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BUILDING TECHNOLOGIES PROGRAM

Building America Systems Integration Research Annual Report: FY 2012

NREL Technical Management Team

May 2013

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Building America Systems Integration Research Annual Report: FY 2012

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May 2013

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Definitions

ACH50	Air changes per hour at 50 Pascals
ARBI	Alliance for Residential Building Innovation
ARIES	Advanced Residential Integrated Energy Solutions
BA	Building America
BAB	Building America Benchmark
BA-PIRC	Building America Partnership for Improved Residential Construction
BARA	Building America Retrofit Alliance
BED	Buried or encapsulated duct
BESTEST	Building Energy Simulation Test
BESTEST-EX	Building Energy Simulation Test for Existing Homes
BSC	Building Science Corporation
CARB	Consortium for Advanced Residential Buildings
CZ	Climate zone
DOE	U.S. Department of Energy
EEM	Energy efficiency measure
ESMP	Energy Savings Measure Package
FSEC	Florida Solar Energy Center
ft	Foot
ft^2	Square foot
HERS	Home Energy Rating System
HPWH	Heat pump water heater
HVAC	Heating, ventilation, and air conditioning
ICF	Insulating concrete form
IECC	International Energy Conservation Code
in.	Inch
NAHB-RC	National Association of Home Builders-Research Center
NCTH	New Construction Test House
NGBS	National Green Building Standard
NREL	National Renewable Energy Laboratory
NSP	Neighborhood Stabilization Program
PARR	Partnership for Advanced Residential Retrofit
PV	Photovoltaic
RH	Relative humidity
RHA	Raleigh Housing Authority
SEER	Seasonal energy efficiency ratio
STC	Standing Technical Committee
WSP	Water separation plane

Executive Summary

This Building America FY 2012 Annual Report includes an overview of the Building America (BA) program activities and the work completed by the National Renewable Energy Laboratory and the BA industry consortia (the BA teams). The report summarizes major technical accomplishments and progress toward U.S. Department of Energy Building Technologies Office's multi-year goal of developing the systems innovations that enable risk-free, cost effective, reliable, and durable efficiency solutions that reduce energy use by 30%–50% in new and existing homes.

Over the past several years the BA program has made significant progress toward its 30% savings goal and has begun to target research gaps leading to 50% savings. A comprehensive planning effort that started in FY 2011 resulted in the development of a multi-year research plan defining the critical path to near- and long-term cost and performance goals (see Appendix C). Overall morale and productivity remained high throughout the year despite a 50% reduction in program scope at the beginning of FY 2012.

BA is a collaborative, cost-shared research program. Hard costs for research projects, including labor, materials, and equipment, are contributed as cost share by industry partners. These investments by BA's partners have remained high despite the overall slowdown in the U.S. economy, and demonstrate the residential construction industry's commitment to the value of the building science-based innovations developed by the BA program.

The residential homebuilding and remodeling industry involves many players with narrow operating margins, limited technical resources, and severe constraints in investments in new technology platforms. The research sponsored by the BA program plays a critical role in reducing the relatively large risks associated with moving new ideas into broad markets before they have been fully evaluated and integrated with standard construction practices.[1] It achieves the economies of scale, proven performance, and cost reductions required before innovations can successfully enter broad markets.

The BA program clearly demonstrates the performance and cost benefits associated with buildings science-based innovations and acts as a catalyst that accelerates the transition of new ideas from niche markets into broad use and provides identifies areas for improvement in system performance before building failures cause costly callbacks and warranty repairs (see Figure ES–1).

[1] Research investments by the residential homebuilding and remodeling industry are estimated at 1/10th of 1% of sales compared to values as high as 3%–5% for other sectors. Examples of feedback from industry partners on the value of the program are included in Section 1.3.

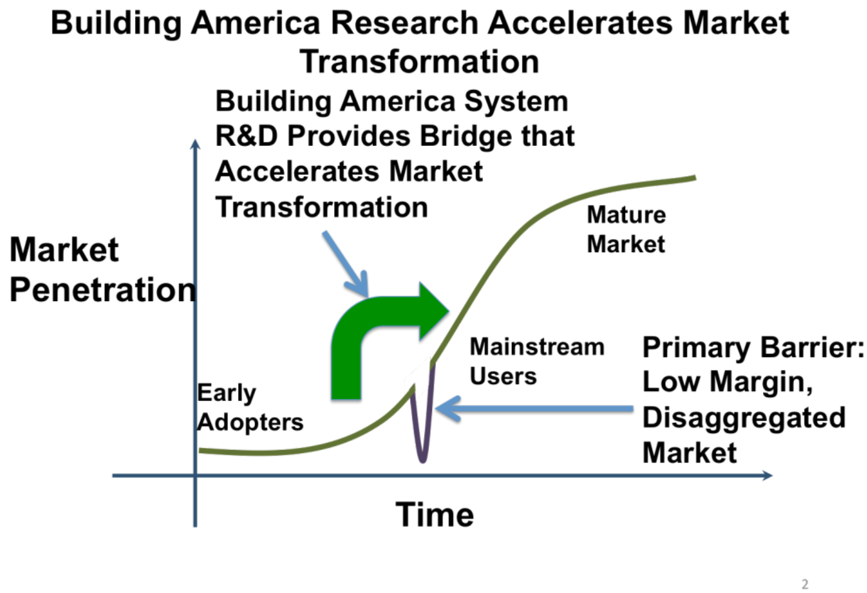

Figure ES–1. BA research accelerates market transformation

By taking a total system perspective rather than focusing on a single technology or subsystem, BA research results also identify internal cost and performance tradeoffs that allow overall home performance to increase and minimize increases in overall home costs. This approach is critical to achieving market success in residential buildings, where capital availability for investments in energy upgrades is low and first costs and risks often drive market transformation decisions. The current results of BA's evaluation of whole-system level cost and performance tradeoffs are included in Appendix B for new and existing homes.

Large system research challenges must be resolved to enable residential energy system innovations that are cost effective and reliable when implemented in broad markets and are proven to reduce energy use by 50%. There are currently only very limited investments in energy upgrades beyond the 30% savings level that also reduce net energy-related operating costs.[2]

Research highlights demonstrating progress in addressing remaining system research performance gaps are discussed in Sections 3.3 and 3.4; detailed descriptions of current research activities are included in Appendix C. Although the remaining system R&D performance gaps that must be resolved are still significant in most climates and for most building types, the BA program is on track to achieve these savings if adequate resources are invested to support the continued development of the systems innovations required to reach the 50% performance goal (see Figure ES–2).

[2] Net energy-related operating costs are the sum of the annual utility bill after the upgrade is completed and the annual financing cost of the energy upgrade, relative to a best practice home built to meet IECC 2009. Because of the inherent financial constraints in residential markets, an energy upgrade package is not considered to be cost effective unless it generates, at a minimum, net positive cash flow during its first year of operation.

