Building America: Retrospective Evaluation of a Unique DOE Demonstration and Market Diffusion Program

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ABSTRACT

The IEc team applied a mixed-methods design to evaluate the US DOE's Building America (BA) program, a residential large-scale technology demonstration, peer-to-peer information exchange and market diffusion program for residential energy efficiency (EE) technologies and practices. BA advanced the systems engineering, whole house approach to residential EE that has become the standard practice. BA's marque intervention is the use of building teams, comprised of production homebuilders and building science experts, that work together to conduct large scale demonstrations of EE practices and refine approaches until they are cost-effective.[1] Many EE construction approaches have gained market acceptance as a result of BA's work, including the air tightness, duct tightness, envelope insulation, and thermal bridging requirements that were integrated into EnergyStar Homes and into IECC model energy code.

The large size, complexity, longevity, and multifaceted nature of the Building America program raises several evaluation challenges, including developing a cost-effective methodology that can address 1) the R&D and market diffusion aspects of the program, 2) economic, energy, and environmental impacts of the program, and 3) the attribution of program results to the program, despite many rival factors. The IEc team used a modeling approach to estimate energy savings, and a Delphi panel of building science experts to consider and assign attribution of the energy savings for the four practices to the Building America program. We analyzed health impacts from reduced electricity generation. We used in-depth interviews with builders and a citation analysis as complementary qualitative methods. The study's final report is available online.

Introduction and Background

This evaluation focuses on the research and development, demonstration, and market transformation activities conducted by the U.S. Department of Energy's (DOE) Building America (BA) program, and, to a lesser extent, model code development activities conducted by DOE's Building Energy Codes Program (BECP). The study addresses the research question: "How did the BA program impact the residential construction market?" and "Do the benefits of the program outweigh the program's costs?" The study estimates the economic rate of return by comparing the economic benefits

[1] In the U.S, the term production homebuilder refers to a homebuilder that builds many homes using the same or similar template, as opposed to a custom homebuilder, which builds unique homes. Production builders are far more common in the US market for new homes.

attributable to a subset of key practices advanced by BA to DOE's total investment in the BA program from its inception in 1994 through 2015.

BA supports research, development, and demonstration projects that aim to advance cost-effective energy efficiency technologies and practices in the new home and retrofit sectors. BA is based on a comprehensive "whole-house" approach to advancing residential energy efficiency while maintaining housing comfort and affordability. BA brings together building science experts, builders, developers, designers, manufacturers, and other segments of the housing industry to test and demonstrate housing solutions in real-world settings. These efforts aim to encourage the market's adoption of proven, energy-saving technologies and practices. Specifically, BA facilitates market adoption by influencing energy efficiency provisions of voluntary above-code programs--, Energy Star for Homes (ES Homes), Home Performance with Energy Star, Zero Energy Ready Homes) and other above code programs.. Over time, the BA program aims for these practices to become standard practice, and to be adopted into model building energy codes – e.g., the International Energy Conservation Code (IECC).

Scope

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

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

- **Air Tightness**: From 2006 to 2012, the IECC gradually reduced the air leakage rate allowed in new homes from about 11-14 air changes per hour at 50 Pascals (ACH50) to three ACH50 through stricter prescriptive requirements for air sealing. In addition, beginning in 2012, IECC required blower door testing to verify compliance with the air tightness requirements. ES Homes began implementing the Thermal Bypass Checklist in 2006, mandating even tighter building envelopes.

- **Duct Tightness:** IECC began mandating duct leakage testing for ducts outside conditioned spaces in 2009, and tightened the leakage requirement in 2012. ES Homes has maintained strict duct leakage testing requirements since 2006.

- **Envelope Insulation**: IECC has gradually increased the level of insulation required for the building envelope, including attics, walls, and foundations. Only small changes were made in a few climate zones in IECC 2006, but substantial increases in R-value were made in IECC 2009 and 2012. These changes carried over to ES Homes, which does not have additional requirements for envelope insulation beyond existing code. Changes to window performance were not included in this study because the evaluation was not able to establish clear attribution to BA.

- **Thermal Bridging:** In 2012, IECC began to require a layer of continuous insulating sheathing in colder climates to reduce thermal bridging through wall framing. In addition, advanced framing techniques developed by BA reduced the average framing factor significantly, shifting from 2x4 16” on-center to 2x6 24” on-center framing.

