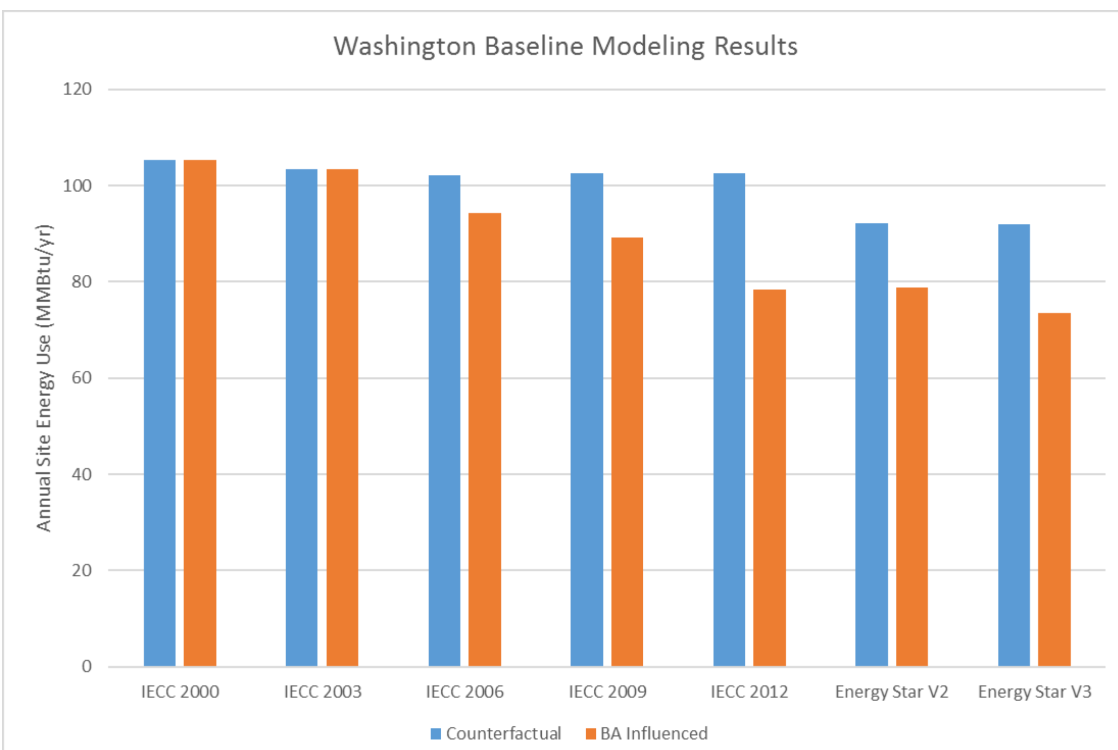


Figure 11. Modeling Results for the Houston Baseline Cases

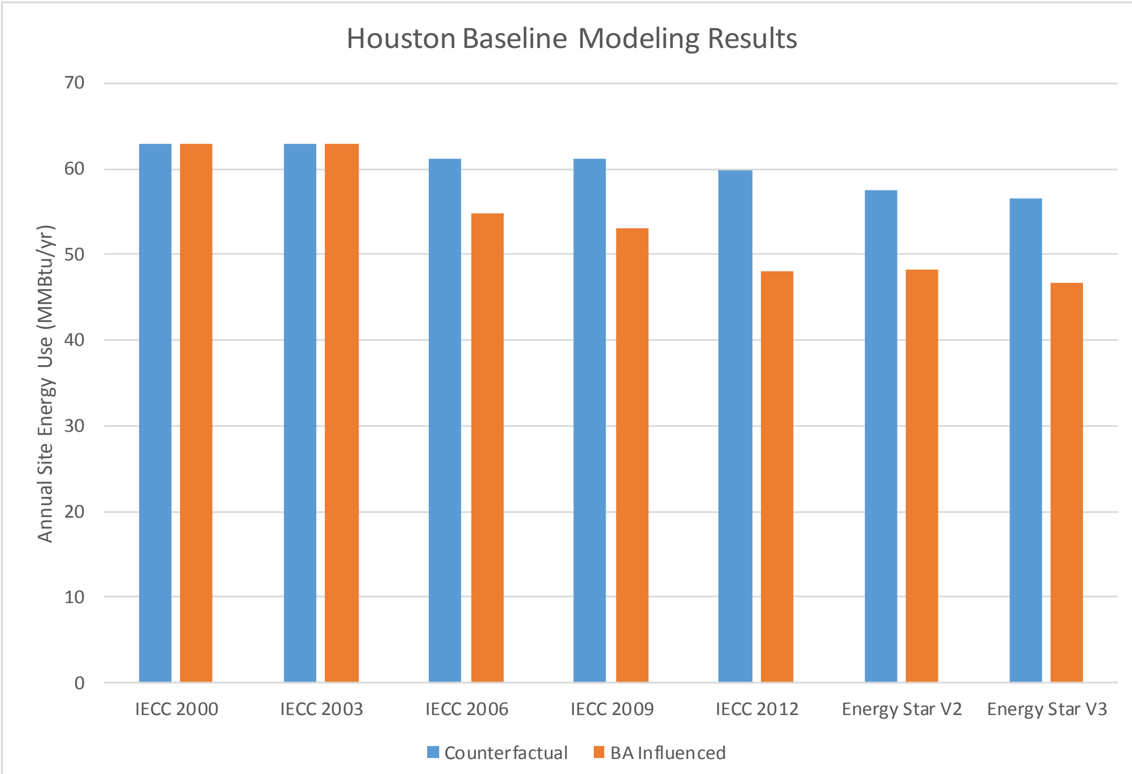


Figure 12. Modeling Results for the El Paso Baseline Cases

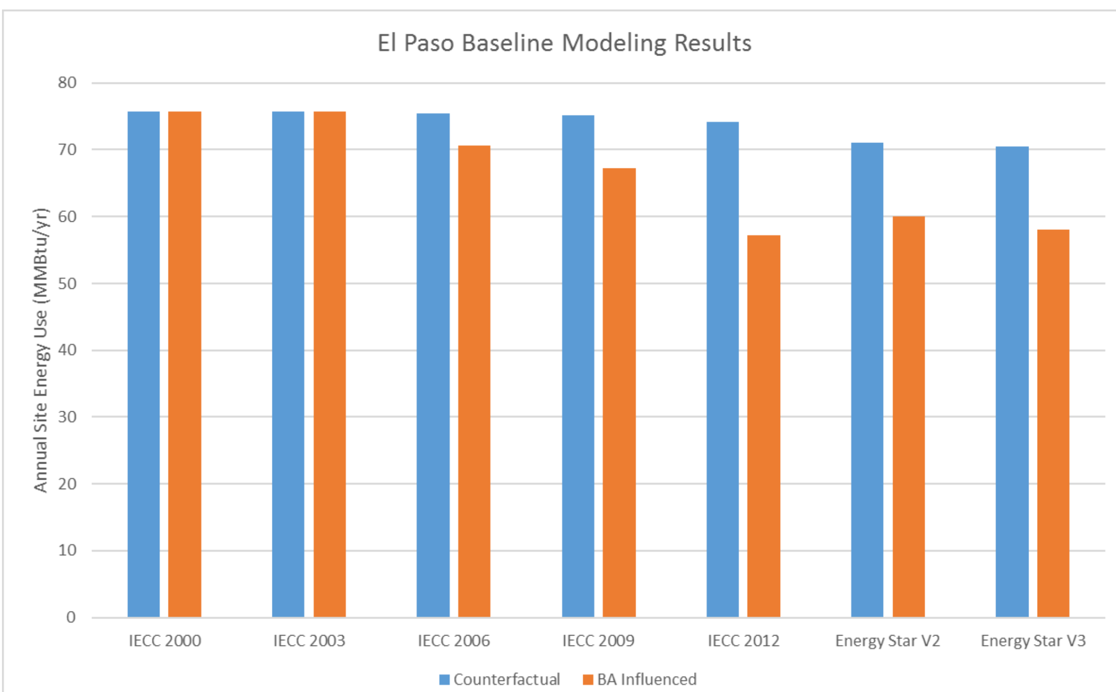
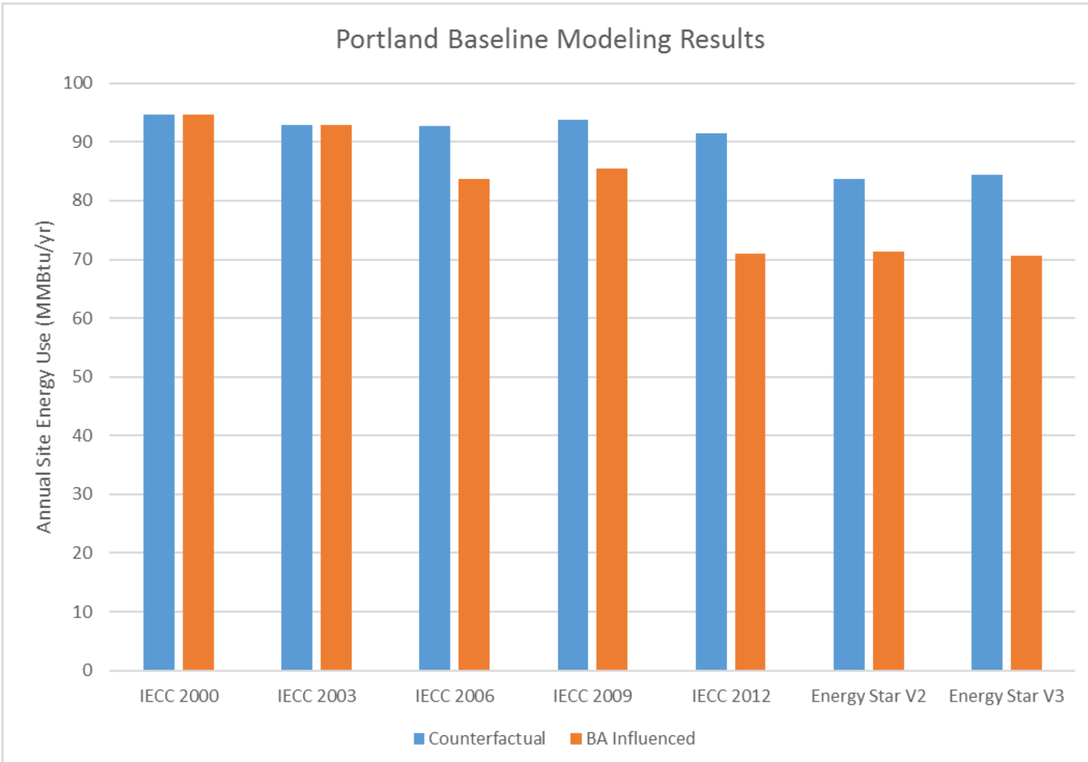


Figure 13. Modeling Results for the Portland Baseline Cases



Step 8: Postprocessing

A post-processing spreadsheet further refined the modeling output by applying adjustment factors generated as part of the sensitivity analysis to expand the dataset beyond the original 130 runs to all state/climate combinations (78 not including California) and all time periods. We applied weighting factors when analyzing energy use across each state to reflect the correct mix of house sizes, foundation types, heating fuels, and other attributes. The spreadsheet also included detailed energy savings estimates, which we then rolled up on a nationwide scale based on the number of housing starts and ES market penetration, as applicable, in each state during the relevant time period.

Table 16 summarizes the basic characteristics of the 78 representative cities used for the state level roll-up. The selected cities represent the most populous cities within each combination of state and climate region based on U.S. Census data. Because the locations within which houses were built in each state during our study period were not known, we used existing population as a reasonable proxy, but it is possible that there were high growth areas that differed from census data on population demographics. We assumed that weather differences within these state-level climate regions are small enough that any variation introduced by choosing a single high-population city roughly cancel out when averaged across 78 locations. The weighting factors for building attributes within each state/climate combination are summarized in Table 17. To the extent possible, we used state-level data from the U.S. Census, but for some attributes regional data from U.S. Census Characteristics of New Housing or the DOE Residential

Energy Consumption Survey (RECS) provided the best available data source. We only provided weighting factors (equivalent to percent market penetration) for non-baseline attributes. Baseline weighting factors are implied, and would be calculated as 100% minus the weighting factor(s) for non-baseline attributes.

Table 16. Representative Cities in Each State/Climate Combination

State	City	Climate Region	% of State[35]	HDD/yr[36]	CDD/yr[37]	Rainfall (in/yr)[38]
Alabama	Montgomery	Hot Humid	36%	2149	2320	52.3
Alabama	Birmingham	Mixed Humid	64%	2653	2014	54.5
Alaska	Anchorage	Cold/Very Cold/Subarctic	100%	10121	5	15.9
Arizona	Phoenix	Hot-Dry/Mixed-Dry	97%	923	4626	7.7
Arizona	Flagstaff	Cold/Very Cold/Subarctic	3%	6830	123	22.8
Arkansas	Little Rock	Mixed Humid	99%	3108	2069	49.3
Arkansas	Texarkana	Hot Humid	1%	2440	2335	44.5
Colorado	Denver	Cold/Very Cold/Subarctic	99%	5667	721	15.4
Colorado	Trinidad	Hot-Dry/Mixed-Dry	1%	5342	753	15.3
Connecticut	Bridgeport	Cold/Very Cold/Subarctic	100%	5274	830	41.6
Delaware	Wilmington	Mixed Humid	100%	4756	1142	41.4
District of Columbia	Washington	Mixed Humid	100%	3996	1555	38.6

[35] Pacific Northwest National Laboratory. "Cost-Effectiveness Analysis of the Residential Provisions of the 2015 IECC." https://www.energycodes.gov/development/residential/iecc_analysis#table. (Exceptions for % Construction: Oregon and Washington, for which the PNNL analysis was not performed; New York, where the multi-family distribution skews the results; and Texas, Oklahoma, Louisiana, and Colorado where the percentage for one climate was rounded to 0%. For these states, the number of housing units in each climate region from the 2010 Census was used to estimate the weighting factor.)
[36] ASHRAE Fundamentals Handbook 2013.
[37] Ibid.
[38] Ibid.