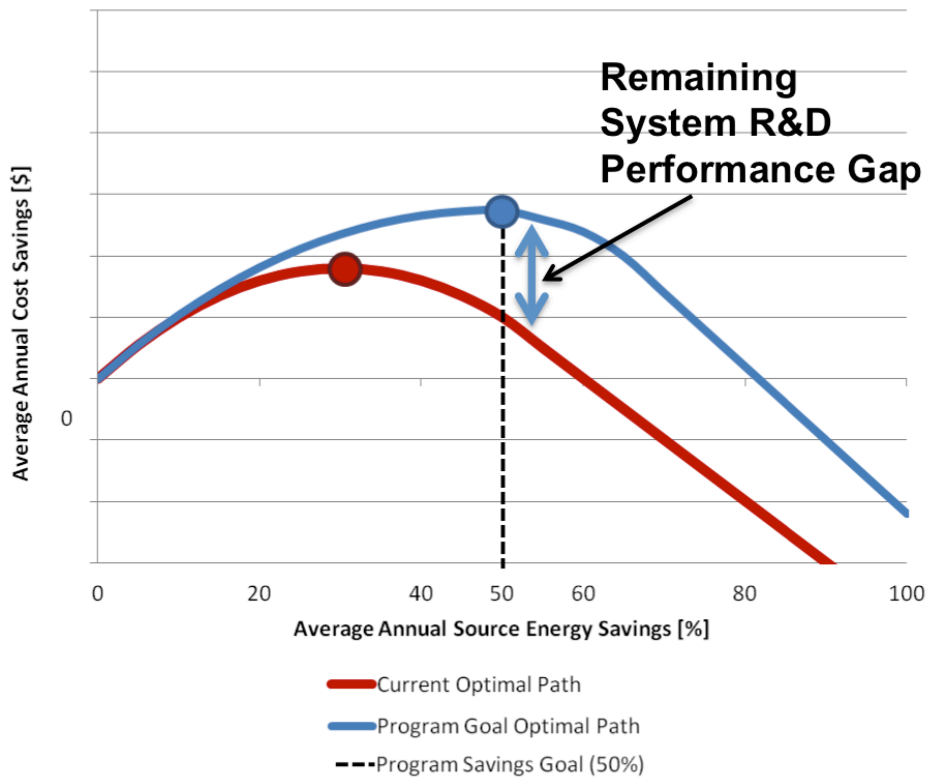

Figure ES–2. Remaining system R&D performance gap

1 Introduction

Building America (BA) is the leading national R&D program for the residential building industry. BA works on the key innovations required to reduce the energy use of new and existing houses by 30%–50% in ways that are marketable, reduce builder risk, and improve the comfort and quality of life for U.S. homeowners.

The primary objective of the BA program is to be the system integration innovation catalyst that accelerates residential building market transformation and supports increasing levels of cost-effective whole-house energy savings. This objective is accomplished by: (1) identifying and resolving the crosscutting system-level barriers that cannot be easily resolved by other stakeholders; (2) participating in cost-shared research partnerships to enable and accelerate the development of robust and innovative solutions; and (3) providing neutral third-party evaluations of the whole-building costs, benefits, and risks associated with innovative construction solutions. This work includes multi-scale studies ranging from detailed laboratory-based systems evaluations and energy simulations to market-based evaluations of average cost impacts and energy savings in large numbers of completed homes.

By conducting cost-shared R&D with leading industry partners, BA can advance and accelerate the adoption of industry best practices. The success of BA research is demonstrated through "better practice, practiced." We measure our success against the willingness of leading industry participants to voluntarily adopt value-added energy-saving technologies and practices.

The Building America Annual Report summarizes key program objectives and accomplishments, including the work performed by the National Renewable Energy Laboratory (NREL) and the BA industry consortia (the BA teams).

1.1 Background: U.S. Residential Market

Residential buildings use 22% of U.S. annual primary energy, a percentage that is expected to grow slightly over time.[3] In the past three decades, 500,000 to approximately 2 million new single-family housing units have been built each year.[4] The average homeowner spends approximately $2,250–$2,500 per year on household energy,[5] which buys comfort via heating and cooling, hot water, and other services (lighting, appliances, televisions, etc.). Individually and in aggregate, energy use in the residential sector represents a significant energy cost savings potential. A BA goal is to deliver these savings in a market-driven, cost-effective way.

BA research leads to cost- and energy-saving innovations for homeowners. Perhaps more importantly, BA research leads to higher quality and confidence in construction and is therefore highly valued by the building industry (see Section 1.3). Equipment and material manufacturers conduct product R&D; BA is the preeminent national organization researching the technical integration of the many complex systems that are installed in residential buildings. By one estimate, the building industry invests less than 1% of annual revenue on R&D; corporate

[3] http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=2.1.1
[4] http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=2.5.1
[5] http://www.bls.gov/cex/2010/Standard/tenure.pdf Numbers represent 2010 average, including natural gas, electricity, and fuel oil.

America spends approximately 4%.[6] BA works to fill this R&D gap to the benefit of the entire building community.

1.2 Building America: Goals Built on a Legacy of Success

1.2.1 Proven Performance Energy Saving Goals

BA sets whole-house energy performance goals to track research progress and to measure energy and cost savings. Energy savings are evaluated using a source energy[7] metric compared to a reference house. The Building America Benchmark (BAB) house aligns with the prescriptive requirements of 2009 International Energy Conservation Code (IECC) and defines the reference house for new construction. The reference house for existing construction is the pre-retrofit house. Using the source energy use of the reference as a baseline, energy savings from improvements (e.g., insulation, high-efficiency equipment) are simulated using the BA House Simulation Protocols.[8] In this framework, different combinations of energy efficiency measures (EEMs) and renewable energy measures can be evaluated to reach target levels of source energy savings. The BA program sets savings targets as percentage reductions in source energy relative to the reference house (see Table 1). A comparison of the BA program targets to the 2012 and 2015 IECC residential energy code updates is provided in Appendix A.

Table 1. Proven Energy Savings Goals

Energy Savings Target	Target—Existing Homes	Target—New Homes
30% Innovations	2014	2013
50% Innovations	2017	2016

1.2.2 Catalyst for Innovation and Market-Driven Change

> It's a heady ambition that drives Building America today: **to be the catalyst for moving the nation's enormous housing stock up to and beyond current energy standards**. The program is achieving that goal—finding cost-effective ways to slash energy use—by mixing the talents of leading building scientists with those with a stake in housing, including the building trades, building owners and managers, among others.
> *– Emanuel Levy, ARIES Principal Investigator*

The construction industry is notoriously risk averse. When a common response to a question asking why things are done a certain way is "That's how we've always done it," clearly there is an opportunity to innovate and deliver 21st century technologies and solutions. BA challenges the business-as-usual model by providing data that demonstrate a better way to build. BA-developed

[6] Rashkin, S. and E. Werling. (2012) "The Road to Peak Performance Homes: Top Innovations from Building America Transforming American Housing." Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings. Pacific Grove, CA.
[7] "Source energy" accounts for the energy required to generate and deliver the energy used on-site. BA definitions for source energy can be found in the BA House Simulation Protocols. http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/house_simulation_revised.pdf
[8] BA House Simulation Protocols ensures consistency of modeling results by defining a variety of simulation conditions, rules and assumptions.

solutions are so successful and provide such high stakeholder value that they are voluntarily adopted in the marketplace (many are included in the BA "Top Innovations").[9]

The key to BA success is the demonstration of successful system solutions and innovations to the nation's leading builders, remodelers, home performance contractors, and manufacturers. The research and proven performance have demonstrated that BA is a catalyst for innovation and market-driven change. One measure of our success is very simple: we want to see better practice, practiced. This takes time and can only be realized on a solid foundation of many years of building science R&D where new ideas are explored, tested, and re-evaluated. It takes time to identify, respond to, and mitigate risk with new technologies and systems. In this way, BA innovation successes and technical approaches are very similar to that of the transistor developed at Bell Labs, as summarized by Richard Nelson in 1962:[10]