Methodology

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

Table 1. Summary of evaluation methods

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

Approach Used to Determine BA Program Impacts

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

Approach Used to Determine Energy Impacts

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

The energy modeling was conducted using a range of housing attributes in several locations throughout the U.S., with adjustment factors applied to the results to accurately extrapolate them over the broad range of housing characteristics and weather conditions present in different parts of the country. The results were rolled up nationwide using state-level weighting factors and data for actual housing starts (approximately 9 million) and actual ES Homes (approximately 1 million) built over the period 2006-2015.

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

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

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

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

Approach Used to Determine Environmental Health Impacts

As electricity generation from power plants falls in response to the reduction in residential electricity demand, power plant emissions of carbon dioxide (CO_2), sulfur dioxide (SO_2), oxides of nitrogen (NOx), and fine particulate matter (PM2.5) also decline. A reduction in the emissions of these pollutants leads to significant public health improvements, namely reduced incidences of premature mortality and various morbidity impacts. The evaluation uses the attribution-adjusted energy impacts (i.e., the modeled energy savings adjusted downward based on the Delphi panel results) to estimate environmental health benefits that result from reduced air emissions due to avoided electricity generation. Health benefits are reported two ways: in terms of incident rates and in terms of the dollar value of avoided adverse health events. These estimates reflect the full suite of health impacts that the U.S. Environmental Protection Agency (EPA) considers in its regulatory impact analyses of air pollution policy. However, these values do not account for health improvements that may result from improved indoor air quality in homes.

Approach Used to Determine Knowledge Impacts

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

Approach Used to Determine Economic Performance

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

Sources of Uncertainty and Study Limitations

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

Table 7. Sources of uncertainty, directionality, and approach for addressing

Source of uncertainty	Directionality	Approach for addressing
Code compliance rates	Unclear	The energy modeling exercise assumes full compliance with code, as there is no defensible way to adjust for non-compliance in the context of this study's modeling approach. A PNNL field study suggests that compliance may average 100% because of over-compliance – i.e., builders who comply with code frequently exceed the energy use reduction targets in code.
Exclusion of California from energy modeling analysis	Understates program benefits	The study excluded California from the estimate of energy savings because of the inability to clearly attribute aspects of CA Title 24 (California's state energy code) to BA. However, qualitative evidence suggests that BA helped builders comply with CA Title 24 in a cost-effective manner.
Selection of BA activities to evaluate	Understates program benefits	The study only quantified the benefits of four practices, and there are many more the study did not quantify that may have produced additional energy savings. Also, many building science experts interviewed stated there are benefits associated with BA moisture management, but the study was not able to quantify moisture management benefits. The study was also not able to quantify the benefits of "enablers," such as climate maps, that facilitate but do not directly produce energy savings.

Table 7. Sources of uncertainty, directionality, and approach for addressing

Source of uncertainty	Directionality	Approach for addressing
Timeframe for effective useful life benefits: from home construction to first major renovation	Understates program benefits	The study limits remaining effective useful life benefits to the average time until major renovation (25 years). This is because *some* renovations trigger the need to update to the current code. Also EULs for the practices themselves vary between 20-30 years. However, the effective useful life of the affected components in three of the four studied building practices (e.g., walls) is much longer than 25 years.
Building energy modeling assumptions	Understates program benefits	The study takes a conservative approach to modeling energy savings, such as: 1) excluding California from the energy modeling analysis (see above); excluding energy savings prior to Energy Star version 2.0 (due to the timeline of BA activities and when practices were adopted into ES), which greatly reduces reported savings from duct leakage; and 3) assumes the bare minimum performance levels, even though many homes would exceed these levels.

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

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

- **Limited interview coverage.** While interviews play an important role in this evaluation, the Paperwork Reduction Act limits systematic data collection from non-federal entities to nine people/organizations without obtaining an ICR. As such, the interviews and Delphi panel were limited to nine non-federal respondents per type of interview.

  We selected Delphi panelists based on their professional reputation and experience, and their ability to provide informed responses to our specific questions. However, the small number of respondents may not be representative of their peer groups. It should be noted, however, that guidance on Delphi panel construction indicates that panels with as few as 10 individuals are recommended where qualifications for panelists are homogeneous, as they were for this panel (Okoli and Pawlowski 2004, Hsu and Sanford 2007). Furthermore, some guidance indicates that "researchers should use the minimally sufficient number of subjects for the task at hand." (Hsu and Sanford).

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

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

  Limited technology coverage: This evaluation focuses primarily on four practices that result in significant energy savings and in which BA played a direct role. However, BA has worked on many additional technologies and practices that the evaluation was not able to address.