State	City	Climate Region	% of State[35]	HDD/yr[36]	CDD/yr[37]	Rainfall (in/yr)[38]
Florida	Jacksonville	Hot Humid	100%	1327	2632	51.3
Georgia	Atlanta	Mixed Humid	70%	2671	1893	50.8
Georgia	Savannah	Hot Humid	30%	1761	2455	49.2
Hawaii	Honolulu	Hot Humid	100%	0	4679	22
Idaho	Boise	Cold/Very Cold/Subarctic	100%	5453	957	12.1
Illinois	Chicago	Cold/Very Cold/Subarctic	77%	5872	1034	36.5
Illinois	Belleville	Mixed Humid	23%	4579	1401	37.1
Indiana	Indianapolis	Cold/Very Cold/Subarctic	80%	5272	1087	39.9
Indiana	Evansville	Mixed Humid	20%	4424	1437	43.1
Iowa	Des Moines	Cold/Very Cold/Subarctic	100%	6172	1034	33.1
Kansas	Wichita	Mixed Humid	99%	4464	1682	29.3
Kansas	Hays	Cold/Very Cold/Subarctic	1%	5398	1346	21.8
Kentucky	Louisville	Mixed Humid	100%	4109	1572	44.4
Louisiana	New Orleans	Hot Humid	99%	1286	2925	61.9
Louisiana	Bastrop	Mixed Humid	1%	2189	2462	53
Maine	Portland	Cold/Very Cold/Subarctic	100%	7023	370	44.3
Maryland	Baltimore	Mixed Humid	99%	4552	1261	41.4
Maryland	Mountain Lake Park	Cold/Very Cold/Subarctic	1%	5063	848	41.2
Massachusetts	Boston	Cold/Very Cold/Subarctic	100%	5596	750	41.5
Michigan	Detroit	Cold/Very Cold/Subarctic	100%	6103	807	32.6

State	City	Climate Region	% of State[35]	HDD/yr[36]	CDD/yr[37]	Rainfall (in/yr)[38]
Minnesota	Minneapolis	Cold/Very Cold/Subarctic	100%	7472	765	28.3
Mississippi	Jackson	Hot Humid	60%	2282	2294	55.2
Mississippi	Southaven	Mixed Humid	40%	2898	2253	52.1
Missouri	Kansas City	Mixed Humid	97%	5012	1372	37.8
Missouri	St. Joseph	Cold/Very Cold/Subarctic	3%	5292	1251	35.4
Montana	Billings	Cold/Very Cold/Subarctic	100%	6705	630	14
Nebraska	Omaha	Cold/Very Cold/Subarctic	100%	6025	1132	29.9
Nevada	Las Vegas	Hot-Dry/Mixed-Dry	86%	2015	3486	4.1
Nevada	Reno	Cold/Very Cold/Subarctic	14%	5043	791	7.5
New Hampshire	Manchester	Cold/Very Cold/Subarctic	100%	6214	730	39.3
New Jersey	Newark	Mixed Humid	68%	4687	1257	43.7
New Jersey	Paterson	Cold/Very Cold/Subarctic	32%	4996	1050	47.2
New Mexico	Albuquerque	Hot-Dry/Mixed-Dry	71%	3994	1370	8.9
New Mexico	Santa Fe	Cold/Very Cold/Subarctic	29%	5339	637	14
New York	New York City	Mixed Humid	59%	4843	984	41.6
New York	Buffalo	Cold/Very Cold/Subarctic	41%	6508	563	38.8
North Carolina	Charlotte	Mixed Humid	84%	3065	1713	43.1
North Carolina	Boone	Cold/Very Cold/Subarctic	2%	4740	556	48.3
North Carolina	Wilmington	Hot Humid	14%	2444	2030	54.3
North Dakota	Fargo	Cold/Very Cold/Subarctic	100%	8729	555	21.2
Ohio	Columbus	Cold/Very Cold/Subarctic	91%	5255	1015	38.1

State	City	Climate Region	% of State[35]	HDD/yr[36]	CDD/yr[37]	Rainfall (in/yr)[38]
Ohio	Cincinnati	Mixed Humid	9%	4744	1155	41.1
Oklahoma	Oklahoma City	Mixed Humid	99%	3438	1950	34.1
Oklahoma	Guymon	Hot-Dry/Mixed-Dry	1%	3586	1896	20.4
Oregon	Portland	Marine	78%	4214	433	36.3
Oregon	Bend	Cold/Very Cold/Subarctic	22%	6470	237	8.3
Pennsylvania	Philadelphia	Mixed Humid	23%	4512	1332	41.4
Pennsylvania	Pittsburgh	Cold/Very Cold/Subarctic	77%	5583	782	36.9
Rhode Island	Providence	Cold/Very Cold/Subarctic	100%	5562	743	45.5
South Carolina	Columbia	Mixed Humid	63%	2500	2166	49.8
South Carolina	Charleston	Hot Humid	37%	1880	2357	51.5
South Dakota	Sioux Falls	Cold/Very Cold/Subarctic	100%	7470	745	23.9
Tennessee	Memphis	Mixed Humid	100%	2898	2253	52.1
Texas	Houston	Hot Humid	87%	1371	3059	49.7
Texas	El Paso	Hot-Dry/Mixed-Dry	10%	2383	2379	8.8
Texas	Wichita Falls	Mixed Humid	2%	2811	2456	28.5
Utah	Salt Lake City	Cold/Very Cold/Subarctic	87%	5507	1218	16.2
Utah	St. George	Hot-Dry/Mixed-Dry	13%	2971	2735	8.1
Vermont	Burlington	Cold/Very Cold/Subarctic	100%	7352	505	34.5
Virginia	Virginia Beach	Mixed Humid	100%	3308	1569	44.2
Washington	Seattle	Marine	77%	4320	264	37.2
Washington	Spokane	Cold/Very Cold/Subarctic	23%	6627	434	16.5

State	City	Climate Region	% of State[35]	HDD/yr[36]	CDD/yr[37]	Rainfall (in/yr)[38]
West Virginia	Charleston	Mixed Humid	63%	4444	1076	42.5
West Virginia	Morgantown	Cold/Very Cold/Subarctic	37%	5063	848	41.2
Wisconsin	Milwaukee	Cold/Very Cold/Subarctic	100%	6684	690	32.9
Wyoming	Cheyenne	Cold/Very Cold/Subarctic	100%	7050	338	14.5

Table 17. Weighting Factors for Representative Cities

State	City	% Electric Heating[39]	% Oil Heating[40]	% Conditioned Basement[41]	% Crawl-space[42]	% Slab[43]	Avg Floor Area (ft^2)[44]	% Two Story[45]	% Three Story[46]	% Attached[47]	% Multi-Family[48]	% Concrete[49]	% Urban[50]
Alabama	Montgomery	64%	0%	9%	37%	44%	2215	14%	1%	2%	16%	10%	54%
Alabama	Birmingham	64%	0%	9%	37%	44%	2215	31%	2%	2%	16%	10%	50%
Alaska	Anchorage	12%	0%	9%	51%	37%	2095	38%	2%	8%	24%	0%	56%
Arizona	Phoenix	60%	0%	1%	6%	91%	2095	16%	1%	5%	21%	0%	64%
Arizona	Flagstaff	60%	0%	1%	6%	91%	2095	38%	2%	5%	21%	0%	56%
Arkansas	Little Rock	48%	0%	1%	30%	67%	2215	31%	2%	2%	16%	10%	50%
Arkansas	Texarkana	48%	0%	1%	30%	67%	2215	14%	1%	2%	16%	10%	54%
Colorado	Denver	21%	0%	28%	31%	31%	2095	38%	2%	7%	26%	0%	56%
Colorado	Trinidad	21%	0%	28%	31%	31%	2095	16%	1%	7%	26%	0%	64%
Connecticut	Bridgeport	16%	10%	24%	14%	17%	2051	38%	2%	5%	35%	1%	56%
Delaware	Wilmington	34%	0%	31%	23%	28%	2215	31%	2%	15%	18%	10%	50%
District of Columbia	Washington	40%	0%	31%	23%	28%	2215	31%	2%	25%	63%	10%	50%

39 U.S. Census. American FactFinder, 2014. http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml
40 U.S. Census. Characteristics of New Housing. https://www.census.gov/construction/chars/completed.html
41 Pacific Northwest National Laboratory. "Cost-Effectiveness Analysis of the Residential Provisions of the 2015 IECC." https://www.energycodes.gov/development/residential/iecc_analysis#table. (Exceptions for foundation type: Oregon, Washington, and Tennessee, for which PNNL analysis was not available. Instead, RECS data for the corresponding climate region was used.)
42 Ibid.
43 Ibid.
44 2009 DOE Residential Energy Consumption Survey. http://www.eia.gov/consumption/residential/data/2009/#structural
45 Ibid.
46 Ibid.
47 U.S. Census. American FactFinder, 2014. http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml
48 Ibid.
49 U.S. Census. Characteristics of New Housing. https://www.census.gov/construction/chars/completed.html
50 2009 DOE Residential Energy Consumption Survey. http://www.eia.gov/consumption/residential/data/2009/#structural

State	City	% Electric Heating[39]	% Oil Heating[40]	% Conditioned Basement[41]	% Crawlspace[42]	% Slab[43]	Avg Floor Area (ft^2)[44]	% Two Story[45]	% Three Story[46]	% Attached[47]	% Multi-Family[48]	% Concrete[49]	% Urban[50]
Florida	Jacksonville	92%	0%	0%	12%	88%	2215	14%	1%	6%	30%	10%	54%
Georgia	Atlanta	53%	0%	7%	27%	57%	2215	31%	2%	4%	21%	10%	50%
Georgia	Savannah	53%	0%	7%	27%	57%	2215	14%	1%	4%	21%	10%	54%
Hawaii	Honolulu	28%	0%	9%	51%	37%	2095	14%	1%	8%	38%	0%	54%
Idaho	Boise	33%	0%	37%	26%	27%	2095	38%	2%	3%	15%	0%	56%
Illinois	Chicago	15%	0%	39%	24%	23%	2056	38%	2%	6%	33%	1%	56%
Illinois	Belleville	15%	0%	39%	24%	23%	2056	31%	2%	6%	33%	1%	50%
Indiana	Indianapolis	28%	0%	30%	21%	28%	2056	38%	2%	4%	19%	1%	56%
Indiana	Evansville	28%	0%	30%	21%	28%	2056	31%	2%	4%	19%	1%	50%
Iowa	Des Moines	21%	0%	47%	16%	22%	2056	38%	2%	4%	19%	1%	56%
Kansas	Wichita	22%	0%	33%	23%	30%	2056	31%	2%	5%	18%	1%	50%
Kansas	Hays	22%	0%	33%	23%	30%	2056	38%	2%	5%	18%	1%	56%
Kentucky	Louisville	52%	0%	9%	37%	44%	2215	31%	2%	2%	18%	10%	50%
Louisiana	New Orleans	62%	0%	1%	30%	67%	2215	14%	1%	3%	18%	10%	54%
Louisiana	Bastrop	62%	0%	1%	30%	67%	2215	31%	2%	3%	18%	10%	50%
Maine	Portland	5%	10%	24%	14%	17%	2051	38%	2%	2%	19%	1%	56%
Maryland	Baltimore	40%	0%	31%	23%	28%	2215	31%	2%	21%	25%	10%	50%
Maryland	Mountain Lake Park	40%	0%	31%	23%	28%	2215	38%	2%	21%	25%	10%	56%
Massachusetts	Boston	15%	10%	21%	11%	16%	2051	38%	2%	5%	42%	1%	56%
Michigan	Detroit	9%	0%	36%	21%	16%	2056	38%	2%	5%	18%	1%	56%
Minnesota	Minneapolis	16%	0%	47%	16%	22%	2056	38%	2%	7%	22%	1%	56%
Mississippi	Jackson	55%	0%	9%	37%	44%	2215	14%	1%	1%	14%	10%	54%
Mississippi	Southaven	55%	0%	9%	37%	44%	2215	31%	2%	1%	14%	10%	50%
Missouri	Kansas City	34%	0%	36%	18%	25%	2056	31%	2%	3%	20%	1%	50%
Missouri	St. Joseph	34%	0%	36%	18%	25%	2056	38%	2%	3%	20%	1%	56%
Montana	Billings	23%	0%	37%	26%	27%	2095	38%	2%	3%	17%	0%	56%

State	City	% Electric Heating[39]	% Oil Heating[40]	% Conditioned Basement[41]	% Crawl-space[42]	% Slab[43]	Avg Floor Area (ft^2)[44]	% Two Story[45]	% Three Story[46]	% Attached[47]	% Multi-Family[48]	% Concrete[49]	% Urban[50]
Nebraska	Omaha	30%	0%	33%	23%	30%	2056	38%	2%	4%	20%	1%	56%
Nevada	Las Vegas	34%	0%	3%	11%	86%	2095	16%	1%	5%	30%	0%	64%
Nevada	Reno	34%	0%	3%	11%	86%	2095	38%	2%	5%	30%	0%	56%
New Hampshire	Manchester	9%	10%	24%	14%	17%	2051	38%	2%	5%	26%	1%	56%
New Jersey	Newark	12%	10%	18%	24%	27%	2051	31%	2%	9%	36%	1%	50%
New Jersey	Paterson	12%	10%	18%	24%	27%	2051	38%	2%	9%	36%	1%	56%
New Mexico	Albuquerque	17%	0%	3%	11%	86%	2095	16%	1%	4%	15%	0%	64%
New Mexico	Santa Fe	17%	0%	3%	11%	86%	2095	38%	2%	4%	15%	0%	56%
New York	New York City	11%	10%	26%	12%	20%	2051	31%	2%	5%	51%	1%	50%
New York	Buffalo	11%	10%	26%	12%	20%	2051	38%	2%	5%	51%	1%	56%
North Carolina	Charlotte	62%	0%	2%	55%	39%	2215	31%	2%	4%	17%	10%	50%
North Carolina	Boone	62%	0%	2%	55%	39%	2215	38%	2%	4%	17%	10%	56%
North Carolina	Wilmington	62%	0%	2%	55%	39%	2215	14%	1%	4%	17%	10%	54%
North Dakota	Fargo	40%	0%	47%	16%	22%	2056	38%	2%	5%	26%	1%	56%
Ohio	Columbus	23%	0%	30%	21%	28%	2056	38%	2%	5%	23%	1%	56%
Ohio	Cincinnati	23%	0%	30%	21%	28%	2056	31%	2%	5%	23%	1%	50%
Oklahoma	Oklahoma City	37%	0%	1%	30%	67%	2215	31%	2%	2%	15%	10%	50%
Oklahoma	Guymon	37%	0%	1%	30%	67%	2215	16%	1%	2%	15%	10%	64%
Oregon	Portland	50%	0%	7%	47%	40%	2095	26%	2%	4%	23%	0%	63%
Oregon	Bend	50%	0%	31%	20%	23%	2095	38%	2%	4%	23%	0%	56%
Pennsylvania	Philadelphia	22%	10%	25%	14%	29%	2051	31%	2%	18%	20%	1%	50%
Pennsylvania	Pittsburgh	22%	10%	25%	14%	29%	2051	38%	2%	18%	20%	1%	56%
Rhode Island	Providence	10%	10%	24%	14%	17%	2051	38%	2%	3%	41%	1%	56%
South Carolina	Columbia	71%	0%	2%	55%	39%	2215	31%	2%	3%	18%	10%	50%

State	City	% Electric Heating[39]	% Oil Heating[40]	% Condi-tioned Basement[41]	% Crawl-space[42]	% Slab[43]	Avg Floor Area (ft^2)[44]	% Two Story[45]	% Three Story[46]	% Attached[47]	% Multi-Family[48]	% Concrete[49]	% Urban[50]
South Carolina	Charleston	71%	0%	2%	55%	39%	2215	14%	1%	3%	18%	10%	54%
South Dakota	Sioux Falls	29%	0%	47%	16%	22%	2056	38%	2%	3%	19%	1%	56%
Tennessee	Memphis	60%	0%	18%	31%	35%	2215	31%	2%	3%	18%	10%	50%
Texas	Houston	59%	0%	0%	20%	80%	2215	14%	1%	3%	24%	10%	54%
Texas	El Paso	59%	0%	0%	20%	80%	2215	16%	1%	3%	24%	10%	64%
Texas	Wichita Falls	59%	0%	0%	20%	80%	2215	31%	2%	3%	24%	10%	50%
Utah	Salt Lake City	11%	0%	37%	26%	27%	2095	38%	2%	6%	21%	0%	56%
Utah	St. George	11%	0%	37%	26%	27%	2095	16%	1%	6%	21%	0%	64%
Vermont	Burlington	4%	10%	24%	14%	17%	2051	38%	2%	4%	23%	1%	56%
Virginia	Virginia Beach	54%	0%	24%	33%	33%	2215	31%	2%	11%	22%	10%	50%
Washington	Seattle	55%	0%	7%	47%	40%	2095	26%	2%	4%	26%	0%	63%
Washington	Spokane	55%	0%	31%	20%	23%	2095	38%	2%	4%	26%	0%	56%
West Virginia	Charleston	44%	0%	31%	23%	28%	2215	31%	2%	2%	12%	10%	50%
West Virginia	Morgantown	44%	0%	31%	23%	28%	2215	38%	2%	2%	12%	10%	56%
Wisconsin	Milwaukee	15%	0%	45%	10%	15%	2056	38%	2%	4%	25%	1%	56%
Wyoming	Cheyenne	23%	0%	37%	26%	27%	2095	38%	2%	4%	16%	0%	56%

The application of adjustment factors and weighting factors in each state-climate combination resulted in the calculation of estimated average energy use and energy savings broken down by fuel type (electricity, natural gas, and fuel oil) for a typical new house constructed to either minimum code or ES standards during each year of the analysis period (2006-2015). We also estimated projected future savings through 2045, and those results are used elsewhere in the IEc evaluation, but are not presented in this report.