> One of the most important things which can be learned from the history of the transistor is that the distinction between basic research and applied research is fuzzy. In the transistor project the results included both an advance in fundamental physical knowledge and the invention and improvement of practical devices. The scientists involved, though many of them were not interested in devices, were able to predict roughly the nature of the practical advances; indeed in some instances they were able to predict quite closely. And several of the scientists were motivated by the hope both of scientific advance and practical advance. Thus the project was marked by duality of results, and of motives. (p. 581)

Having proven the basic transistor effect with laboratory built hardware, no one knew if the invention would prove economical. By minimizing risk and finding market-viable solutions, "Much money and talent were spent in improving the operating characteristics of transistors and making them more predictable and reliable, in developing new circuits and designs to take advantage of the transistor's strong points, and in developing an economic production technology." (p. 565)

1.3 A Legacy of Success: Better Practice, Practiced

For almost 20 years, BA has built a reputation in the residential industry of delivering innovative solutions while consistently meeting its goals. Our team leaders and industry partners tell this story best (emphasis added to all quotations):

> There are very few universities in the United States that develop the technical skills required to understand and solve the issues faced by changes in building codes. Building more energy efficient homes means building tighter, less leaky, building envelopes. This has a huge impact on the durability, indoor air quality, and moisture tolerance of buildings. NREL and Building America research supports the development of building scientists. **There would be very little access to quality Building Science for home builders if there was no NREL**

[9] The BA top innovations are summarized here: http://www1.eere.energy.gov/buildings/residential/ba_innovations.html
[10] http://www.nber.org/chapters/c2141.pdf

and Building America Research.
– Jim Peterson, Director of R&D, Pulte Group, Inc.

Our work on insulating sheathing water management and cladding attachment has directly led to the transformation of thousands of production builder houses as our large builder team members transition from traditional housewrap and OSB sheathing to insulating sheathing. **Without the fundamental research done through the program this transformation would not have been possible**.
– Dr. Joseph Lstiburek, Principal, Building Science Corp.

United Technologies Corp. (UTC) has long been a supporter of the U.S. Department of Energy's Building America program as a means to accelerate industry adoption of new technologies and building systems approaches. Being an active participant in this unique public-private cost-shared program provides leading equipment manufacturers such as Carrier direct access to innovative builders in all climate zones, allowing alternative building practices to **undergo rigorous energy performance and market acceptance evaluation prior to widespread product release**.
– John Galbraith, Vice President of Engineering— RCS

DOE's Building America program has been at the center of enabling a transformation in residential design and construction over the last 20 years. Without the core research and innovation coming from the teams and national labs we would not have seen the progress we have with energy codes. Building America has led the development of research and innovation to prove to industry that **building homes that are 30% more energy efficient than the 2006 IECC is not only possible but can be profitable**. Yet more work remains. As we look to 2015 IECC and beyond we simply do not have the technological solutions to safely, durably and cost-effectively meet these new standards.
– Brad Oberg, CTO, IBACOS, Inc.

BASF was pleased to participate in the research project with Steven Winter Associates on encapsulated ducts using closed-cell SPF. We found that this project proved that using ccSPF to not only insulate, but provide an air and vapor seal over the ducts provided a low/zero-cost, systems-integrated approach that targeted a real need in the industry. This solution can be used in both existing homes, to provide efficiency improvements and cost savings, or built into the design of new high performance homes. **Participating in this research has allowed us to present a solution with a market-ready innovation for the improvement of the large existing home stock**.
– Kelly M Frauenkron, National Insulation Program Manager, BASF

K Hovnanian over the last five plus years has been committed to identifying, modeling, testing and verifying building performance improvements. We are seeking methods that can be successfully applied in a production building environment, working with today's trade base. At the core of our learning and experiences over these years has been the support of the Building America

program. **In all my home building years, over 35, I have never experienced such a public-private partnership that has produced the kind of meaningful, permanent results that the Building America program has**.
– Dean Potter, VP Quality and Home Production Processes, K. Hovnanian

Throughout my years of involvement in the Building America program, I have been pleased to be part of what I believe to be truly transformational research. This is not simply a demonstration effort. **This is the kind of research that transforms the way builders conduct business, and it is so successful that it transforms entire markets**. For example, work initiated in the Gainesville, FL market back in the mid-90's via partnerships with a few forward thinking local industry members has now resulted in systems innovations so common in the marketplace that they are included in the Multiple Listing Service. Real Estate Professionals, Appraisers, Builders, and Homebuyers alike are now learning about and discussing elements of systems engineering including interior ducts, advanced framing, [Home Energy Rating System] HERS Index, and Challenge Home certification during the home buying process.
– Eric Martin, Program Director, Building America Partnership for Improved Residential Construction, Florida Solar Energy Center

From A.O. Smith Corporation's position as a leading supplier of water heaters and boilers in and for the U.S., we believe that the DOE Building America Program is delivering significant energy saving benefits to the Country, to consumers, and to manufacturers such as ourselves. We have worked with the NorthernSTAR Team on their combi-heating research to reduce the energy used for space and water heating in weatherized homes, along with varying levels of involvement in water-heating-related aspects of the work being done by the ARBI, CARB, BSC, and PARR Teams. **The work being done by the Teams is advancing the knowledge and capability of today's generation of home builders and remodelers in designing more cost effective and energy efficient home systems and envelopes. It also provides equipment manufacturers with coordinated information on how energy systems interact in a home, and enables the development of products that more efficiently work with other components of those systems**. This type of system insight, along with coordinated information from the Standing Technical Committees (we have a representative on the Hot Water [Standing Technical Committee] STC), provides a breadth and depth of knowledge that would be extremely difficult, if not impossible, to obtain without the overarching and coordinating sponsorship of an entity like DOE. The work of the Building America Program is, in a very real way, providing current and future energy savings to the Country.
– Charlie Adams, Chief Engineer and Director of Government Affairs, A.O. Smith

Building America is the only comprehensive, whole-house, third-party residential energy efficiency research program in the United States. The residential construction industry lacks any significant investment in research and development – let alone focused on improving energy efficiency to the aggressive levels targeted by Building America. These two facts combined underscore the

incredible importance of continuing the good work started by our program. However, research and development activities alone are not enough to move the dial on residential energy efficiency. Significant effort must be undertaken to ensure that research results get off the shelf, and into the hands of practitioners who can change the face of our nation's housing stock.
– Darren Harris, Building Media/BARA

Building America provides an invaluable resource for the residential construction community. The program's research and demonstrations enable builders and remodelers to implement energy efficient construction strategies sooner and with less risk than they otherwise could. **Hanley Wood's partnership with BA is critical to our ability to transfer the extensive technical expertise of the program to the market. Our audiences – upwards of 500,000 remodelers, builders, architects reached each year—are the very people who bring BA research results into everyday practice**. The continuation of this important work and of partnerships like ours is critical to meeting our nation's energy efficiency and renewable energy goals.
– Sal Alfano, Editorial Director, Hanley Wood Business Media

Additional quotes from BA team leaders and industry partners can be found in Appendix E.