Results

Energy Impacts

Table 2 provides estimated total, cumulative nationwide site energy savings for all four studied practices combined. The energy modeling analysis for the four selected practices found an estimated cumulative site energy savings of 250 trillion Btu or nearly 18.000 GWh, or approximately 6% of site energy use for houses built in the U.S. between 2006 and 2015 (excluding the state of California).

Table 2. Gross total nationwide site energy savings based on modeling study

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

The Delphi panel used in this study resulted in the following adjustments presented in Table 3 below. Net energy savings – the portion of savings that can be fairly attributed to the BA program – were estimated at approximately 140 trillion BTU using the mean attribution estimate for each practice. Using the low-end and high-end estimates, the portion of energy savings attributed to the program ranges from 55 trillion BTU to 206 trillion BTU. As noted above, Delphi panelists were asked to consider BA's influence on the timing and scale of market adoption of the four practices. Overall, panel members mostly agreed that the selected practices would have been adopted at a later point in time, and at a smaller scale, without the BA program. The attribution estimates in Table 3 reflect the Delphi panel's assessment of BA's role in accelerating the timing and increasing the scale of market adoption of the four practices. Influential external factors mentioned by panelists included above code programs, utility incentives, manufacturer influence, and the influence of other experts and advocates (in particular for duct leakage).

Table 3. Attribution adjustments from Delphi Panel

Practice	Gross energy saved (2006 – 2015) (trillion BTU)	Attribution to BA	Net energy saved (2006-2015) (trillion BTU)
Air Tightness	183	57%	104
Duct Tightness	26	64%	16
Insulation	39	45%	17
Thermal Bridging	3	66%	2
Total	**250**		**140**

Table 4 summarizes the net energy savings, overall and by fuel source, and the associated energy cost savings attributable to the BA program for the four practices. In keeping with DOE's evaluation guidance, this study uses the 7% real discount rate set by the Office of Management and Budget (OMB) as the primary discount rate. Cash flows are discounted back to 1994 (the first year of DOE's investment in the BA program) in constant \$2015 (the cutoff year for the study), also in keeping with DOE evaluation guidance.[2] At the 7% real discount rate, energy cost savings through 2015 are estimated at \$689 million. The evaluators also conducted a sensitivity analysis of the estimated financial savings due to attributed energy savings. The sensitivity analysis uses the maximum and minimum attribution percentages from the Delphi panel to calculate upper- and lower-bound figures. The upper-bound estimate yields energy savings of over \$1 billion. The lower-bound estimate yields \$271 million in energy savings, which exceeds the program cost of \$162 million.

Table 4. Energy and cost savings (2006-2015)

Metric	Unit of measure	Base case	Low-end estimate	High-end estimate
Total energy savings – all fuels	Million MMBtu	139.8	55.3	205.5
Electricity savings	Million kWh	9,992	3,889	14,544
Natural gas savings	Million therms	1,021	406	1,504
Fuel oil savings	Million gallons	26	10	39
Monetary value of energy savings @ 7% real discount rate (discount year = 1994)	Million, 2015\$	\$689	\$271	\$1,010
Monetary value of energy savings @ 3% real discount rate (discount year = 1994)	Million, 2015\$	\$1,416	\$557	\$2,074
Monetary value of energy savings undiscounted	Million, 2015\$	\$2,492	\$980	\$3,650

Environmental Health Impacts

The residential electricity savings associated with the BA program result in air quality benefits from avoided electricity generation, in addition to financial savings to homeowners. As shown in Table 5,

[2] Although the benefits for the four selected practices began to accrue in 2006, the study discounts benefits and costs to 1994, as 1994 was the first year that program costs were incurred. The study compares the discounted benefits for the four practices to discounted total program costs.

the monetary value of avoided adverse health events due to reduced air emissions is $185 million (at a 7% real discount rate).[3]

Table 5. Environmental health impacts

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

Social Rate of Return

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

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

Table 6. Economic performance metrics

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

[3] The base case is used for all calculations.

* While benefits for the four selected practices began to accrue in 2006, the program costs and activities associated with bringing the four practices to market go back to the program's inception in 1994.
** The $713 million includes $689 million energy cost savings plus $185 million environmental health benefits, minus $162 million program costs. Note: Total may not sum exactly due to rounding.
*** The 3% discount rate is presented for informational purposes only; the 7% rate is the primary discount rate for this evaluation.