The use of adjustment factors—instead of relying on models of typical housing characteristics in the five primary cities—avoided significant errors in the estimation of interim energy savings nationwide. Two examples of the step-by-step application of adjustment factors, and the resulting avoided errors, are shown in Figure 14 (Chicago, site natural gas savings) and Figure 15 (Birmingham, site electricity savings).

The true diversity of housing characteristics both within a city and across the country is extensive, and the resulting impact on estimated energy savings should not be neglected. Direct modeling of many tens of thousands of combinations would provide the most accurate results, but our approach provides an affordable compromise with reasonable accuracy.

Figure 14. Effect of Weighting Factors on Estimated Average Natural Gas Site Energy Savings for Homes Built in Chicago, Illinois, in 2015

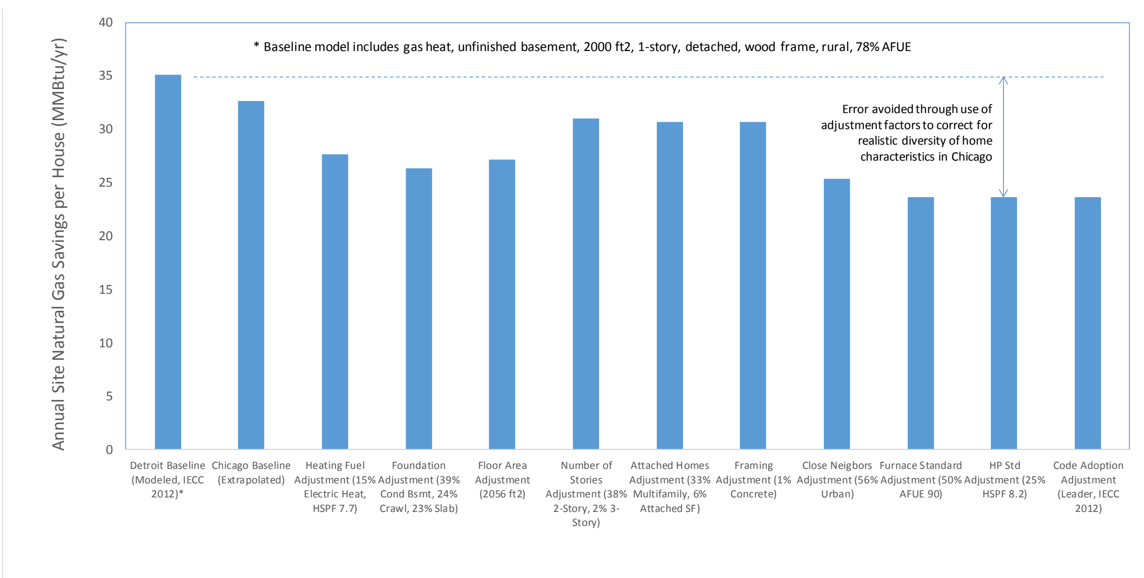
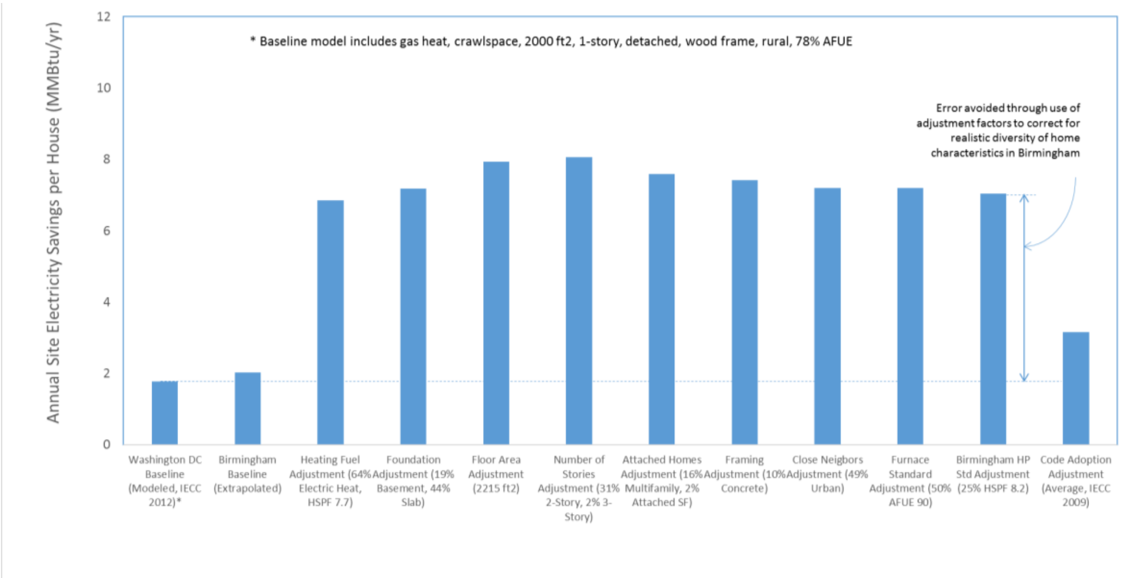


Figure 15. Effect of Weighting Factors on Estimated Average Electricity Savings for Homes Built in Birmingham, Alabama, in 2015



FINAL RESULTS

We can make several interesting observations from the initial set of baseline runs presented in Figures 9-13:

- The estimated savings for the BA-influenced cases steadily increase from 2003-2012, as more of the four BA practices become relevant, and the corresponding code requirements grow stricter.
- The IECC (including BA practices) shows a gradual improvement over time from 2003-2012, consistent with the findings of PNNL.[51] One exception is for IECC 2009 in Portland, where the change in how duct leakage is expressed resulted in an overall weakening of the code for the baseline case (as discussed under Step 3).
- The IECC counterfactual cases do not improve consistently from 2000-2012, indicating that the four BA practices selected constituted a significant portion of energy code improvements during this time.
- The estimated savings for ES homes relative to the IECC is split nearly equally between the four BA practices and other ES requirements such as windows, equipment, and lighting.

Other findings from the modeling effort require the final step of the modeling process, which was to use home construction statistics to estimate state-level cumulative site energy savings, and interim nationwide savings, for each year, sorted by fuel type and BA practice. A summary of estimated interim cumulative nationwide site energy savings for all four BA practices combined is provided in Table 18. The interim 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. Again, in a

[51] OV Livingston, PC Cole, DB Elliott, R Bartlett. 2014. Building Energy Codes Program: National Benefits Assessment, 1992-2040. PNNL-22610 Rev 1. Richland, WA.

future step, the IEc team will potentially downward adjust these interim aggregate energy savings estimates using adjustments for attribution assigned by the Delphi Panel.

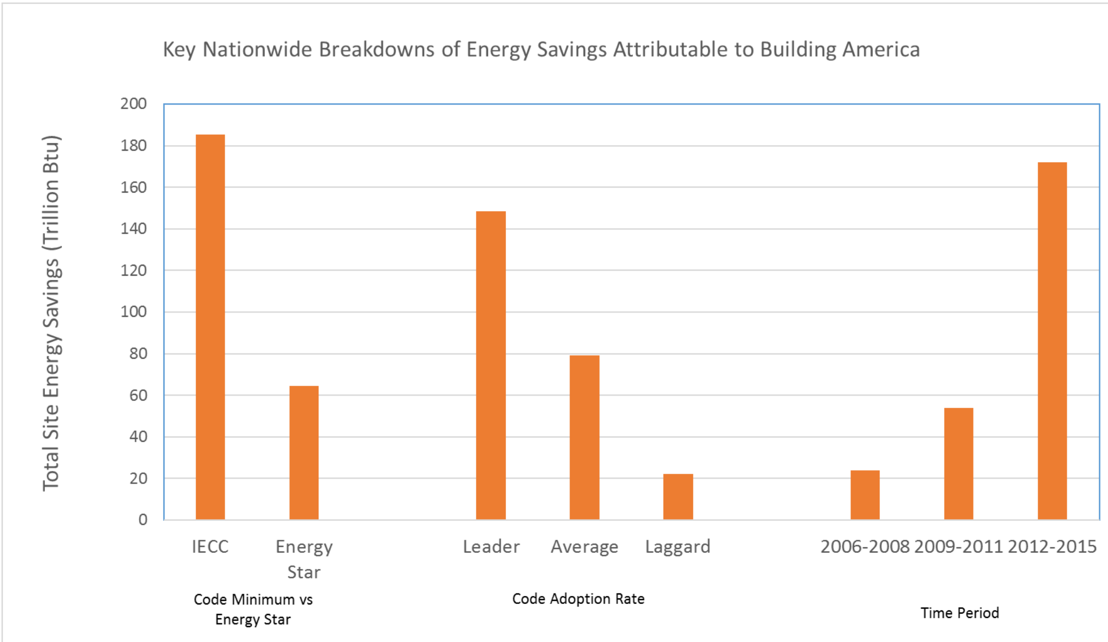
Table 18. Estimated Interim Cumulative Nationwide Site Energy Savings Based on Modeling Study

Estimated Cumulative Site Electricity Savings (GWh)	17,808
Estimated Cumulative Site Natural Gas Savings (Million Therms)	1,826
Estimated Cumulative Site Fuel Oil Savings (Million Gallons)	47
Estimated Cumulative Site Energy Savings - All Fuels (Trillion Btu)	250

The IEc team disaggregated these interim results in several ways to provide insights into the largest contributors to energy savings. Figures 16-22 provide a variety of breakdowns of nationwide site energy savings, including by efficiency program (code vs. ES), code adoption rate, time period, state, and individual BA practice.

As shown in Figure 16, 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 BA energy savings compared to the ES 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 BA 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 16. Breakdowns of Estimated Interim Cumulative Nationwide Site Energy Savings for Four BA Practices by Compliance Program, Code Adoption Rate, and Time Period



Figures 17 and 18 show the interim state-wide site energy savings estimates for the 50 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 is 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 low construction rates and slower code adoption.

Figure 17. Breakdown of Estimated Interim Cumulative Nationwide Site Energy Savings for Four BA Practices by State (25 Most Impacted States, Excluding California)

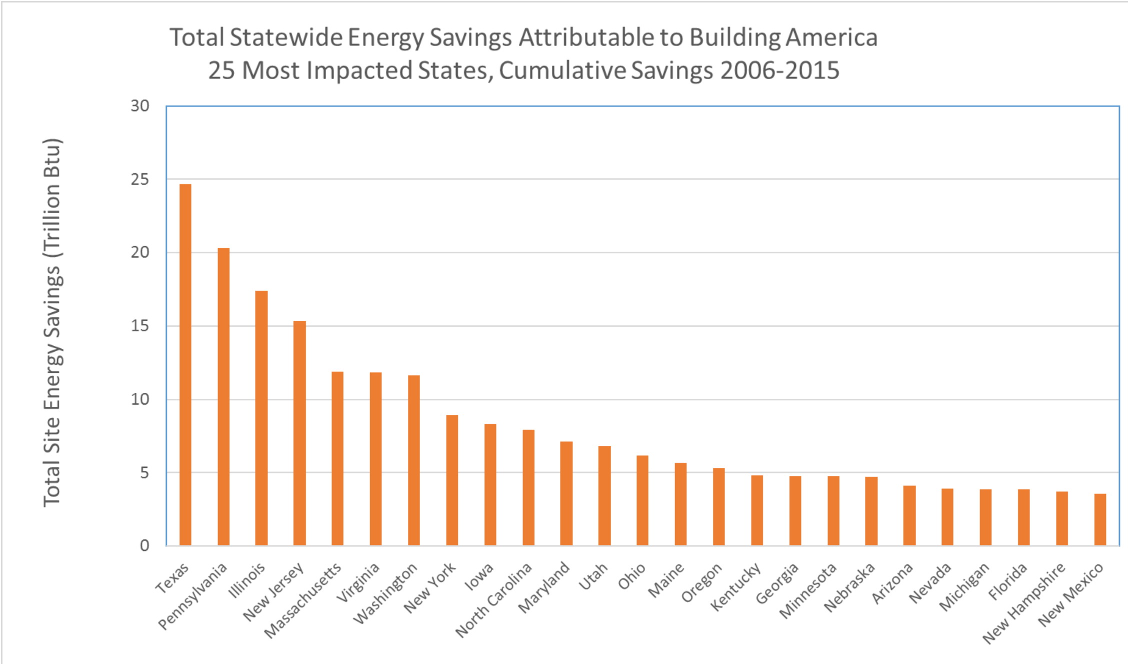
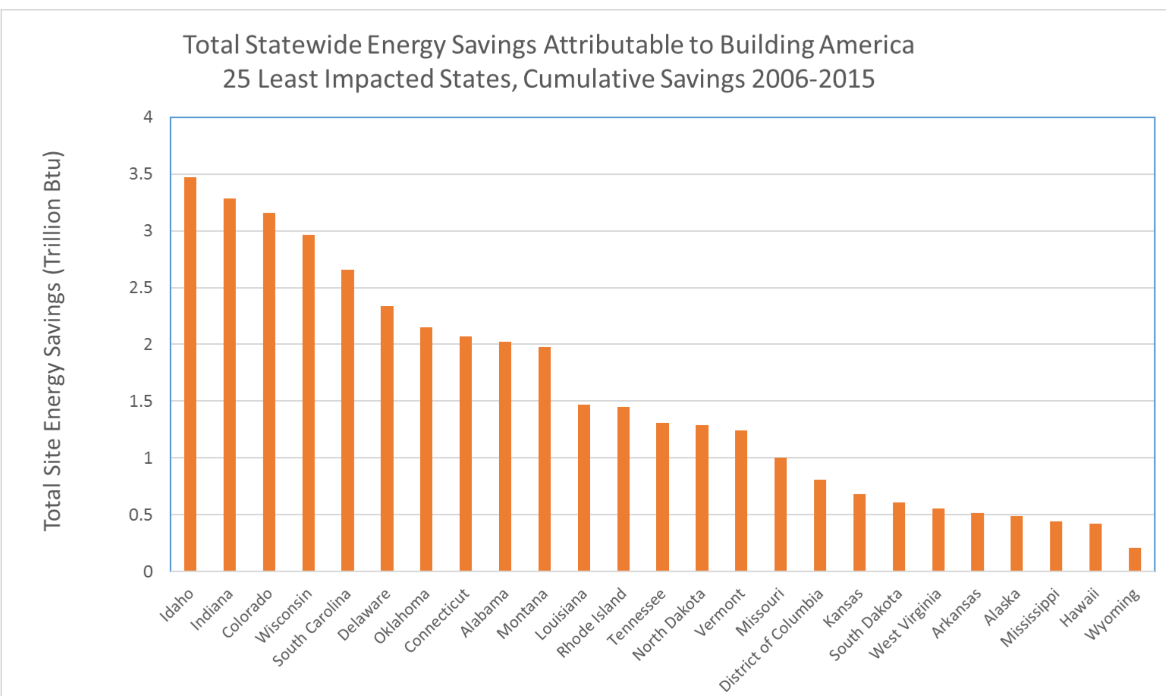