2 Building America Technical Approach: Accelerating Residential Energy Systems Innovation

2.1 House as a System, Multi-Scale Research

Houses are complex systems, disparate parts assembled by a variety of tradespeople and building professionals. Building components and systems interact in complex ways, and making sense of these interactions requires a deep understanding of building physics and operations. BA has led the United States in conducting the systems engineering necessary to evaluate complex building interactions and communicating the key results to industry decision makers.

BA approaches the challenge of proving performance in residential systems by taking a multi-scale system research approach:

- Components are studied individually under carefully controlled conditions to evaluate building performance, which include a full range of seasonal operating conditions in major U.S. climate regions. This allows BA researchers to verify the stated performance and evaluate the potential risks, durability concerns, and health and safety impacts. These evaluations can take place in either a laboratory or a controlled test house.

- Once rigorously vetted at the system or component level, whole-house assessments of EEM packages are conducted using either occupied or unoccupied test houses. This step in the BA research process focuses heavily on systems integration. The integrated performance is evaluated, and risks continue to be assessed and mitigated. Quality control steps are defined to ensure successful repeatability at scale. This is an important step and relies heavily on industry participation, contribution, and commitment.

- The final step in the evaluation process is to look at system solutions at scale. BA does this through studies of multiple buildings and whole communities. During this analysis phase many practical lessons are learned, cost-performance tradeoffs in the field are analyzed and refined, and energy performance is studied in aggregate.

Through a multi-scale research approach, BA can conduct robust analyses and deliver confidence to the building community that the system solutions we recommend are cost effective, safe, and reliably energy efficient.

2.2 Optimized Solutions, Proven Performance

BA combines engineering analysis techniques with technical field evaluations to determine the most advanced, market-ready solutions that result in peak performance.

An important step in developing innovative market-ready solutions is to evaluate them compared to current standard practice and other alternatives to glean a comprehensive understanding of their relative performance and cost tradeoffs. The Building Energy Optimization (BEopt[11]) software is designed to find optimal building designs. This publicly available tool was originally developed by NREL researchers and is used by BA teams and industry.

[11] Available at http://beopt.nrel.gov/

In BEopt, cost-benefit results can be plotted in terms of annual costs, the sum of utility bills, and financing for energy options, versus percent of source energy savings (see Figure 1). The path to peak performance or net-zero energy extends from the reference building to an optimal peak performance building with up to 100% energy savings. The optimal path is defined as the lower bound of results from all possible building designs (connecting minimal cost points for various levels of energy savings).

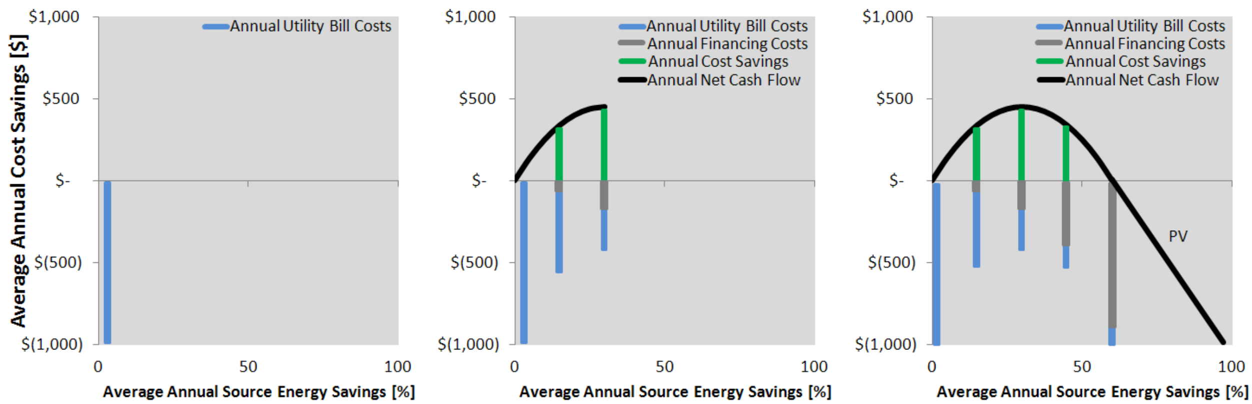

Figure 1. BEopt: Path to peak performance

Points of particular significance on the path are shown in Figure 1. The base case (left) is a scenario where the annual utility bill cost is $1,000. As building EEMs are implemented (center), financing costs and source energy savings increase, and utility bill costs decrease, resulting in annual cost savings. Additional EEMs are implemented until an annual maximum savings point occurs. EEMs are evaluated until the marginal cost of efficiency exceeds the cost of producing photovoltaic (PV) energy.

Then PV capacity is installed until net-zero energy is achieved (shown right without additional PV financing costs for scaling purposes).

BEopt analysis is an important first step in evaluating a new technology or system. Preliminary analysis can be done at much lower cost than field studies and sets a confident course for our cost-share project partners. NREL engineers carefully validate the predicted performance of equipment with laboratory experiments. However, to change standard practice in the marketplace, there is no substitute for demonstrating and verifying whole-house performance in the field.

The BA teams (see Table 2) are leaders in addressing the practical (e.g., quality control/assurance, constructability) and technical challenges of residential system innovations. Teams lead BA's work to field validate the predicted performance at the system, whole-house, and community levels. Often with NREL's field test expertise and support and always with cost-sharing industry partners, BA teams prove the performance of the next generation of residential innovations.

2.3 Delivering Unique System Integration Tools and Capabilities

BA's projects are on the leading edge of energy efficiency for new and existing homes. NREL manages the program and provides technical support, analysis, and testing centered on the performance of whole buildings and the interaction of components in that context, including evaluation, analysis, laboratory and real-world testing, and integrated research program management. BA key capabilities include:

- **System evaluation and analysis** on residential building products, systems, and strategies to understand interactions between building components, to develop whole-house strategies, and to predict performance at various levels of energy savings. This work provides unique software solutions and data that are critical in the development of new products and systems, the design of whole buildings for utilities, and the development of performance targets and packages for energy efficiency programs.
- **Full suite of laboratory and real-world testing capabilities** spanning individual building components and systems to whole buildings, the data necessary to develop better products, systems, and strategies that improve energy efficiency in homes are delivered. This effort includes working for utilities and manufacturers to conduct laboratory and field testing on novel technologies and systems. Laboratory testing provides accurate, third-party performance maps; field testing ensures that innovations can reliably deliver whole-house cost and performance benefits that maximize value and minimize risk.
- **Research program management** for BA combines extensive technical capability with the ability to evaluate, develop, and manage complicated research efforts. This work integrates the full scope of technical expertise offered by the NREL Residential Buildings Group, and has created strategic and highly collaborative multi-year programs with significant results.

These unique capabilities provide the advanced technical capabilities BA needs to be successful.

2.4 Risk Analysis, Mitigation, and Field Performance

The BA teams are industry consortia that comprise consultants, academics, engineers, builders, architects, manufacturers, and others that represent the residential industry across various stakeholder communities and regions. Descriptions of all teams are included in Table 2. The teams are critical to the success of BA research and do much of the "heavy lifting" needed to successfully prove innovative solutions to a risk-averse building community.