The evaluation has a primarily retrospective focus; however, because energy savings in affected homes persist over time, the study also analyzed the energy savings that will continue to accrue beyond 2015 from homes built during the study period. The evaluators calculated remaining useful life benefits at 25 years on average as discussed above. Thus, the last year of the analysis of remaining effective useful life benefits is 2039. In accordance with DOE evaluation guidance, the evaluation reports separately for retrospective benefits and effective useful life benefits. Including the effective useful life benefits for homes built during the study period increases the energy and health, benefits as follows:

- **Energy impacts:** At the 7% real discount rate, energy savings through 2015 were estimated at $689 million. Including effective useful life savings brings the total to almost $2.2 billion.
- **Environmental health impacts:** Through 2015, the monetary value of avoided adverse health events due to reduced air emissions was $185 million at a 7% real discount rate. Including effective useful life benefits increases the total from $185 million to $356 million.

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

- **Net present value at 7% real discount rate**: increases from $713 million to over $2.3 billion.
- **Net present value at 3% real discount rate**: increases from over $1.5 billion to over $7.3 billion.
- **Benefit-to-cost ratio at 7% real discount rate:** increases from 5.4 to 15.6.
- **Benefit-to-cost ratio at 3% real discount rate:** increases from 7.2 to 30.1.
- **Social return on EERE investment:** increases from 30.2% to 32.4%.

Knowledge Impacts

The citation analysis focused on 306 articles in 15 trade journals that mention BA, alone or in combination with one or more technologies or practices that BA worked on. The number of articles mentioning BA was relatively flat from the program's inception in 1994 through 2000. It spiked in 2003, which coincides with an IECC code update. We also observe spikes in 2009 and 2011, which coincide with the 2009 and 2012 updates to the IECC. Air sealing, air barriers, and insulation were the most common topics, which further reinforces this evaluation's focus on the energy efficiency results of these practices. Twenty-one of the 306 articles (6.9%) were cited a total of 174 times (8.3 times on average). Of the 21 cited articles, just over half were cited five times or less, while 11% were cited more than 20 times. Insulation and air leakage were the most frequently discussed technologies and practices in the 21 cited articles. The final report provides tables with the citation counts (IEc 2018). The analysis also looked at who is citing the original articles. There appears to be some degree of cross-citing by the 15 journals, and by DOE, NREL, and BA teams. Citing entities also include several trade journals with an energy and/or engineering focus, as well as several international journals. Citations were also found in professional conference proceedings, which align with interview findings about conferences as an important method for disseminating BA's research.

Conclusions

The study addresses the research question: "How did the BA program impact the residential construction market?" and "Do the benefits of the program outweigh the program's costs?" The answers to these questions are both positive; BA has been successful in helping to mainstream energy efficiency practices into typical new homes, and program benefits outweigh costs by at least five to one.

Acknowledgements

The authors wish to thank the program managers, building science experts, builders, analysts, and other individuals who contributed their time and expertise to this evaluation. Jack Mayernik (NREL), Mark Friedrichs (DOE BTO), and Yaw Agyeman (LBNL) provided project management and oversight. Eric Werling and David Cohan provided useful program information about Building America (BA) and the Building Energy Codes Program (BECP), respectively. Ed Pollock provided a historical overview of BA. Rosemarie Bartlett and program analysts at PNNL provided valuable input for the analysis of energy code changes and code compliance. Lawrence Berkeley National Laboratory (LBNL) and PNNL provided information about BA publications for the publication citation analysis. Jeff Dowd provided review of the evaluation project. Cheryl Oros, Ed Vine, Paula Gruendling, and Greg Tassey served as external peer reviewers for the Evaluation Plan. Lori Lewis, Alan O'Connor, and Maryann Feldman were the peer reviewers for the Evaluation Report. IEc was the lead contractor for this project. Angela Vitulli and Daniel Kaufman, Principals at IEc, managed the contractor team. They were assisted by Jason Price, Nora Scherer, Dan Leistra-Jones, Sahil Gulati, Rachel Mak, Jacob Lehr, Michelle Predi, and Megan Willis-Jackson. Rosalie Ruegg (TIA Consulting) provided input on the evaluation design, and reviewed internal drafts of the Evaluation Plan and Final Report. Peter Yost (BuildingGreen) assisted with the selection of building energy practices for portfolio analysis. Robert Hendron (Hendron Eenrgy Consulting Services) conducted the building energy modeling analysis, and Ren Anderson of Eigen Energy advised on building modeling approach. Ross Strategic conducted scoping interviews with program managers and staff.

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