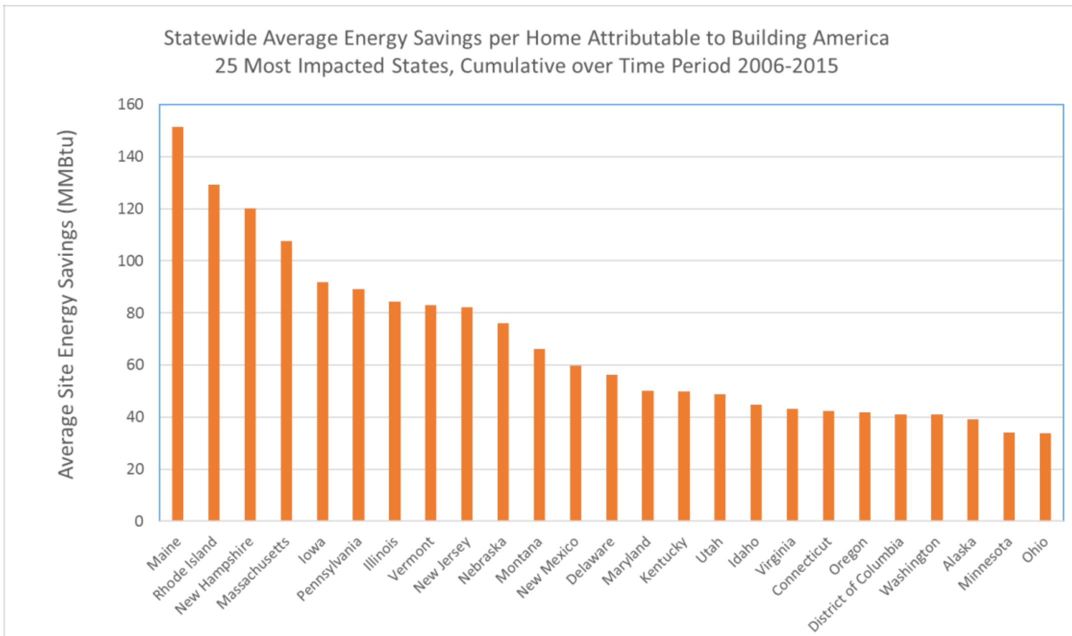
Figure 18. Breakdown of Estimated Interim Cumulative Nationwide Site Energy Savings for Four BA



Practices by State (25 Least Impacted States, Excluding California)

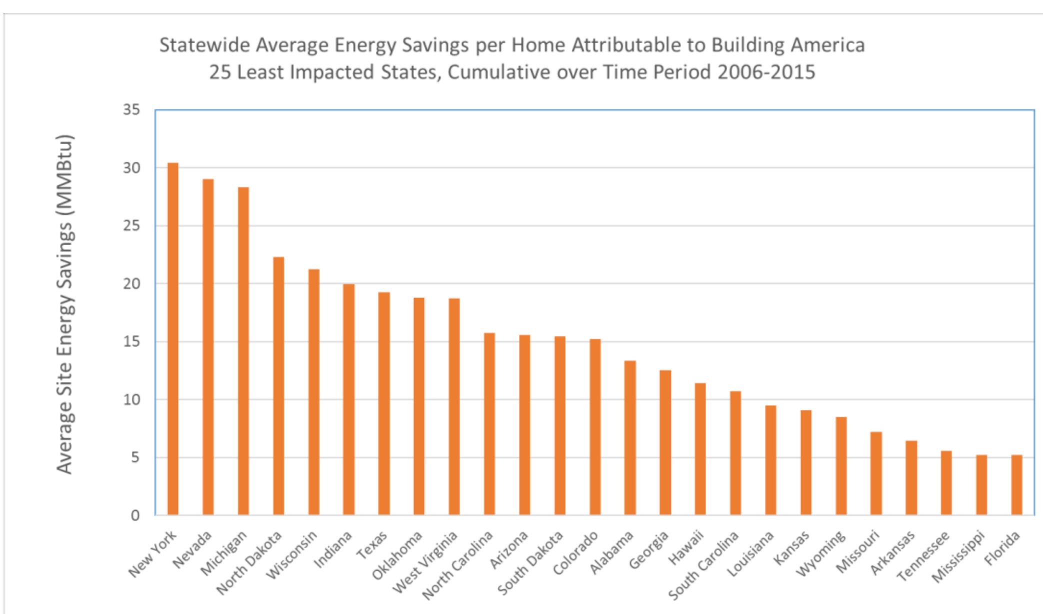
Figures 19 and 20 show the per-house average interim site energy savings estimates for new homes in each state over the evaluation period. We made the calculation by simply dividing the cumulative savings in Figures 17-18 by the total number of houses built between 2006 and 2015. In this case, all five 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 19. Estimated Interim Average Site Energy Savings per House for Four BA Practices Ordered by



State (25 Most Impacted States, Excluding California)

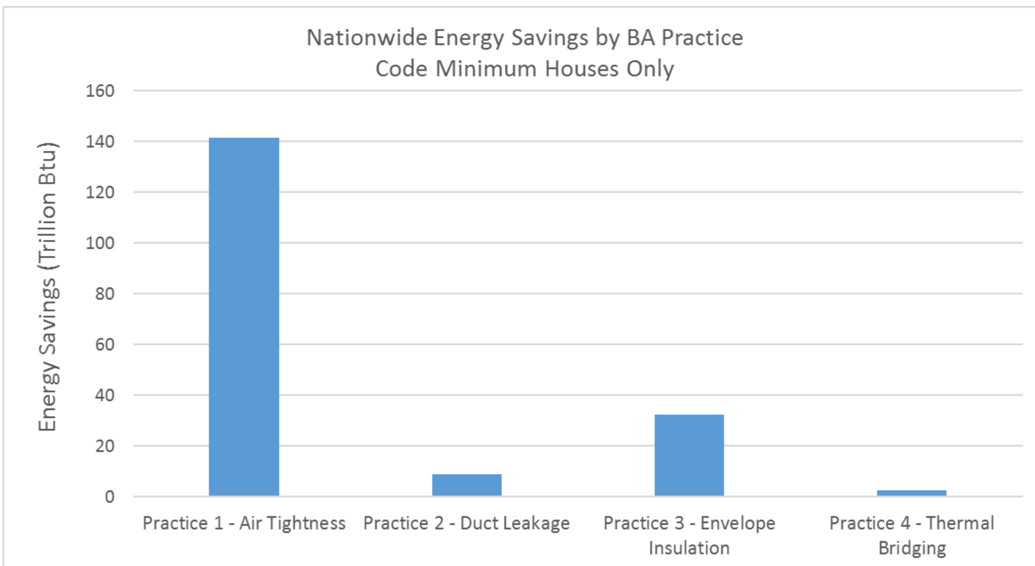
Figure 20. Estimated Interim Average Site Energy Savings per House for Four BA Practices Ordered by



State (25 Least Impacted States, Excluding California)

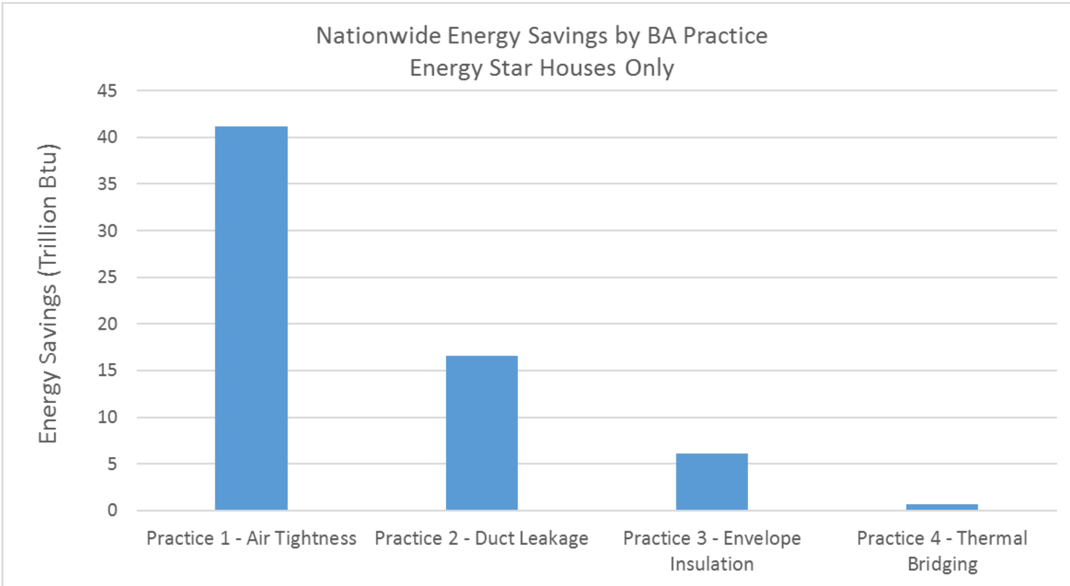
The breakdown of estimated site energy savings for each of the four BA practices in code minimum homes is shown in Figure 21. It is not surprising that air tightness is the largest contributor, because its influence began in IECC 2006, the reduction in air leakage rate was very large (from 11-14 ACH50 to 3 ACH 50), and air infiltration has a substantial effect on space conditioning energy. Envelope insulation improvements have also proved significant, while duct leakage and thermal bridging improvements had less impact in the context of energy codes. Because we assumed that both code minimum and BA home have mechanical ventilation systems, infiltration savings estimates represent the savings for infiltration measures only, not the net savings of infiltration and mechanical ventilation taken together.

Figure 21. Breakdown of Estimated Interim Cumulative Nationwide Site Energy Savings by Individual BA Practice (Code Minimum Houses)



As shown in Figure 22, 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. The reason is that while the IECC does not have strict duct leakage requirements in cold climates because the ducts are usually within the thermal envelope, ES requires very tight ducts in all climates. At first glance it may seem like duct leakage is unimportant when ducts are in basements and walls within the thermal envelope, but duct leakage can induce higher infiltration by way of pressure imbalances within the house. Additionally, ducts in unconditioned basements are within the thermal envelope, but not in conditioned space, resulting in wasted energy when duct leakage occurs in the basement. Finally, the duct leakage requirement for ES was very strict (4 cfm/100 ft^2) throughout the evaluation period, while comparable duct tightness was not adopted in the model codes until IECC 2012.

Figure 22. Breakdown of Estimated Interim Cumulative Nationwide Site Energy Savings by Individual



BA Practice (Energy Star Houses)

NONCOMPLIANCE

IEc's evaluation plan stated that we would downward adjust estimated interim energy savings by applying a code non-compliance factor, using the same methodology developed by PNNL in 2014. However, the 2014 PNNL study referenced in the evaluation plan caps compliance at 100%. Thus, the IEc team determined that this is not an appropriate reference study for our evaluation, because we hypothesize (and this is borne out by the newer/ongoing PNNL study) that homebuilders who build to code, in practice, frequently exceed the energy use reductions targets in code.

PNNL is currently conducting an updated residential compliance study, which is the broadest compliance study that allows for energy "overcompliance." However, the current PNNL study dataset has the following limitations that also make it a poor fit for this evaluation:

- 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 the 8 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 are 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 8 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.

- Our analysis treats EnergyStar 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 towards a higher compliance rate than if the analysis were limited to code-minimum homes.

PNNL's current data indicate that most states wind up with energy compliance greater than 100%. 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 Information Collection Request (ICR) from the Office of Management and Budget because it would require input from more than nine non-federal experts. As a point of reference, IEc is currently conducting a Delphi Panel to estimate compliance rates in New York State, and this is requiring input from multiple code officials from different parts of the state and in different sectors, and that is for only one state. The DOE evaluation schedule and resources do not permit obtaining an additional ICR for this purpose.

As such, we do not apply a compliance adjustment factor to our energy modeling results.

If needed, IEc will perform additional sensitivity analysis if the final benefit results from the overall evaluation, when compared to program costs, suggest that factoring noncompliance into our calculations could substantially impact the results of the study.

CONCLUSIONS

This modeling study estimates interim energy savings of about 6% of site energy use for four BA practices in the houses built in the U.S. between 2006 and 2015, excluding California. While the development of stricter model energy codes, the adoption of these model codes by states, and deployment of ES homes were the proximate causes of these estimated savings, it is unlikely that the aggressive energy efficiency levels associated with these programs could have been achieved without the research and demonstration efforts of the BA program in collaboration with lead builders around the country. The modeling approach included a balance between large numbers of energy models reflecting the true diversity of homes built in the U.S., and a more concise use of modeling combined with sensitivity analysis and adjustment factors.

The interim energy savings estimated through this modeling effort includes the full impact of the four BA practices considered across the diversity of construction practices used in homes throughout the U.S. As a next step, it is reasonable to limit the estimated savings that are directly attributable to the BA program by considering the contributions of other, rival factors including market forces and utility programs. The results from this study will be used as an input to a Delphi panel of leading industry experts, who will consider the attribution of the estimated interim savings to BA activities.

Following the Delphi Panel, the IEc team will then estimate the economic and environmental impacts of these savings, including avoided social cost of carbon and health impacts from avoided electricity generation. The IEc team will also explore other areas of program benefit, including other areas of cost savings, knowledge benefits, and energy security benefits. The evaluation will collect qualitative evidence of program attribution from production builders, via survey, to understand the differences in rate and timing of adoption of these technologies among builders that participated in BA and those that did not. The survey will also: explore moisture management as a potential economic benefit of BA; probe if BA helped California builders come into compliance with state-specific energy codes; and explore spillover to non-participants and to the retrofit market. The IEc team is using a citation analysis, in addition to the survey, to capture knowledge benefits.