Table 2. Summary of the BA Teams

BA Team	Description
Advanced Residential Integrated Energy Solutions (ARIES)	The Levy Partnership, Inc. (New York, New York): Accelerates the development and commercialization of innovative and cost-effective approaches for dramatically reducing energy use of the nation's new and existing affordable housing. The team is broadly representative, including more than 50 organizations drawing from all stakeholders in the affordable housing community.
Alliance for Residential Building Innovation (ARBI)	Davis Energy Group (Davis, California): Evaluates and demonstrates innovative technologies and residential construction techniques and deployment strategies. ARBI

	combines research on specific technologies with deployment activities in the new and existing home sectors, including research on what motivates homeowners to invest in home energy upgrades, and strategic approaches to reducing costs through efficient home evaluation and bulk purchasing.
Building America Retrofit Alliance (BARA)	Building Media, Inc. (Kent, Washington): Combines technical expertise and real-world construction experience with communications and outreach expertise to bridge the gap between research and market integration. BARA focuses exclusively on the home renovation and retrofit market to develop, deploy, and promote technically sound, cost-effective measures that radically improve home performance.
Building America Partnership for Improved Residential Construction (BA-PIRC)	Florida Solar Energy Center (FSEC), University of Central Florida (Orlando, Florida): Develops cost-effective efficiency solutions for new and existing homes in hot-humid and marine climates. FSEC manages residential energy research facilities, including the Manufactured Housing Laboratory, the Flexible Retrofit Test Facility, the Building Science Lab, the Hot Water Systems Laboratory, and the Climate-Controlled Air Conditioning Laboratory.
Building Science Corporation (BSC)	Building Science Corporation (Somerville, Massachusetts): Develops energy-efficient enclosure, ventilation, and dehumidification systems for durable, high performance homes. BSC has worked with dozens of industry partners during the past decade and is responsible for the construction of more than 10,000 BA houses and 100,000 ENERGY STAR® houses (through its partner MASCO and the Environments for Living program). BSC provides advanced solutions to technical challenges, code barriers, and market requirements for new and existing homes.
Consortium for Advanced Residential Buildings (CARB)	Steven Winter Associates, Inc., (Norwalk, Connecticut): Improves new and existing homes (specializing in multifamily and affordable housing) by leveraging new technologies, underused technologies, and innovative market delivery strategies. Researches advanced building systems and whole-house performance, and transfers that knowledge to the marketplace to elevate home performance industry wide.
IBACOS	IBACOS (Pittsburgh, Pennsylvania): Develops and demonstrates integrated systems of design, procurement, construction, quality assurance, and marketing needed to transform residential building retrofits and new construction.
National Association of Home Builders— Research Center (NAHB-RC)	NAHB-RC (Upper Marlboro, Maryland): Is an integrated, system-based technology advancement center with the primary mission of removing technological, regulatory, and cost barriers to building innovation by leveraging its access to remodelers and home builders.

NorthernSTAR	University of Minnesota (St. Paul, Minnesota): Develops high performance, energy-efficient solutions for new and existing homes in cold and severe cold climates, using a holistic integration of information and technologies across the building system, the construction/delivery system, and the market/user system.
Partnership for Advanced Residential Retrofit (PARR)	Gas Technology Institute (Des Plaines, Illinois): Applies strong experience in design, development, integration, and testing of advanced building energy equipment, components and systems in laboratory and test house settings to improve performance, quality, and market acceptance of whole-house residential energy efficiency retrofits in cold climates.

The BA teams conduct the market-integrated residential research needed to advance the industry like no other organization in the United States today. Their longstanding relationships with some of the nation's biggest and most innovative builders ensures that BA innovations are thoroughly vetted by "boots on the ground."

3 Summary of the Current Building America Research Portfolio

3.1 Summary of the Energy Evaluation Method

3.1.1 Energy Savings Measure Packages

BA and NREL focus on attaining cost-optimal energy savings solutions. BEopt evaluates various combinations of EEM and renewable energy packages and generates a cost-optimal savings path. This analysis is used to assess and compare our current estimates of the cost effectiveness of different measure packages, which are then evaluated in the field. A combination of measures that deliver energy savings on the cost-optimal path is an energy savings measure package (ESMP). ESMPs are representative measure packages that attain energy savings goals for specific prototype buildings and inform new and existing home market stakeholders. These packages are optimized for maximum energy cost savings to homeowners for source energy savings given the local energy costs, climates, and building characteristics (e.g., foundation types). This analysis is used to inform design; packages are only validated once they undergo thorough field evaluation. For more detail, consult Appendix B for ESMPs in different representative climates.

In general, the most cost-effective measures appear early in the optimization (see Figure 2 for an example). Although actual savings resulting from these measures will vary based on occupancy, the measures in the optimal savings curve can be visualized in three regions: high cost-effective measures (green), medium cost-effective measures (blue), and low cost-effective measures (red). The characteristics of measures in the high cost-effective region are generally low capital cost, result in high energy savings, and have short payback periods. Conversely, measures in the low cost-effective region are generally high capital cost and may result in significant energy savings but have longer payback periods.