APPENDIX G. HOUSING PERMIT DATA AND ENERGY STAR HOMES DATA BY STATE AND BY YEAR

STATE		TOTAL CONSTRUCTION*												
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2006-2008	2009-2011	2012-2015
Alabama	AL	29833	23892	15932	12209	10582	10883	12278	11125	12338	12338	69656	33675	48078
Alaska	AK	2529	1605	877	867	877	842	963	1054	1430	1430	5012	2586	4877
Arizona	AZ	63135	46559	24240	14038	11943	12268	20243	23343	24142	24142	133934	38250	91871
Arkansas	AR	13292	10405	7906	6468	6611	6176	7574	7072	7107	7107	31603	19255	28861
California	CA	147003	99338	54619	32691	38960	38955	50182	68706	71341	71341	300960	110606	261568
Colorado	CO	36371	27098	16845	8813	10894	12223	20302	24254	25503	25503	80314	31930	95561
Connecticut	CT	8730	7157	4675	3434	3598	2950	4088	4762	4674	4674	20562	9983	18198
Delaware	DE	6173	5100	3198	3038	2981	2850	3824	4576	4957	4957	14471	8869	18314
District of Columbia	DC	1534	1532	454	867	595	3362	2807	2435	3068	3068	3520	4824	11377
Florida	FL	188112	93839	54980	33000	36426	39537	58466	78154	76469	76469	336931	108963	289558
Georgia	GA	99376	68338	32547	17318	16633	17201	22430	32991	36142	36142	200261	51152	127706
Hawaii	HI	7037	6303	3702	2459	3007	2425	2716	3444	2828	2828	17042	7892	11818
Idaho	ID	16753	11773	6375	4753	4007	3689	6025	7675	8229	8229	34900	12450	30158
Illinois	IL	53689	38322	19849	10143	11152	10548	12503	14122	17897	17897	111861	31842	62418
Indiana	IN	28185	22864	15369	11821	12344	11806	12851	16401	16325	16325	66418	35972	61902
Iowa	IA	12632	10614	7906	7277	7256	7135	8836	10043	9466	9466	31152	21667	37811
Kansas	KS	13759	10765	7473	6077	4897	4942	5782	7446	6836	6836	31997	15916	26900
Kentucky	KY	15995	14201	9636	7139	7548	7106	8677	8258	8700	8700	39832	21794	34335
Louisiana	LA	27494	21728	15252	12188	11158	11722	12727	13677	14705	14705	64474	35069	55814

STATE		TOTAL CONSTRUCTION*												
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2006-2008	2009-2011	2012-2015
Maine	ME	7162	5699	3508	3069	2995	2629	2897	3283	3134	3134	16369	8694	12449
Maryland	MD	21738	17056	11857	10272	10954	12043	13536	15868	14704	14704	50651	33269	58813
Massachusetts	MA	17517	13759	8724	7232	8291	7001	9770	12599	12597	12597	40001	22524	47562
Michigan	MI	28128	17139	10458	6733	8777	9003	11348	15079	15045	15045	55726	24513	56518
Minnesota	MN	24912	17039	10853	8880	9104	8326	14139	15605	15237	15237	52803	26309	60218
Mississippi	MS	16033	15341	10493	6720	5117	5080	5849	6399	6554	6554	41866	16917	25356
Missouri	MO	27311	20182	12110	9267	9143	8648	11281	12666	14250	14250	59602	27058	52448
Montana	MT	4393	3949	2312	1635	1904	1766	2557	4301	3502	3502	10654	5304	13862
Nebraska	NE	7830	7233	5915	5017	5028	4796	5655	6886	6816	6816	20978	14841	26173
Nevada	NV	36000	24223	12701	6205	6175	5754	8629	10624	11856	11856	72925	18134	42966
New Hampshire	NH	5519	4383	3017	2172	2500	2208	2156	2644	3095	3095	12920	6880	10990
New Jersey	NJ	30702	22671	15995	11078	12018	11242	15101	20493	23496	23496	69368	34338	82586
New Mexico	NM	13264	9018	5874	4513	4393	3965	4334	4743	4617	4617	28155	12872	18311
New York	NY	47280	45458	41226	16321	17332	19081	20820	26628	29371	29371	133964	52734	106189
North Carolina	NC	95455	81692	50351	31502	31790	30690	43468	46764	45724	45724	227498	93982	181679
North Dakota	ND	3224	3063	2582	2785	3348	5292	8807	8693	9979	9979	8869	11426	37457
Ohio	OH	33095	25700	16628	12692	12997	12663	15364	18066	18015	18015	75423	38352	69459
Oklahoma	OK	15465	14065	10043	8406	7852	8203	11354	12922	13195	13195	39574	24461	50666
Oregon	OR	25062	19680	10559	6582	6468	6929	9471	13064	14392	14392	55301	19979	51318
Pennsylvania	PA	37741	32192	23507	17623	19184	14293	17564	20193	22841	22841	93440	51100	83439
Rhode Island	RI	2321	1851	1034	922	896	698	728	913	926	926	5206	2517	3493
South Carolina	SC	48312	38466	24231	14971	13663	14790	17780	23504	25825	25825	111009	43424	92935
South Dakota	SD	5036	4781	3619	3412	2778	2607	3821	4859	4236	4236	13436	8797	17152
Tennessee	TN	44386	35384	20866	14276	15204	14149	18552	21930	24932	24932	100636	43630	90346
Texas	TX	202854	161476	115838	79821	82703	88578	119843	131822	148285	148285	480169	251102	548235
Utah	UT	25190	19452	9937	9030	8602	9156	12246	14842	15873	15873	54579	26788	58835
Vermont	VT	2536	1971	1375	1268	1244	1189	1203	1374	1409	1409	5882	3701	5394

STATE		TOTAL CONSTRUCTION*												
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2006-2008	2009-2011	2012-2015
Virginia	VA	45474	36410	25490	20061	19667	21112	24577	28800	25906	25906	107374	60839	105190
Washington	WA	46599	43397	26228	16144	19132	18811	24982	29044	29621	29621	116224	54087	113267
West Virginia	WV	5539	4570	3250	2187	2251	2069	2476	2451	2505	2505	13359	6507	9936
Wisconsin	WI	25700	20641	14184	10113	10073	9066	10936	12592	13032	13032	60525	29252	49591
Wyoming	WY	3466	4342	2598	2125	2088	1933	1997	2159	1829	1829	10407	6145	7814
TOTAL												3839793	1683171	3507772

* Assumes 50% of multi-family homes in the 3-4 story category of the U.S. Census are in 3-story buildings, which fall under the IECC residential code requirements. 4-story multi-family buildings are considered commercial buildings.

STATE	ENERGY STAR											
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2006-2008	2009-2011	2012-2015
Alabama	241	317	824	1160	1340	1664	1319	71	66	42	1382	4164	1498
Alaska	1024				8	26					1024	34	0
Arizona	19998	7388	5944	3931	5476	5476	5133	11295	9994	6211	33330	14883	32633
Arkansas	181	98	77	144	156	241	377	27	23	7	356	541	434
California	27919	12792	6772	6806	4645	3777	6780	6484	4165	1389	47483	15228	18818
Colorado	2204	1701	2151	2339	4233	4105	2658	2187	2741	2014	6056	10677	9600
Connecticut	1606	693	978	164	468	471	452	352	571	222	3277	1103	1597
Delaware	1217	485	286	558	912	1045	1221	895	1405	745	1988	2515	4266
District of Columbia		1	1	85	42	20	7	4	86	51	2	147	148
Florida	3406	2179	2329	3676	5019	6932	7394	5443	5776	3063	7914	15627	21676
Georgia	1051	1664	2908	2694	3179	4731	2356	988	726	763	5623	10604	4833
Hawaii	2126	1723	3058	2057	1459	282	391	288	9		6907	3798	688
Idaho	469	313	363	556	730	716	1268	1015	837	284	1145	2002	3404
Illinois	771	510	749	417	694	743	979	961	1081	932	2030	1854	3953
Indiana	2285	1965	2163	1661	2353	3050	2120	1018	932	1099	6413	7064	5169
Iowa	6004	2842	3961	2754	3777	3252	2868	1528	1169	724	12807	9783	6289

STATE	ENERGY STAR											
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2006-2008**	**2009-2011**	**2012-2015**
Kansas	14	37	178	1287	979	401	94	61	41	15	229	2667	211
Kentucky	780	754	1778	1637	2121	1706	738	305	225	105	3312	5464	1373
Louisiana	377	77	15	240	74	90	91	13	6	3	469	404	113
Maine	15	24	21	57	82	45	34	23	16	34	60	184	107
Maryland	855	707	592	889	3636	3979	3838	4463	4741	3225	2154	8504	16267
Massachusetts	2660	1322	950	2358	2382	2416	1095	691	365	101	4932	7156	2252
Michigan	719	632	609	1165	1849	2322	902	822	1148	887	1960	5336	3759
Minnesota	878	1171	967	669	849	411	154	18	49	85	3016	1929	306
Mississippi	54	39	225	715	222	105	85	36	23	18	318	1042	162
Missouri	17	102	160	695	717	1039	904	325	661	444	279	2451	2334
Montana	30	67	79	150	140	124	101	88	39		176	414	228
Nebraska	78	116	698	974	654	648	116	91	63	48	892	2276	318
Nevada	19147	8269	4455	2090	3514	2254	2479	3072	2921	2766	31871	7858	11238
New Hampshire	855	426	670	797	691	499	411	298	247	46	1951	1987	1002
New Jersey	5520	6492	4036	3200	4745	4877	2248	1181	1327	1548	16048	12822	6304
New Mexico	570	507	653	558	1168	1076	640	307	144	40	1730	2802	1131
New York	2568	2453	2735	2315	2519	2502	3239	1911	1240	1258	7756	7336	7648
North Carolina	1954	2905	4228	5054	6834	10267	6633	7015	6980	4914	9087	22155	25542
North Dakota	23	82	266	94	54	63	14	3			371	211	17
Ohio	3533	2086	2740	3549	5613	4783	3252	2428	2404	1490	8359	13945	9574
Oklahoma	1137	2249	2548	3342	2824	1420	275	99	39		5934	7586	413
Oregon	1110	962	899	726	522	635	1031	438	284	107	2971	1883	1860
Pennsylvania	483	352	549	1176	2122	2686	2679	1562	1985	868	1384	5984	7094
Rhode Island	624	408	397	384	377	377	175	80	17	2	1429	1138	274
South Carolina	148	205	467	922	1436	1836	1219	731	1206	701	820	4194	3857
South Dakota	4	31	55	209	230	302	27	118	9	99	90	741	253
Tennessee	404	490	403	651	1099	1203	1162	724	719	525	1297	2953	3130

STATE	ENERGY STAR											
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2006-2008**	**2009-2011**	**2012-2015**
Texas	60839	40453	32004	29424	35656	30208	21756	20849	19850	13592	133296	95288	76047
Utah	3555	2536	2594	2353	3507	2382	1072	689	979	601	8685	8242	3341
Vermont	808	678	502	606	568	580	322	243	171	28	1988	1754	764
Virginia	646	905	636	1685	3761	4508	3614	3104	3508	1388	2187	9954	11614
Washington	1073	1602	1429	1484	1850	1524	1108	799	804	487	4104	4858	3198
West Virginia	3	2	5	12	22	69	37	7	75	26	10	103	145
Wisconsin	1675	1663	1748	1470	1792	884	67	2	8	9	5086	4146	86
Wyoming		1	19	1	10	12	58	26	16	13	20	23	113

STATE	ALL CONSTRUCTION EXCEPT ENERGY STAR												
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2006-2008	2009-2011	2012-2015
Alabama	29592	23575	15108	11049	9242	9219	10959	11054	12272	12296	68275	29510	46581
Alaska	1505	1605	877	867	869	816	963	1054	1430	1430	3987	2552	4877
Arizona	43137	39171	18296	10107	6467	6792	15110	12048	14148	17931	100604	23366	59237
Arkansas	13111	10307	7829	6324	6455	5935	7197	7045	7084	7100	31247	18714	28426
California	119084	86546	47847	25885	34315	35178	43402	62222	67176	69952	253477	95378	242752
Colorado	34167	25397	14694	6474	6661	8118	17644	22067	22762	23489	74258	21253	85962
Connecticut	7124	6464	3697	3270	3130	2479	3636	4410	4103	4452	17285	8879	16601
Delaware	4956	4615	2912	2480	2069	1805	2603	3681	3552	4212	12483	6354	14048
District of Columbia	1534	1531	453	782	553	3342	2800	2431	2982	3017	3518	4677	11230
Florida	184706	91660	52651	29324	31407	32605	51072	72711	70693	73406	329017	93336	267882
Georgia	98325	66674	29639	14624	13454	12470	20074	32003	35416	35379	194638	40548	122872
Hawaii	4911	4580	644	402	1548	2143	2325	3156	2819	2828	10135	4093	11128
Idaho	16284	11460	6012	4197	3277	2973	4757	6660	7392	7945	33756	10447	26754
Illinois	52918	37812	19100	9726	10458	9805	11524	13161	16816	16965	109830	29989	58466
Indiana	25900	20899	13206	10160	9991	8756	10731	15383	15393	15226	60005	28907	56733
Iowa	6628	7772	3945	4523	3479	3883	5968	8515	8297	8742	18345	11885	31522
Kansas	13745	10728	7295	4790	3918	4541	5688	7385	6795	6821	31768	13249	26689
Kentucky	15215	13447	7858	5502	5427	5400	7939	7953	8475	8595	36520	16329	32962
Louisiana	27117	21651	15237	11948	11084	11632	12636	13664	14699	14702	64005	34664	55701
Maine	7147	5675	3487	3012	2913	2584	2863	3260	3118	3100	16309	8509	12341
Maryland	20883	16349	11265	9383	7318	8064	9698	11405	9963	11479	48497	24765	42545
Massachusetts	14857	12437	7774	4874	5909	4585	8675	11908	12232	12496	35068	15368	45311
Michigan	27409	16507	9849	5568	6928	6681	10446	14257	13897	14158	53765	19177	52758
Minnesota	24034	15868	9886	8211	8255	7915	13985	15587	15188	15152	49788	24381	59912
Mississippi	15979	15302	10268	6005	4895	4975	5764	6363	6531	6536	41549	15875	25194
Missouri	27294	20080	11950	8572	8426	7609	10377	12341	13589	13806	59324	24607	50113
Montana	4363	3882	2233	1485	1764	1642	2456	4213	3463	3502	10478	4891	13634

STATE	ALL CONSTRUCTION EXCEPT ENERGY STAR												
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2006-2008	2009-2011	2012-2015
Nebraska	7752	7117	5217	4043	4374	4148	5539	6795	6753	6768	20086	12565	25855
Nevada	16853	15954	8246	4115	2661	3500	6150	7552	8935	9090	41053	10276	31727
New Hampshire	4664	3957	2347	1375	1809	1709	1745	2346	2848	3049	10968	4893	9988
New Jersey	25182	16179	11959	7878	7273	6365	12853	19312	22169	21948	53320	21516	76282
New Mexico	12694	8511	5221	3955	3225	2889	3694	4436	4473	4577	26426	10069	17180
New York	44712	43005	38491	14006	14813	16579	17581	24717	28131	28113	126208	45398	98542
North Carolina	93501	78787	46123	26448	24956	20423	36835	39749	38744	40810	218411	71827	156138
North Dakota	3201	2981	2316	2691	3294	5229	8793	8690	9979	9979	8498	11214	37441
Ohio	29562	23614	13888	9143	7384	7880	12112	15638	15611	16525	67064	24407	59886
Oklahoma	14328	11816	7495	5064	5028	6783	11079	12823	13156	13195	33639	16875	50253
Oregon	23952	18718	9660	5856	5946	6294	8440	12626	14108	14285	52330	18096	49459
Pennsylvania	37258	31840	22958	16447	17062	11607	14885	18631	20856	21973	92056	45116	76345
Rhode Island	1697	1443	637	538	519	321	553	833	909	924	3777	1378	3219
South Carolina	48164	38261	23764	14049	12227	12954	16561	22773	24619	25124	110189	39230	89077
South Dakota	5032	4750	3564	3203	2548	2305	3794	4741	4227	4137	13346	8056	16899
Tennessee	43982	34894	20463	13625	14105	12946	17390	21206	24213	24407	99339	40676	87216
Texas	142015	121023	83834	50397	47047	58370	98087	110973	128435	134693	346872	155814	472188
Utah	21635	16916	7343	6677	5095	6774	11174	14153	14894	15272	45894	18546	55493
Vermont	1728	1293	873	662	676	609	881	1131	1238	1381	3894	1947	4631
Virginia	44828	35505	24854	18376	15906	16604	20963	25696	22398	24518	105187	50886	93575
Washington	45526	41795	24799	14660	17282	17287	23874	28245	28817	29134	112120	49229	110070
West Virginia	5536	4568	3245	2175	2229	2000	2439	2444	2430	2479	13349	6404	9792
Wisconsin	24025	18978	12436	8643	8281	8182	10869	12590	13024	13023	55439	25106	49506
Wyoming	3466	4341	2579	2124	2078	1921	1939	2133	1813	1816	10386	6123	7701

APPENDIX H. DETAILED METHOD FOR ENVIRONMENTAL HEALTH BENEFITS ANALYSIS

Approach to Estimate Environmental Impacts

Air Quality Benefits

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.[52]

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 (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.

Below we describe our approach for estimating the emissions reductions associated with the BA program in a given year ($M_{t,p}$) and the damage per ton of emissions ($D_{t,p}$).

Emissions Reductions

We estimate the emissions reductions achieved under the BA program based on state-level estimates of the residential electricity savings associated with the program, by year, and estimates of power 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

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[52] 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.

$E_{p,t,s}$ 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. While conceptually straightforward, this approach required us to account for the following details:

- ***Transmission losses:*** Due to electricity transmission losses, the avoided electricity production associated with the BA program will exceed the electricity savings realized by residential electricity consumers. To estimate reduced electricity *production*, we adjust the state-level residential electricity savings based on the corresponding regional transmission loss factor from the U.S. EPA's Emissions & Generation Resource Integrated Database (eGRID),[53] which reports values for 2007, 2009, 2010, 2012, and 2014. For the intervening years, we interpolate between the values provided in eGRID. For future years (through 2039), we use the average for the three most recent years reported (i.e., 2010, 2012, and 2014). Because transmission losses have not followed a clear trend over time, this approach provides an average value.
- ***Variation in emission factors over time and between regions:*** The emissions per MWh of electricity vary across different regions of the U.S. For example, because the Southeast relies more heavily on coal-fired generation than the Northeast, power produced in the Southeast is more SO_2-intensive than electricity produced in the Northeast. Similarly, due to changes in both market conditions and air pollution policy over time, the emissions per MWh of electricity produced has also changed over time and will continue to change in the future.

Our specification of emission factors for CO_2, SO_2, NO_x, and $PM_{2.5}$ accounts for both of the factors described in the second bullet above, though our approach for estimating emission factors differs by pollutant and time period. For each year between 2006 and 2015, we use emission factors for CO_2, NO_x and SO_2 by North American Electricity Reliability Council (NERC) region (see Figure 2-1) from eGRID.[54] While eGRID includes data on CO_2, NO_x and SO_2, it does not include emissions or emissions factors for $PM_{2.5}$. In the absence of these data in eGRID, we derived $PM_{2.5}$ emission factors based on state-level $PM_{2.5}$ emissions data for the 2006-2015 period from the U.S. EPA's National Emissions Inventory (NEI)[55] and state-level power generation estimates from eGRID. For each year, we summed across the states in each NERC region to estimate the region's $PM_{2.5}$ emissions and its power generation. For each year and NERC region, the ratio of these two values represents our estimate of the $PM_{2.5}$ emissions factor.

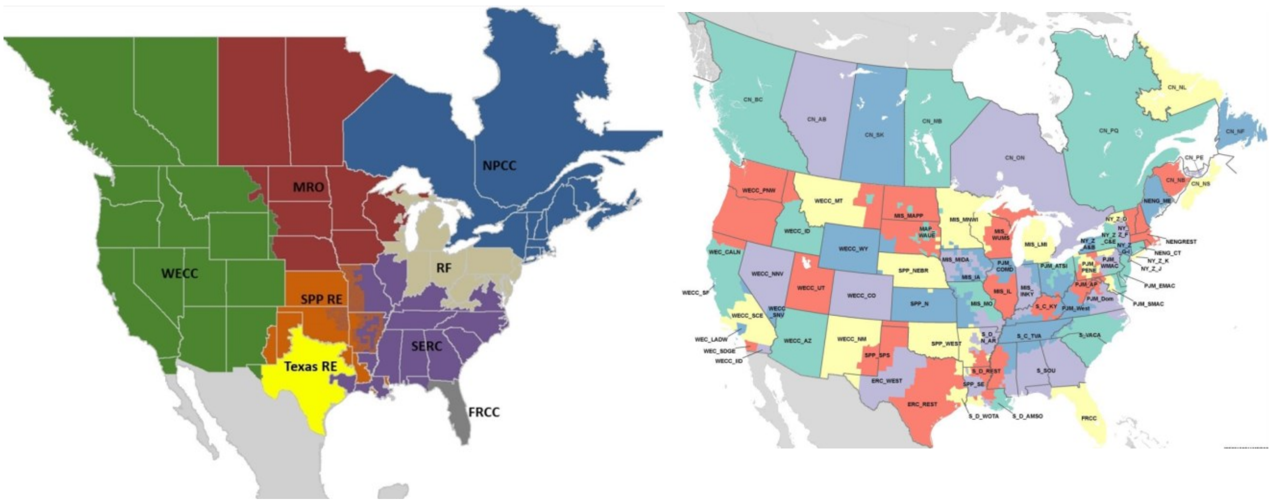
For the 2016-2039 period, we estimated emission factors for CO_2, NO_x, and SO_2 using the base case emissions and electricity generation projections from the U.S. EPA's Integrated Planning Model, specifically base case v.5.15.[56] These projections are reported by model year[57] and IPM model region (see Figure 1 for IPM model regions). The model regions in IPM largely represent sub-regions of each NERC

[53] U.S. EPA, eGRID2014, available at https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid.
[54] eGRID includes data for 2005, 2007, 2009, 2010, 2012, and 2014. We interpolate for the intervening years and assume that the 2014 emission factors are also applicable in 2015.
[55] U.S. EPA, 2014 National Emissions Inventory: state tier, updated December 19, 2016.
[56] U.S. EPA, Power Sector Modeling Platform v.5.15: Results Using EPA's Base Case v.5.15. August 3, 2015.
[57] The IPM model years include 2016, 2018, 2020, 2025, 2030, and 2040. We interpolate to estimate emission factors for the intervening years.

region. For consistency with our specification of emission factors for the 2006-2015 period, we aggregated the IPM regional data to NERC regions. We then calculated the CO_2, NO_x, and SO_2 emission factors for each region and model year as the ratio of CO_2, NO_x, or SO_2 emissions to total generation.

FIGURE 1. NERC REGIONS AND IPM REGIONS

NERC Regions **IPM Regions**



Sources: Map for NERC regions: http://www.nerc.com/AboutNERC/keyplayers/Pages/default.aspx, accessed June 30, 2027. Map for IPM regions from U.S. EPA, *Documentation for EPA Base Case v.5.13 Using the Integrated Planning Model*, November 2013.

We used a different approach to forecast emission factors for $PM_{2.5}$, as $PM_{2.5}$ is not included in IPM's emissions projections. Future changes in the emission factor for $PM_{2.5}$ may reflect changes in the use of abatement technology (e.g., fabric filters or baghouses that limit $PM_{2.5}$ emissions) or changes in the mix of fuels used by the power sector. With respect to the latter, substitution away from coal-fired power generation will lead to reduced emissions of $PM_{2.5}$, as coal is more $PM_{2.5}$-intensive than its major substitutes. While insufficient information is available to account for changes in the use of abatement technology, IPM projections include information on the power sector's reliance on coal versus other generating resources. We use these projected changes in the generation mix as the basis for approximating the change in the power sector's $PM_{2.5}$ emissions factor over time. More specifically, we estimate the percentage change in the $PM_{2.5}$ emissions factor, by region, by (1) calculating the percentage change in coal's share of electricity generation in the region and (2) scaling this percentage by coal's initial market share in the region.[58] For example, if the IPM runs indicate that coal's share of electricity generation in a region is 50% in 2016 and 45% in 2018, this represents a 10% reduction in coal's share of generation. Because not all generation is from coal, we scale this value by coal's initial market share (50%) to calculate a 5% reduction in the $PM_{2.5}$ emission factor between 2016 and 2018.

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

[58] To implement this approach, we assume that the $PM_{2.5}$ emission factors in 2016 (the first IPM model year) are the same as in 2015.

overestimate benefits of the BA program associated with reduced $PM_{2.5}$ emissions.[59] 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.[60] This suggests that additional installations of $PM_{2.5}$ controls at power plants are likely to be limited.

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 $PM_{2.5}$. These estimates are presented in Chapter 3.

Avoided Damage per Ton of Emissions

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.[61,62] 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 the following:

- 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

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[59] 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 below and benefits over the full 2015-2039 period are 14% to 18% lower than the estimates presented below.

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

[61] 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. Collectively, these sources include damage per ton values for 2005, 2016, 2020, 2025, and 2030. For the intervening years, we interpolate between the values obtained from these two sources. For the post-2030 period, we assume that damages per ton remain flat at 2030 values. Because the damage per ton of emissions will likely increase after 2030 due to growth in the population affected by air pollution, we may underestimate the benefits of emissions reductions achieved after 2030.

[62] 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.

- Respiratory hospital admissions
- 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 for premature mortality is consistent with EPA practice.[63]

Table 1 presents 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%.

[63] 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.

TABLE 1. AIR POLLUTANT DAMAGE PER TON VALUES (2015$)

	3% DISCOUNT RATE (2015$)						7% DISCOUNT RATE (2015$)					
	LOW			HIGH			LOW			HIGH		
YEAR	$PM_{2.5}$	SO_2	NO_X	$PM_{2.5}$	SO_2	NO_X	$PM_{2.5}$	SO_2	NO_X	$PM_{2.5}$	SO_2	NO_X
2005	$108,685	$28,258	$3,913	$239,107	$63,037	$9,021	$95,643	$24,998	$3,478	$217,370	$57,603	$8,151
2010	$119,553	$32,605	$4,673	$271,712	$72,819	$10,868	$108,685	$29,345	$4,130	$249,975	$66,298	$9,347
2015	$141,290	$36,953	$5,543	$304,318	$82,601	$12,716	$130,422	$32,605	$4,891	$271,712	$74,993	$10,651
2020	$152,159	$40,213	$5,869	$336,923	$90,209	$13,042	$130,422	$35,866	$5,326	$304,318	$81,514	$11,955
2025	$163,027	$43,474	$6,304	$369,529	$97,816	$14,129	$141,290	$39,127	$5,652	$326,055	$89,122	$13,042
2030	$173,896	$46,735	$6,738	$391,266	$105,424	$15,216	$152,159	$42,387	$6,086	$358,660	$94,556	$14,129
2035	$173,896	$46,735	$6,738	$391,266	$105,424	$15,216	$152,159	$42,387	$6,086	$358,660	$94,556	$14,129

Sources: Values derived from U.S. EPA (2013) and U.S. EPA (2017).
Notes: The 3% and 7% discounting shown in this table was performed by EPA for any damages occurring after the year shown. For example, the values shown in 2025 reflect damages in 2025, as well as future damages discounted back to 2025 at the 3% of 7% discount rate. EPA's discounting reflects that the original damage per ton values assume a cessation lag in mortality damages. While most of the damages occur in the year of the emissions, and almost all occur in the immediate five years after, some portion of damages occur up to 20 years later. To calculate the discounted figures in this evaluation, IEc multiplied the damage per ton values by total avoided emissions, then discounted back to 1994 to arrive at the final discounted results.

APPENDIX I. DETAILED METHOD FOR PUBLICATION CITATION ANALYSIS

Approach to Estimate Knowledge Benefits

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 efficiency construction 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. These are the focus of this assessment of BA 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
- 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.

The publication citation search was facilitated by the use of a publications citation database and search engine. 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, as explained in further detail below, we directly searched in the online archives of trade journals to identify publications that are not indexed in Google Scholar.

Initially, we had planned on drawing a statistically valid sample of BA publications from a list provided by DOE, searching for these publications in Google Scholar, and analyzing the resulting citation information (e.g., counts and organizational linkages). To this end, IEc coordinated with PNNL and

NREL to obtain a sample frame of BA publications.[64] In total, the universe for our citation analysis was 1,124 publications (666 PNNL plus 458 NREL). Our next step was to draw a statistically valid random sample of publications to search on from the 1,124 publications.

The sample size required to attain a confidence level of 90%, with a margin of error of 10%, was 64 publications. To ensure adequate representation of different publication types within our sample, we stratified our sample by PNNL vs. NREL publication list, and by date and type of publication. We searched for all 64 publications in Google Scholar; however, none were found in Google Scholar. Although our experience suggests that Google Scholar is more comprehensive than the alternatives for this type of publication search, it did not include any of the 64 publications in our sample.

However, this result does not mean 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 references to 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, as summarized in Table 1.

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[64] PNNL, who currently manages the BA Solutions Center, provided a total of 1,336 publications, including BA Solution Center Data (1,008 entries) and a separate file with Case Studies Data (328 entries). IEc merged the files and took steps to clean the data. PNNL instructed us to delete General Publications, which are not BA. We deleted 416 General Publications. Because our study period is through 2015, we deleted 19 publications from 2016 and 2017 (eight Solution Center and 11 case studies). Because the scope of our study is new residential construction, we deleted 214 publications that were coded as "Construction Type = Existing Homes." This left New Homes (the focus of our study) or New and Existing Homes. We deleted 21 duplicate entries between the Solution Center Data and the Case Studies Data. This left 666 publications. In addition, NREL, who previously managed the BA Solutions Center, provided a separate list of 675 publications. We deleted 121 entries that were already contained in the PNNL dataset, and deleted another 96 publications from 2016 and 2017 (outside our study period, which ends in 2015). This left 458 entries.

TABLE 1. TRADE JOURNALS SEARCHED FOR THE KNOWLEDGE BENEFITS ANALYSIS

JOURNAL	DESCRIPTION
ASHRAE Journal	This monthly publication contains articles on technology, case studies of high-performing buildings, and editorials. It is published by ASHRAE, which focuses on building systems, energy efficiency, indoor air quality, refrigeration, and sustainability technologies.
Builder	Geared toward homebuilders, this monthly magazine provides current news on home designs, building materials, building products, and home plans. It is published by Hanley Wood, a company serving the information, media, and marketing needs of the residential, commercial design, and construction industry.
Buildings	Buildings.com is a community of facility managers and building owners who are responsible for the operation of commercial and public buildings. The site offers the latest news, archived articles, research, and newsletters on facility management. According to the website, users of Buildings.com include professionals in business development and management firms, office, education, healthcare, retail, hospitality, and government who are involved in the development, construction, modernization, and management of buildings.[65]
Construction Today	This magazine covers timely issues of interest to construction industry leaders. According to the magazine's website, "Construction Today is all about Best Practices – in the general building, heavy construction and associated specialty trade sectors. Its readers are leaders at major contractors, engineering and design firms, equipment manufacturers, and suppliers of construction materials and building products, as well as public and private project owners and regulators."[66]
Engineering News-Record	This weekly magazine provides news, analysis, data, and opinion for the construction industry worldwide. Subscribers include contractors, project owners, engineers, architects, public works officials and industry suppliers. It covers the design and construction of high-rise buildings, stadiums, airports, long-span bridges, dams, tunnels, power plants, industrial plants, water and wastewater projects, and toxic waste cleanup projects. It also covers the construction industry's financial, legal, regulatory, safety, environmental, management, corporate and labor issues. It is owned by BNP Media.[67]
Fine Homebuilding	This magazine aims to be at the forefront of the movement for high-performance, energy-efficient home construction. From job sites across the country, it showcases innovative, affordable, and buildable housing solutions. It is published by The Taunton Press.[68]
Journal of Light Construction	This monthly journal provides practical construction information about building materials, products, and business management to home builders and remodelers.
Professional Builder	The trade publication and website cater to the information needs of the housing and light construction marketplace. Established in 1936, Professional Builder magazine is published monthly (with two additional issues in the fall and December).[69]
Walls & Ceilings	This is a free magazine written for the wall and ceiling contractor, interior contractor, architect, supplier or distributor. It covers all aspects of the industry: drywall, lath and plaster, stucco, ceilings and acoustics, exterior insulation finish systems, fireproofing, metal

65 https://www.buildings.com/about-us
66 http://www.construction-today.com/about-us/the-magazine
67 https://en.wikipedia.org/wiki/Engineering_News-Record
68 http://www.taunton.com/about-us/
69 http://en.wikipedia.org/wiki/Professional_Builder

JOURNAL	DESCRIPTION
	framing and architectural decorative ornamentation, insulation, windows/doors, trims/moldings, spray textures and paints.[70]
Green Builder	Green Builder magazine focuses on green building and sustainable development. It offers practical, cost-effective information to building professionals across the country with an interest in green building. Green Builder Media, LLC focuses on green building in the residential building industry.[71]
Greenbuilding advisor	GreenBuildingAdvisor.com is dedicated to providing information about designing, building, and remodeling energy-efficient, sustainable, and healthy homes. It aims to be single resource where design and construction professionals and knowledgeable homeowners can get the information they need to design, build, and remodel green. It provides how-to advice, a green-products database, green business strategies, design tools, and alternate paths to code compliance.[72]
Remodeling	This is a free monthly magazine written for residential remodelers. It provides tips and expert advice to help remodelers win contracts, work with suppliers, and improve their profitability.[73] We included this magazine on our list to look for "spillovers" of BA's practices to the home retrofit market.
Professional Remodeler	This trade publication and website caters to the information needs of residential, commercial, and general remodeling contractors. Established in 1997, the magazine is published monthly.[74] We also included this publication to assess knowledge spillovers to the retrofit market.
Journal of the National Institute of Building Sciences	Published through a relationship with Stamats Commercial Buildings Group, the journal focuses on different aspects of the built environment, such as: building enclosure design; building information modeling; security and disaster preparedness; and industry leadership and advocacy. Articles highlight cutting-edge research, case studies, and the newest technologies in the building industry, as well as the latest activities of the Institute's Councils, Committees and Programs. It is published three times per year.[75]
National Institute of Building Sciences newsletter	The National Institute of Building Sciences' monthly e-newsletter, Building Sciences, provides information about the Institute's activities and industry news.[76]

70 http://www.freeconstructionmagazines.com/walls-ceilings-magazine/construction-magazines/
71 https://www.greenbuildermedia.com/about-green-builder-media
72 http://www.greenbuildingadvisor.com/about-us
73 http://www.freeconstructionmagazines.com/remodeling-magazine/construction-magazines/
74 https://en.wikipedia.org/wiki/Professional_Remodeler
75 http://www.nibs.org/?page=journals
76 http://www.nibs.org/?page=buildingsciences

We searched each of the 15 publications in two different ways: on Google Scholar, and on the publication's own website.