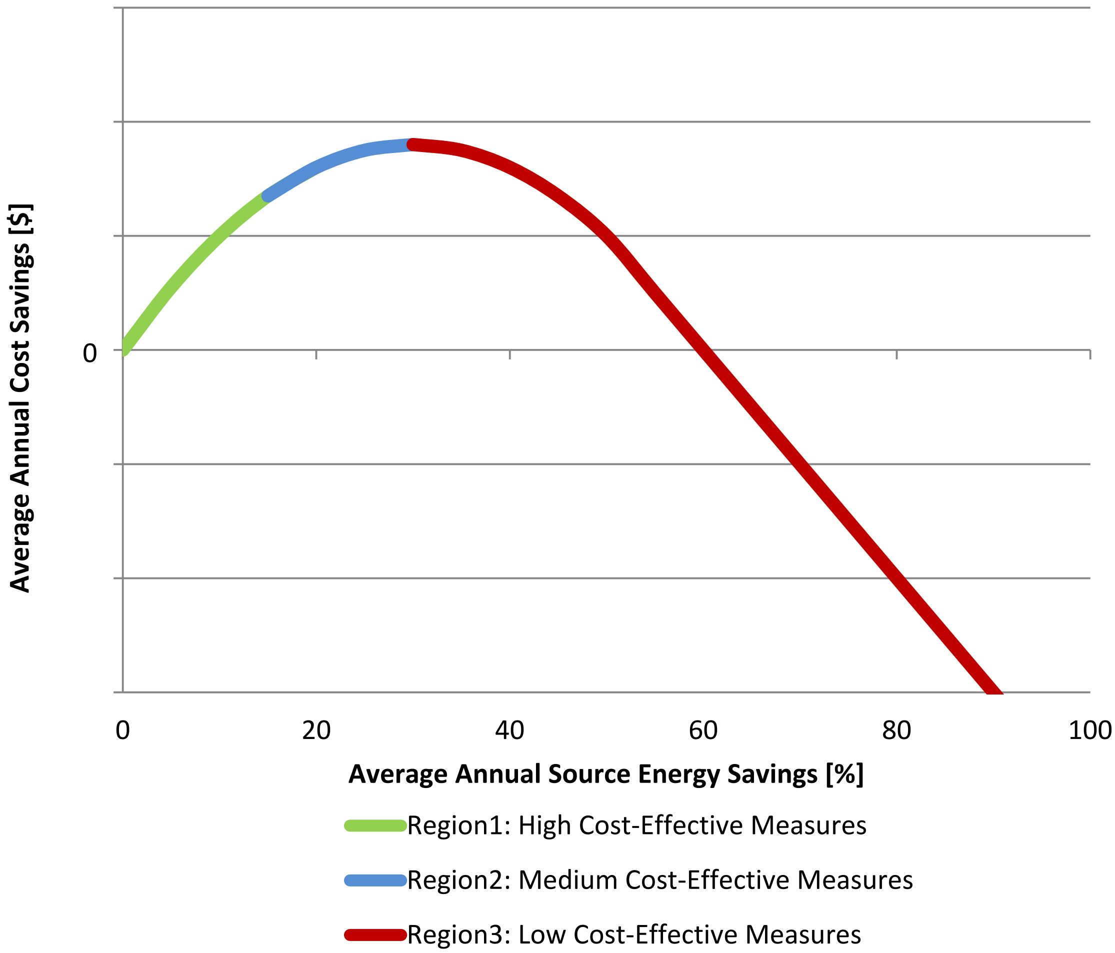

Figure 2. Generalized cost-effective regions for a retrofit scenario

3.1.2 Visualizing Energy Savings: Efficiency and Cost Gaps

Two useful visualizations of BEopt optimizations are "Efficiency and Cost Gaps" and the "Maximum Savings Goal." The *Efficiency Gap* is the difference between the BA program goal (50% whole-house source energy savings) and the maximum energy savings that can be achieved through EEMs that have a lower marginal cost than PV. The example in Figure 3 shows an efficiency gap of 25% source energy savings, which means that EEMs alone can achieve 25% source energy savings, and the remaining savings to reach the BA program goal are achieved via PV. The *Cost Gap* is the additional average annual cost savings required to achieve the BA program goal with zero additional cost. The efficiency gap and the cost gap represent cost reductions and system performance improvements that must be realized to achieve the cost-neutral BA program goal.

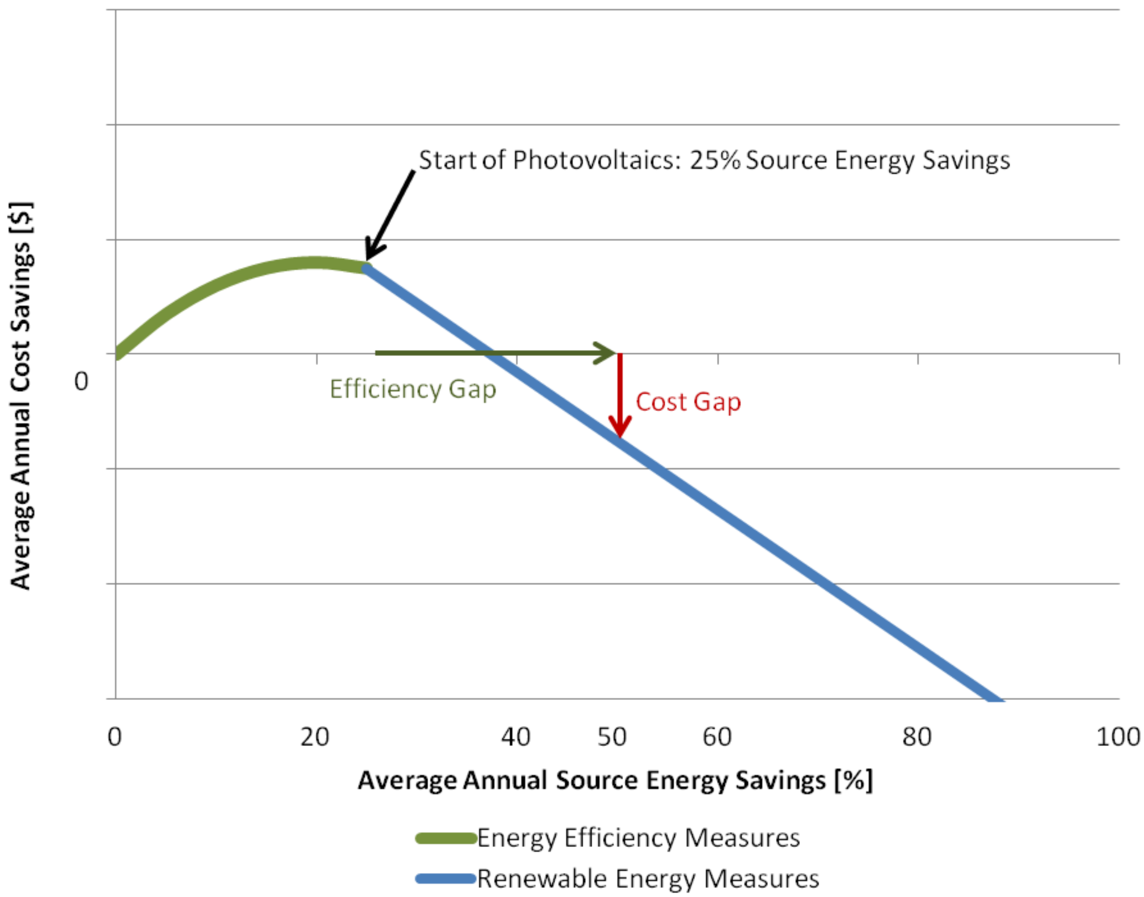

Figure 3. Example of the efficiency gap and cost gap

3.1.3 Visualizing Energy Savings: Maximum Savings Goal

The maximum savings goal is illustrated in Figure 4. In this example scenario, the current optimal path represents the current energy savings potential given measure performance and cost. The current maximum cost savings occurs at an energy savings level below the BA program goal. The program goal optimal path achieves maximum cost savings at the BA program goal, 50%. BA research will contribute to increasing energy savings and achieve the program goal for source energy savings.