First, we searched within each trade journal using the advanced search function in Google Scholar. Specifically, we searched for key terms (see below) and specified that we wanted to search within each publication on our list above. 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 through Google Scholar; citation counts are not provided on the journals' individual websites. However, as our search progressed, it became apparent 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 searched the individual websites – in addition to searching through the journals in Google Scholar – 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. We selected the search terms based on our interviews with building science experts, and based on the review of BA project data that we conducted during the scoping phase of the evaluation. 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 on the following terms: (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.

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 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.

APPENDIX J. PRESENT VALUE MULTIPLIERS

YEAR	PV MULTIPLIERS			
	3% DISCOUNT RATE, BEGINNING OF YEAR (USED FOR PROGRAM COSTS)	3% DISCOUNT RATE, END OF YEAR (USED FOR PROGRAM BENEFITS)	7% DISCOUNT RATE, BEGINNING OF YEAR (USED FOR PROGRAM COSTS)	7% DISCOUNT RATE, END OF YEAR (USED FOR PROGRAM BENEFITS)
1994	1.0000	0.9710	1.0000	0.9348
1995	0.9709	0.9427	0.9346	0.8736
1996	0.9426	0.9152	0.8734	0.8164
1997	0.9151	0.8886	0.8163	0.7630
1998	0.8885	0.8627	0.7629	0.7131
1999	0.8626	0.8376	0.7130	0.6665
2000	0.8375	0.8132	0.6663	0.6229
2001	0.8131	0.7895	0.6227	0.5821
2002	0.7894	0.7665	0.5820	0.5440
2003	0.7664	0.7442	0.5439	0.5084
2004	0.7441	0.7225	0.5083	0.4752
2005	0.7224	0.7014	0.4751	0.4441
2006	0.7014	0.6810	0.4440	0.4150
2007	0.6810	0.6612	0.4150	0.3879
2008	0.6611	0.6419	0.3878	0.3625
2009	0.6419	0.6232	0.3624	0.3388
2010	0.6232	0.6051	0.3387	0.3166
2011	0.6050	0.5874	0.3166	0.2959
2012	0.5874	0.5703	0.2959	0.2766
2013	0.5703	0.5537	0.2765	0.2585
2014	0.5537	0.5376	0.2584	0.2416
2015	0.5375	0.5219	0.2415	0.2258
2016	0.5219	0.5067	0.2257	0.2110
2017	0.5067	0.4920	0.2109	0.1972
2018	0.4919	0.4776	0.1971	0.1843
2019	0.4776	0.4637	0.1842	0.1722

YEAR	PV MULTIPLIERS			
	3% DISCOUNT RATE, BEGINNING OF YEAR (USED FOR PROGRAM COSTS)	3% DISCOUNT RATE, END OF YEAR (USED FOR PROGRAM BENEFITS)	7% DISCOUNT RATE, BEGINNING OF YEAR (USED FOR PROGRAM COSTS)	7% DISCOUNT RATE, END OF YEAR (USED FOR PROGRAM BENEFITS)
2020	0.4637	0.4502	0.1722	0.1610
2021	0.4502	0.4371	0.1609	0.1504
2022	0.4371	0.4244	0.1504	0.1406
2023	0.4243	0.4120	0.1406	0.1314
2024	0.4120	0.4000	0.1314	0.1228
2025	0.4000	0.3884	0.1228	0.1148
2026	0.3883	0.3771	0.1147	0.1073
2027	0.3770	0.3661	0.1072	0.1002
2028	0.3660	0.3554	0.1002	0.0937
2029	0.3554	0.3451	0.0937	0.0876
2030	0.3450	0.3350	0.0875	0.0818
2031	0.3350	0.3253	0.0818	0.0765
2032	0.3252	0.3158	0.0765	0.0715
2033	0.3158	0.3066	0.0715	0.0668
2034	0.3066	0.2977	0.0668	0.0624
2035	0.2976	0.2890	0.0624	0.0583
2036	0.2890	0.2806	0.0583	0.0545
2037	0.2805	0.2724	0.0545	0.0510
2038	0.2724	0.2645	0.0509	0.0476
2039	0.2644	0.2568	0.0476	0.0445

APPENDIX K. CITATION COUNTS

ARTICLES THAT DIRECTLY MENTION BUILDING AMERICA

	Building America	air leakage	duct leakage	insulation	thermal bridging	advanced framing	Air Barrier	Air Infiltration	Air Sealing	Thermal bypass	Attic Insulation	Radiant Barrier	Attic Interface	Ceiling interface	Floor Insulation
1994	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
1995	0	1	0	1	1	0	1	1	1	0	0	1	0	0	1
1996	2	2	0	4	0	0	1	1	2	0	1	2	0	0	1
1997	1	0	0	2	0	0	1	1	0	1	1	0	0	0	1
1998	0	1	0	2	1	0	0	2	0	0	0	1	1	1	0
1999	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
2000	1	0	0	3	0	0	0	1	2	0	1	0	0	0	1
2001	8	2	1	4	1	3	3	1	3	0	2	1	0	0	4
2002	17	1	2	1	0	2	4	0	2	1	1	4	1	1	1
2003	22	6	4	5	0	4	12	3	12	1	5	5	1	1	5
2004	12	0	0	1	0	5	2	1	2	0	0	1	0	1	3
2005	13	4	2	4	2	1	5	3	5	1	2	2	1	2	3

	Insulated Concrete Forms	Thermal Alignment	Insulation Placement	Structural Insulated Panels	Unconditioned + Infiltration	Unconditioned + Insulation	Unconditioned + Sealing	Unvented Crawl Spaces	Combined Water and Space Heating Systems OR Combined Space and Water Heating Systems	whole-building pressurization testing	Blower door testing	Duct pressure testing	Ducts + conditioned space	Moisture management	Whole-home approach OR home as a system	Vapor retarder classification system	Bulk water management
1994	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	1	1
1995	1	0	0	0	0	1	2	0	0	0	0	0	0	0	1	1	0
1996	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
1997	0	0	0	2	0	0	1	1	0	1	0	0	0	0	0	0	0
1998	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	1	1	1	1	0	0	1	0	0
2000	3	0	0	1	0	1	1	1	0	1	1	0	0	1	0	1	0
2001	5	0	2	2	0	0	0	0	0	2	3	2	2	2	4	1	1
2002	1	0	5	1	1	0	1	1	0	1	0	0	0	2	3	0	0
2003	5	0	1	1	0	1	2	2	1	4	6	3	5	4	6	4	0
2004	5	1	2	2	0	1	0	0	0	2	1	1	0	0	3	1	1
2005	3	1	0	2	0	0	1	1	0	0	1	0	1	2	3	0	0

	Building America	air leakage	duct leakage	insulation	thermal bridging	advanced framing	Air Barrier	Air Infiltration	Air Sealing	Thermal bypass	Attic Insulation	Radiant Barrier	Attic Interface	Ceiling interface	Floor Insulation	Insulated Concrete Forms	Thermal Alignment	Insulation Placement	Structural Insulated Panels	Unconditioned + Infiltration	Unconditioned + Insulation	Unconditioned + Sealing	Unvented Crawl Spaces	Combined Water and Space Heating Systems OR Combined Space and Water Heating Systems	whole-building pressurization testing	Blower door testing	Duct pressure testing	Ducts + conditioned space	Moisture management	Whole-home approach OR home as a system	Vapor retarder classification system	Bulk water management
2006	10	1	1	4	0	1	6	2	6	0	4	4	0	0	4	5	2	2	4	0	1	1	1	0	2	1	1	0	1	4	2	0
2007	9	1	1	3	2	1	5	3	6	0	3	3	3	4	1	2	0	3	2	0	1	1	0	3	2	1	1	0	1	4	0	0
2008	15	2	2	7	0	1	5	3	2	2	3	6	1	0	4	2	0	2	2	2	0	2	1	0	3	4	0	2	4	7	1	0
2009	19	3	4	6	3	4	8	0	4	4	4	4	0	1	2	3	3	1	0	1	1	2	2	0	3	1	2	2	0	1	5	3
2010	18	8	1	6	6	7	9	6	15	3	6	4	2	1	4	4	2	2	4	1	2	3	3	1	3	0	6	3	3	4	2	1
2011	26	4	4	14	3	3	7	5	14	5	9	2	1	2	6	2	2	2	1	4	0	3	2	1	5	2	7	2	4	2	3	0
2012	12	0	0	4	3	6	11	2	8	3	2	0	3	3	3	5	1	1	0	2	0	1	2	1	5	0	2	1	3	5	0	0
2013	23	10	7	5	3	6	8	4	14	2	5	2	1	2	3	2	1	2	0	0	3	3	2	1	1	2	0	0	5	3	3	0
2014	18	2	0	7	4	5	6	3	8	2	3	2	1	1	1	0	2	3	2	0	3	2	3	2	1	2	3	3	2	0	5	1
2015	20	9	2	11	4	4	13	1	6	1	3	1	0	4	2	2	5	2	1	0	0	1	2	3	2	0	0	2	5	5	5	2
2016	21	10	6	6	4	5	13	1	7	3	7	0	0	0	5	6	2	4	1	0	1	5	3	3	1	5	5	3	7	2	3	0
2017	32	8	4	28	14	14	19	11	12	5	16	1	4	2	10	7	2	2	10	4	1	5	4	1	0	6	6	4	11	21	9	2
NA	6	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**306**	**76**	**41**	**131**	**51**	**72**	**139**	**55**	**131**	**34**	**78**	**46**	**21**	**26**	**65**	**63**	**24**	**37**	**38**	**15**	**18**	**37**	**32**	**18**	**41**	**37**	**42**	**30**	**57**	**80**	**47**	**12**

ARTICLES THAT MENTION SELECTED PRACTICES, BUT DO NOT DIRECTLY MENTION BUILDING AMERICA

	air leakage	duct leakage	insulation	thermal bridging	advanced framing	Air Barrier	Air Infiltration	Air Sealing	Thermal bypass	Attic Insulation	Radiant Barrier	Attic Interface	Ceiling interface	Floor Insulation	Insulated Concrete Forms	Thermal Alignment	Insulation Placement	Structural Insulated Panels	Unconditioned + Infiltration	Unconditioned + Insulation	Unconditioned + Sealing	Unvented Crawl Spaces	Systems OR Combined Space and	whole-building pressurization testing	Blower door testing	Duct pressure testing	Ducts + conditioned space	Moisture management	Whole-home approach OR home as a system	Vapor retarder classification system	Bulk water management
Pre-1994	0	4	0	4	2	0	5	6	2	1	3	0	4	3	2	1	0	5	3	1	2	2	2	1	4	1	2	1	1	1	0
1994	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	1	1
1995	0	1	0	1	1	0	1	1	1	0	0	1	0	0	1	1	0	0	0	0	1	2	0	0	0	0	0	0	0	1	1
1996	0	2	0	6	0	0	1	1	2	0	1	2	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
1997	0	0	0	3	1	0	1	2	0	1	1	0	0	0	1	0	0	0	1	0	1	2	1	0	1	0	0	0	1	0	0
1998	0	2	0	7	1	0	0	4	0	0	0	1	1	1	0	0	0	0	0	0	3	1	1	0	1	0	0	0	1	0	0
1999	0	3	0	6	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1	0	3	1	0
2000	0	1	0	8	1	0	0	3	1	0	0	0	0	0	1	3	0	0	1	0	1	0	0	0	0	1	0	0	2	0	1
2001	0	3	1	2	0	0	1	3	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
2002	0	4	4	9	0	1	4	3	1	1	1	1	1	0	1	0	0	3	2	1	1	1	1	0	1	0	1	0	2	3	0
2003	0	1	2	2	0	0	0	0	1	0	0	3	1	1	0	1	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0
2004	0	3	0	9	1	0	2	3	1	0	1	1	0	1	1	3	1	0	2	0	1	1	0	0	0	1	0	0	5	0	0
2005	0	5	2	3	2	0	4	1	4	1	1	2	1	2	1	1	1	0	3	0	1	3	2	0	0	1	1	1	0	2	0
2006	0	1	2	11	1	0	4	1	1	0	1	1	0	0	2	3	2	2	3	0	1	3	1	0	1	1	0	0	1	1	1
2007	0	5	1	7	1	2	6	1	3	0	1	4	3	4	0	2	0	2	2	0	1	1	0	3	2	1	1	0	3	2	0
2008	0	4	0	13	0	0	5	3	1	2	0	3	0	0	2	6	0	0	4	2	2	3	2	0	2	1	0	1	3	0	1

	air leakage	duct leakage	insulation	thermal bridging	advanced framing	Air Barrier	Air Infiltration	Air Sealing	Thermal bypass	Attic Insulation	Radiant Barrier	Attic Interface	Ceiling interface	Floor Insulation	Insulated Concrete Forms	Thermal Alignment	Insulation Placement	Structural Insulated Panels	Unconditioned + Infiltration	Unconditioned + Insulation	Unconditioned + Sealing	Unvented Crawl Spaces	Systems OR Combined Space and	whole-building pressurization testing	Blower door testing	Duct pressure testing	Ducts + conditioned space	Moisture management	Whole-home approach OR home as a system	Vapor retarder classification system	Bulk water management
2009	0	2	1	9	3	1	5	2	2	1	0	3	0	1	0	4	1	0	1	0	1	3	1	0	3	0	2	0	0	0	2
2010	0	7	1	6	6	2	4	5	6	2	2	3	2	1	0	1	2	2	7	1	4	3	2	0	1	0	6	2	0	2	2
2011	0	3	2	11	5	3	4	4	7	4	2	1	1	1	0	4	2	1	4	4	2	5	4	1	2	1	7	2	3	1	0
2012	0	2	1	8	7	2	9	2	3	1	2	2	2	2	3	3	1	0	1	0	0	3	2	1	1	0	1	1	4	2	1
2013	0	5	4	4	5	2	3	4	8	1	5	5	1	2	0	2	0	1	0	0	1	2	2	1	0	1	1	0	3	2	0
2014	0	1	0	2	4	0	6	0	5	2	2	2	1	1	0	0	2	3	2	0	4	4	4	2	1	1	4	2	3	1	3
2015	0	4	0	1	4	1	7	1	1	2	1	0	0	3	1	1	4	1	0	1	4	3	3	4	1	1	1	1	2	2	4
2016	0	5	3	2	8	4	7	3	8	2	2	1	0	0	3	7	2	3	3	0	2	5	2	1	1	4	5	2	3	2	1
2017	0	8	4	12	10	11	13	8	12	3	15	1	3	1	10	5	0	2	11	3	1	7	5	1	0	5	8	3	8	16	4
NA	0	4	0	4	2	0	5	6	2	1	3	0	4	3	2	1	0	5	3	1	2	2	2	1	4	1	2	1	1	1	0
TOTAL	**0**	**76**	**29**	**146**	**63**	**29**	**92**	**62**	**70**	**24**	**41**	**38**	**22**	**24**	**30**	**49**	**18**	**27**	**50**	**13**	**35**	**54**	**37**	**16**	**23**	**21**	**43**	**17**	**49**	**41**	**22**

APPENDIX L. CALCULATIONS INCLUSIVE OF EFFECTIVE USEFUL LIFE CONSIDERATIONS

ENERGY SAVINGS BENEFITS THROUGH 2039

YEAR	ENERGY SAVINGS BENEFITS		
	CONSTANT 2015$, UNDISCOUNTED (THOUSANDS)	CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS)	CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS)
2006	$ 55,218	$ 22,918	$ 37,604
2007	$ 92,895	$ 36,033	$ 61,419
2008	$ 127,117	$ 46,082	$ 81,598
2009	$ 155,574	$ 52,708	$ 96,956
2010	$ 187,055	$ 59,228	$ 113,180
2011	$ 219,181	$ 64,860	$ 128,756
2012	$ 289,285	$ 80,004	$ 164,988
2013	$ 367,688	$ 95,035	$ 203,596
2014	$ 466,639	$ 112,720	$ 250,862
2015	$ 531,089	$ 119,896	$ 277,194
2016	$ 515,596	$ 108,783	$ 261,269
2017	$ 534,779	$ 105,449	$ 263,097
2018	$ 534,658	$ 98,528	$ 255,376
2019	$ 542,584	$ 93,448	$ 251,614
2020	$ 551,786	$ 88,816	$ 248,428
2021	$ 557,147	$ 83,812	$ 243,536
2022	$ 567,255	$ 79,750	$ 240,732
2023	$ 573,906	$ 75,406	$ 236,461
2024	$ 577,173	$ 70,874	$ 230,881
2025	$ 585,176	$ 67,156	$ 227,264
2026	$ 592,172	$ 63,513	$ 223,283
2027	$ 603,576	$ 60,501	$ 220,954
2028	$ 607,428	$ 56,904	$ 215,887
2029	$ 611,491	$ 53,537	$ 211,001
2030	$ 614,177	$ 50,254	$ 205,755

YEAR	ENERGY SAVINGS BENEFITS		
	CONSTANT 2015$, UNDISCOUNTED (THOUSANDS)	CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS)	CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS)
2031	$ 616,734	$ 47,162	$ 200,594
2032	$ 617,916	$ 44,161	$ 195,125
2033	$ 617,408	$ 41,238	$ 189,286
2034	$ 619,564	$ 38,675	$ 184,414
2035	$ 625,076	$ 36,467	$ 180,636
2036	$ 628,014	$ 34,241	$ 176,199
2037	$ 630,475	$ 32,126	$ 171,738
2038	$ 632,226	$ 30,108	$ 167,199
2039	$ 634,601	$ 28,244	$ 162,938
Total: 2006 - 2015	**$ 2,491,740**	**$ 689,484**	**$ 1,416,155**
Total: 2006 - 2039	**$ 16,682,657**	**$ 2,178,640**	**$ 6,579,822**

TOTAL EMISSIONS AVOIDED THROUGH 2039 (TONS)

YEAR	TOTAL EMISSIONS AVOIDED PER YEAR (TONS)			
	$PM_{2.5}$	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
2016	94	708	771	1,223,121
2017	94	707	741	1,219,362
2018	94	707	712	1,215,604
2019	95	720	714	1,215,937
2020	96	732	716	1,216,269
2021	95	724	709	1,209,778
2022	95	715	701	1,203,286
2023	94	707	694	1,196,794
2024	94	699	686	1,190,302
2025	94	690	679	1,183,811
2026	94	691	674	1,183,491
2027	94	692	669	1,183,172
2028	93	693	664	1,182,852
2029	93	694	659	1,182,533
2030	93	695	655	1,182,213
2031	85	632	589	1,075,360
2032	79	582	541	996,095
2033	74	538	500	932,439
2034	68	486	454	853,012
2035	62	433	406	768,705
2036	55	383	361	686,474
2037	43	292	277	530,101
2038	29	192	183	353,234
2039	14	93	89	173,290
TOTAL	**1,922**	**14,207**	**13,848**	**24,357,235**

TOTAL MONETARY DAMAGES AVOIDED PER YEAR THROUGH 2039

TOTAL DAMAGES AVOIDED PER YEAR (2015$)				
	3% DISCOUNT RATE		7% DISCOUNT RATE	
YEAR	LOW ESTIMATE	HIGH ESTIMATE	LOW ESTIMATE	HIGH ESTIMATE
2006	14,019,544	31,375,308	12,505,283	28,711,333
2007	24,267,124	53,459,923	20,839,338	48,311,570
2008	27,850,164	62,514,681	24,835,433	57,398,531
2009	31,823,083	71,527,486	28,560,232	65,444,624
2010	36,545,206	81,970,888	32,901,020	74,506,246
2011	41,520,371	92,219,587	36,463,063	83,600,546
2012	50,904,827	112,871,234	44,891,728	101,747,756
2013	62,274,602	138,393,995	55,045,481	124,312,420
2014	70,313,006	158,888,300	63,849,422	144,545,259
2015	88,448,699	196,977,920	78,582,022	177,454,836
2016	44,511,947	99,571,908	39,914,637	89,457,785
2017	45,240,582	101,081,021	40,659,355	91,020,228
2018	46,143,188	102,339,921	40,628,553	92,337,499
2019	47,596,954	105,482,388	41,936,124	95,349,124
2020	48,204,832	107,625,360	42,553,020	97,361,253
2021	48,622,779	108,449,796	43,020,661	97,245,559
2022	48,243,225	108,993,929	42,614,571	98,919,631
2023	49,581,076	110,513,246	44,078,345	99,507,785
2024	49,185,433	110,980,605	43,657,795	101,096,117
2025	49,538,211	111,678,358	44,061,081	100,871,672
2026	50,371,534	112,449,728	44,893,787	102,657,517
2027	50,453,746	114,992,048	44,975,383	103,428,493
2028	52,232,200	116,490,636	46,753,221	105,939,770

TOTAL DAMAGES AVOIDED PER YEAR (2015$)				
YEAR	3% DISCOUNT RATE		7% DISCOUNT RATE	
	LOW ESTIMATE	HIGH ESTIMATE	LOW ESTIMATE	HIGH ESTIMATE
2029	52,313,604	119,034,468	46,834,008	106,709,577
2030	53,149,581	119,811,035	47,669,369	108,497,045
2031	48,350,223	108,991,741	43,362,951	98,699,429
2032	44,650,755	100,651,852	40,042,718	91,148,855
2033	41,436,875	93,406,280	37,156,109	84,592,707
2034	37,649,274	84,867,623	33,755,897	76,865,090
2035	33,691,421	75,945,398	30,204,181	68,788,484
2036	29,949,153	67,509,406	26,847,198	61,150,419
2037	22,981,664	51,803,258	20,598,659	46,927,412
2038	15,204,066	34,271,286	13,625,408	31,048,444
2039	7,437,639	16,764,938	6,664,605	15,189,316

Note: Values for each year reflect the present value as realized that year.

PRESENT MONETIZED VALUE OF ENVIRONMENTAL HEALTH BENEFITS THROUGH 2039: LOW, HIGH, AND AVERAGE VALUES AT 3% AND 7% DISCOUNT RATE

YEAR	3% DISCOUNT RATE			7% DISCOUNT RATE		
	LOW ESTIMATE	HIGH ESTIMATE	AVERAGE	LOW ESTIMATE	HIGH ESTIMATE	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

YEAR	3% DISCOUNT RATE			7% DISCOUNT RATE		
	LOW ESTIMATE	HIGH ESTIMATE	AVERAGE	LOW ESTIMATE	HIGH ESTIMATE	AVERAGE
2016	$22,555,663	$50,456,350	$36,506,006	$8,421,429	$18,874,339	$13,647,884
2017	$22,257,171	$49,729,192	$35,993,181	$8,017,340	$17,947,657	$12,982,499
2018	$22,040,028	$48,882,075	$35,461,052	$7,487,165	$17,016,262	$12,251,714
2019	$22,072,244	$48,915,588	$35,493,916	$7,222,550	$16,421,733	$11,822,142
2020	$21,703,046	$48,455,683	$35,079,364	$6,849,343	$15,671,287	$11,260,315
2021	$21,253,608	$47,404,723	$34,329,166	$6,471,602	$14,628,659	$10,550,130
2022	$20,473,495	$46,254,923	$33,364,209	$5,991,135	$13,906,999	$9,949,067
2023	$20,428,401	$45,533,682	$32,981,041	$5,791,519	$13,074,474	$9,432,996
2024	$19,675,134	$44,394,410	$32,034,772	$5,360,992	$12,414,175	$8,887,584
2025	$19,239,080	$43,372,355	$31,305,717	$5,056,555	$11,576,275	$8,316,415
2026	$18,992,928	$42,399,932	$30,696,430	$4,815,064	$11,010,489	$7,912,776
2027	$18,469,832	$42,095,662	$30,282,747	$4,508,239	$10,367,457	$7,437,848
2028	$18,563,960	$41,402,191	$29,983,076	$4,379,856	$9,924,470	$7,152,163
2029	$18,051,351	$41,074,077	$29,562,714	$4,100,396	$9,342,603	$6,721,500
2030	$17,805,645	$40,137,903	$28,971,774	$3,900,499	$8,877,663	$6,389,081
2031	$15,726,031	$35,449,835	$25,587,933	$3,316,010	$7,547,647	$5,431,828
2032	$14,099,776	$31,783,753	$22,941,765	$2,861,783	$6,514,250	$4,688,016
2033	$12,703,786	$28,636,653	$20,670,220	$2,481,759	$5,650,180	$4,065,970
2034	$11,206,386	$25,261,027	$18,233,706	$2,107,149	$4,798,160	$3,452,655
2035	$9,736,235	$21,946,900	$15,841,568	$1,762,093	$4,013,078	$2,887,586
2036	$8,402,704	$18,940,821	$13,671,762	$1,463,784	$3,334,091	$2,398,938
2037	$6,260,064	$14,110,888	$10,185,476	$1,049,623	$2,391,227	$1,720,425
2038	$4,020,868	$9,063,386	$6,542,127	$648,873	$1,478,599	$1,063,736
2039	$1,909,668	$4,304,521	$3,107,095	$296,621	$676,028	$486,324
TOTAL	**$387,647,104**	**$870,006,530**	**$628,826,817**	**$104,361,380**	**$237,457,804**	**$170,909,592**

ENVIRONMENTAL HEALTH BENEFITS THROUGH 2039: UNDISCOUNTED, 3%, AND 7% DISCOUNT RATE

YEAR	ENVIRONMENTAL HEALTH BENEFITS		
	CONSTANT 2015$, UNDISCOUNTED (THOUSANDS)	CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS)	CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS)
2006	$ 21,653	$ 8,553	$ 15,457
2007	$ 36,719	$ 13,411	$ 25,695
2008	$ 43,150	$ 14,905	$ 29,003

YEAR	ENVIRONMENTAL HEALTH BENEFITS		
	CONSTANT 2015$, UNDISCOUNTED (THOUSANDS)	CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS)	CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS)
2009	$ 49,339	$ 15,924	$ 32,205
2010	$ 56,481	$ 17,004	$ 35,855
2011	$ 63,451	$ 17,765	$ 39,282
2012	$ 77,604	$ 20,277	$ 46,703
2013	$ 95,007	$ 23,179	$ 55,557
2014	$ 109,399	$ 25,170	$ 61,608
2015	$ 135,366	$ 28,901	$ 74,487
2016	$ 68,364	$ 13,648	$ 36,506
2017	$ 69,500	$ 12,982	$ 35,993
2018	$ 70,362	$ 12,252	$ 35,461
2019	$ 72,591	$ 11,822	$ 35,494
2020	$ 73,936	$ 11,260	$ 35,079
2021	$ 74,335	$ 10,550	$ 34,329
2022	$ 74,693	$ 9,949	$ 33,364
2023	$ 75,920	$ 9,433	$ 32,981
2024	$ 76,230	$ 8,888	$ 32,035
2025	$ 76,537	$ 8,316	$ 31,306
2026	$ 77,593	$ 7,913	$ 30,696
2027	$ 78,462	$ 7,438	$ 30,283
2028	$ 80,354	$ 7,152	$ 29,983
2029	$ 81,223	$ 6,721	$ 29,563
2030	$ 82,282	$ 6,389	$ 28,972
2031	$ 74,851	$ 5,432	$ 25,588
2032	$ 69,124	$ 4,688	$ 22,942
2033	$ 64,148	$ 4,066	$ 20,670
2034	$ 58,284	$ 3,453	$ 18,234
2035	$ 52,157	$ 2,888	$ 15,842
2036	$ 46,364	$ 2,399	$ 13,672
2037	$ 35,578	$ 1,720	$ 10,185
2038	$ 23,537	$ 1,064	$ 6,542
2039	$ 11,514	$ 486	$ 3,107
Total: 2006 - 2015	**$ 688,168**	**$ 185,090**	**$ 415,854**
Total: 2006 - 2039	**$ 2,256,109**	**$ 356,000**	**$ 1,044,681**

COMBINED ENERGY AND ENVIRONMENTAL HEALTH BENEFITS THROUGH 2039

YEAR	TOTAL BENEFITS		
	CONSTANT 2015$, UNDISCOUNTED (THOUSANDS)	CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS)	CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS)
2006	$ 76,871	$ 31,471	$ 53,061
2007	$ 129,614	$ 49,444	$ 87,115
2008	$ 170,267	$ 60,987	$ 110,602
2009	$ 204,913	$ 68,632	$ 129,161
2010	$ 243,536	$ 76,232	$ 149,035
2011	$ 282,631	$ 82,624	$ 168,038
2012	$ 366,889	$ 100,282	$ 211,692
2013	$ 462,694	$ 118,214	$ 259,153
2014	$ 576,038	$ 137,890	$ 312,470
2015	$ 666,455	$ 148,797	$ 351,681
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

YEAR	TOTAL BENEFITS		
	CONSTANT 2015$, UNDISCOUNTED (THOUSANDS)	CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS)	CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS)
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 - 2015	**$ 3,179,908**	**$ 874,574**	**$ 1,832,009**
Total: 2006 - 2039	**$ 18,938,766**	**$ 2,534,640**	**$ 7,624,503**

NET BENEFITS THROUGH 2039

YEAR	NET BENEFITS		
	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

YEAR	NET BENEFITS		
	CONSTANT 2015$, UNDISCOUNTED (THOUSANDS)	CONSTANT 2015$, DISCOUNTED AT 7% (THOUSANDS)	CONSTANT 2015$, DISCOUNTED AT 3% (THOUSANDS)
2013	$ 436,665	$ 111,017	$ 244,309
2014	$ 553,502	$ 132,066	$ 299,992
2015	$ 653,657	$ 145,706	$ 344,801
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 - 2015	**$ 2,811,106**	**$ 712,526**	**$ 1,579,008**
Total: 2006 - 2039	**$ 18,569,964**	**$ 2,372,592**	**$ 7,371,502**