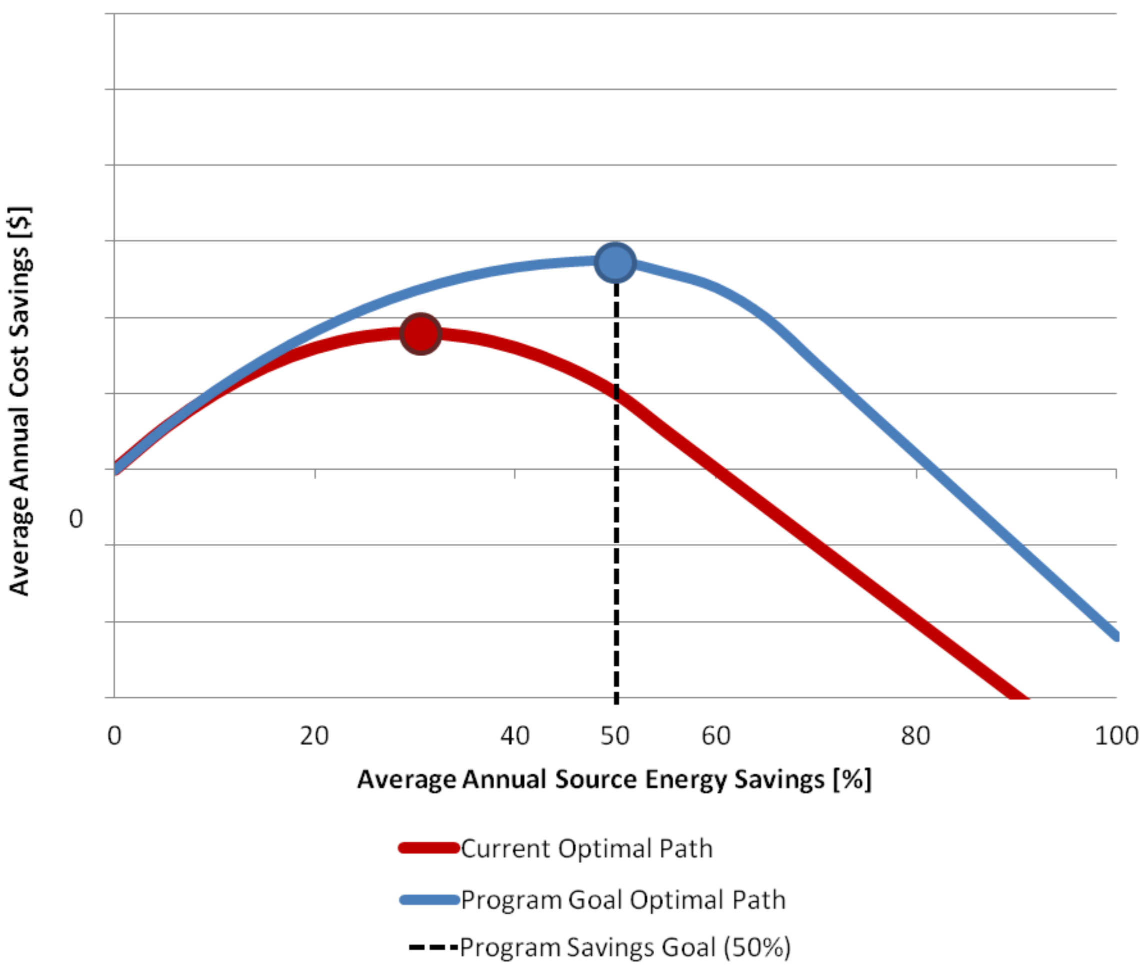

Figure 4. The program goal maximum savings relative to the current maximum savings for an example scenario

3.2 National Renewable Energy Laboratory Key Accomplishments

Summaries of some NREL Residential Buildings Group key accomplishments (as part of BA research) follow. This body of work represents the latest developments in the residential systems integration body of knowledge:

- Evaluation of Humidity Control Options in Hot-Humid Climate Homes. As the BA program researches homes that achieve greater source energy savings over typical mid-1990s construction, proper modeling of whole-house latent loads and operation of humidity control equipment has become a high priority. Long-term high relative humidity (RH) can cause health and durability problems, particularly in a hot-humid climate. NREL researchers used the latest EnergyPlus tool equipped with the moisture capacitance model to analyze the indoor RH in three home types: a BA high performance home, a mid 1990s reference home, and a 2006 IECC-compliant home in the hot-humid climate zone (CZ). They examined the impacts of various dehumidification equipment and controls on the high performance home where the dehumidification equipment energy use can become a much larger fraction of whole-house energy consumption.

- National Residential Efficiency Measures Database Aimed at Reducing Risk for Residential Retrofit Industry. NREL researchers developed the National Residential Efficiency Measures Database, a public database that characterizes the performance and costs of common residential EEMs. The data are available for use in software programs that evaluate cost-effective retrofit measures to improve the energy efficiency of residential buildings.
- New Version of BEopt Software Provides Analysis Capabilities for Existing Homes. A new version of NREL's BEopt software was developed with significantly expanded capabilities to analyze energy efficiency upgrades for existing homes. Like the original BEopt software—developed for analysis of new construction homes targeting net-zero energy—the new version identifies cost-optimal residential building designs at various levels of energy savings, based on simulations driven by hour-by-hour heat transfer, typical weather data, and standard occupants.
- NREL Delivers In-Home HVAC Efficiency Testing Solutions. NREL researchers developed two simple in-home efficiency test methods that can be used by technicians, researchers, and interested homeowners to verify the correct operation and energy efficiency of a home's air conditioning equipment.
- NREL Develops Diagnostic Test Cases To Improve Building Energy Simulation Programs. NREL's Residential and Commercial Buildings research groups developed a set of eight diagnostic test cases to test surface conduction heat transfer algorithms of building envelopes in building energy simulation programs. These algorithms are used to predict energy flow through external opaque surfaces such as walls, ceilings, and floors. The test cases consist of analytical and vetted numerical heat transfer solutions that have been available for decades—these increase confidence in test results. NREL researchers adapted these solutions for comparisons with building energy simulation results. Testing the new cases with EnergyPlus identified issues with the conduction finite difference heat transfer algorithm in versions 5 and 6. NREL researchers resolved these issues for EnergyPlus version 7.
- NREL Develops Heat Pump Water Heater Simulation Model. NREL developed and validated a heat pump water heater (HPWH) simulation model that can be used in whole-house energy simulations to determine the energy savings associated with HPWHs in all climates and installation locations. The model is implemented in BEopt beginning with version 1.2.
- NREL Documents Efficiency of Mini-Split Heat Pumps. NREL researchers tested mini-split heat pumps in a laboratory so that performance across a wide range of temperature, RH, and equipment speed could be evaluated, enabling simulation for any building and climate.
- NREL Evaluates the Thermal Performance of Uninsulated Walls to Improve the Accuracy of Building Energy Simulation Tools. NREL researchers developed models for evaluating the thermal performance of walls in existing homes. The models will improve the accuracy of building energy simulation tools when predicting energy savings. Uninsulated walls are typical in older homes where the wall cavities were not insulated during construction or where the insulating material has settled. Accurate calculation of

heat transfer through building enclosures will help determine the benefit of energy efficiency upgrades to reduce energy consumption in older homes.

- NREL's Field Data Repository Supports Accurate Home Energy Analysis. NREL researchers developed a repository of research-level residential building characteristics and historical energy use data to support ongoing efforts to improve the accuracy of residential energy analysis tools and the efficiency of energy assessment processes. This database will conform to the emerging home performance data transfer standard (HPXML), which will enable greater data transfer and sharing.
- NREL Improves Building Energy Simulation Programs Through Diagnostic Testing. The Building Energy Simulation Test for Existing Homes (BESTEST-EX) enables software developers to evaluate the performance of their audit tools in modeling energy use and savings in existing homes when utility bills are available for model calibration. Similar to NREL's previous energy analysis tests, such as HERS BESTEST and other BESTEST suites included in ANSI/ASHRAE Standard 140, BESTEST-EX compares software simulation findings to reference results generated with state-of-the-art simulation tools such as EnergyPlus, SUNREL, and DOE-2.1E.
- NREL Provides Guidance to Improve Thermal Comfort in High-Performance Homes. NREL researchers have developed recommendations to help residential heating, ventilation, and air-conditioning (HVAC) designers select optimal supply inlet size and system operating conditions to maintain good thermal comfort in low heating and cooling load homes. This can be achieved by using high sidewall supply air jets to create proper combinations of air temperature and air motion in the occupied zone of the conditioned space.
- NREL Test Dehumidifiers, Defines Simplified Simulation Model. NREL tested six residential dehumidifiers over a wide range of temperatures and RH levels to broadly determine moisture removal capacities and efficiencies. Whole-building simulation tool performance curves were derived for use in evaluating the energy, comfort, and cost impacts of dehumidifiers. Knowing only the rated efficiency and capacity, energy professionals can now simulate residential dehumidifiers with low error. This enables quicker and easier equipment evaluation, so better real-world performance and cost impacts can be determined.
- NREL Tests Integrated Heat Pump Water Heater Performance in Different Climates. NREL researchers completed thorough laboratory testing of five integrated HPWHs. These water heaters have the potential to significantly reduce energy use relative to traditional electric resistance water heaters. These tests have provided detailed performance data for these appliances, which have been used to evaluate the cost of saved energy as a function of climate.

3.3 Building America Team High Level Accomplishments

The following summary numbers are for FY 2012 activities only:

- In FY 2012 there were more than 90 BA projects, ranging from cutting-edge research on systems innovation to the documentation of best practice market-ready solutions.

- Approximately 55% of research projects were retrofit focused, 30% were new construction focused, and 15% were applicable to new and existing constructions.
- Approximately 50% of research projects focused on single-family houses, 30% were applicable to all residential, and 20% focused on multifamily buildings. A small percentage of projects focused on manufactured (HUD) houses.
- Approximately 60% of research projects evaluated innovations at the system/measure level, 30% were whole-house evaluations at the 30% savings level, and 10% were whole-house evaluations at the 50% savings level.

Many projects apply to multiple CZs; they are counted here in all applicable CZs: 60 projects apply to the cold CZ, 32 to mixed-humid, 25 to hot-dry, 31 to hot-humid, and 25 to marine.

Most projects focused primarily on HVAC, enclosure, and implementation (often via test house or community-scale evaluations).

More than 75 high-quality peer-reviewed publications, including case studies, are expected from this research. Figure 5 summarizes these relative to their distribution by CZ. Figure 6 summarizes them relative to savings level.

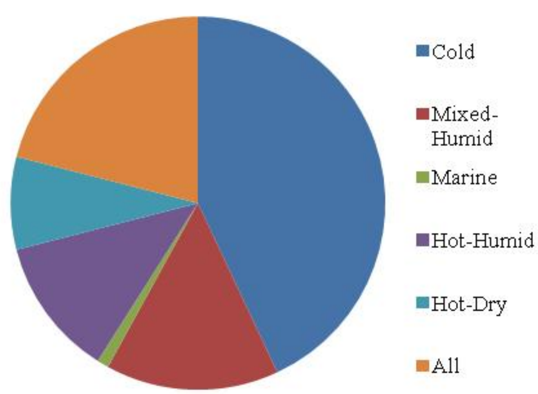

Figure 5. Relative distribution of peer-reviewed publications by CZ

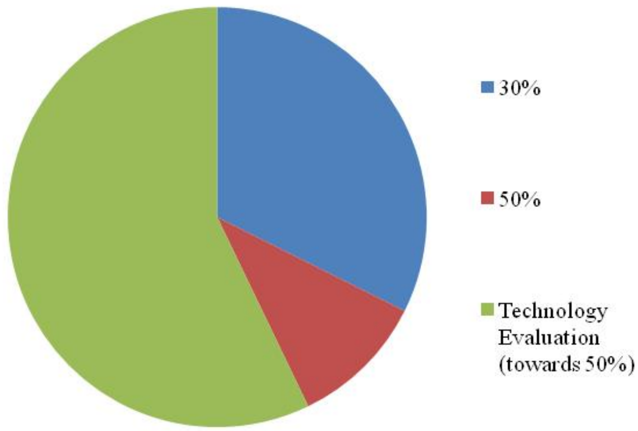

Figure 6. Relative distribution of peer-reviewed publications by savings level

3.4 Building America Team: Project Highlights

The highlights from the BA teams showcase ongoing research on the development, technical evaluation, and performance validation of cutting edge innovations leading to 50% energy savings in new and existing homes. These highlights represent a body of work across multiple scales and savings levels.

3.4.1 Advanced Residential Integrated Energy Solutions (ARIES)

- *Optimizing Air Distribution Retrofit Strategies in Affordable Housing*: ARIES joined with the Raleigh Housing Authority (RHA) to evaluate duct sealing strategies in 40 of its 3,000 housing units. Results showed that both hand sealing and an aerosol-based sealing system were highly cost effective; projected annual savings were $200–$600 and payback was 1–2 years. Based on these findings, RHA plans to seal ducts in 90 additional housing units this year.

- *Fuel Oil Flow Field Measurement Protocol*: ARIES developed and verified a measurement protocol for the Better Buildings program to evaluate the effectiveness of retrofits in properties with oil heat. The results showed that the correlation between estimating oil use based on burner runtime and direct measurements of oil volume based on delivery and height in the tank were very good. The low-cost method can be implemented by field technicians for a fraction of the cost of other techniques.

- *Hydronic Heating Retrofits for Low-Rise Multifamily Buildings*: ARIES is working with Homeowners Rehab, Inc., a nonprofit housing agency in Massachusetts, to study improved boiler controls in a three-building development (see Figure 7). After the first winter, the new controls saved 16% of space heating energy ($3,600) despite being operational for only part of the winter. The utility program that funded some of the work has taken notice and Homeowners Rehab, Inc. plans to modify controls in four other buildings as a result.

Figure 7. Exterior view of test building and typical basement boiler room

- *Advanced Enclosure Research for Factory Built Housing*: ARIES is working with the factory built housing industry to develop and test new, thermally efficient enclosure designs that are geared to the unique construction practices of factory building. This innovative research is intended to reinvent home manufacturing in ways that optimize the energy performance of new construction by leveraging the efficiencies and inherent quality advantages of producing homes in a climate-controlled environment. Twenty-five leading factory building companies and six major insulation suppliers are participating in the research.

3.4.2 Advanced Residential Building Innovation (ARBI)

- *HVAC for Low-Load Homes*: As homes become tighter and more efficient, smaller capacity, high efficiency HVAC systems are needed to meet the needs of high performance, low-load buildings. There is also a need to obtain higher performance from available equipment. ARBI has been conducting research on various strategies that would address these gaps through the use of hydronic delivery for space conditioning. TRNSYS simulations predicted 27% annual HVAC energy savings in hot-dry climates versus traditional ducted systems for small room fan coil units supplied by air-to-water heat pumps. ARBI is currently monitoring two performance homes in Chico, California, and Tucson, Arizona, which use radiant-forced air mixed-mode delivery coupled to an air-to-water heat pump. The success of the Tucson project has led to interest by a national production builder, Shea Homes, in incorporating the system into two model homes in a Phoenix community.

- *Cottle House*: Completed in spring 2012, the Cottle House is the first home in California to be officially certified net-zero energy (HERS index lower than zero) by CalCerts and the California Energy Commission (see Figure 8). ARBI provided support to this project throughout the design and construction stages using BEopt software to identify the most appropriate EEMs for the climate. As a result of BA support and a very cooperative builder, features such as ducts in conditioned space, ventilation cooling, and a downsized high efficiency heat pump were incorporated. Measured performance during the spring showed the PV system produced more than 150% of the energy required to operate the house. The excess capacity is being used to charge an electric vehicle. ARBI continues to provide support through building energy monitoring, which captures energy use by end use and is being used to assess the savings provided by night ventilation cooling.

Figure 8. The Cottle House

- *UC Davis West Village*: West Village is a 224-acre development on the University of California Davis campus that will provide housing for about 4,350 faculty and staff in single and multifamily units. It is the largest planned net-zero energy ready community in the country. The project vision is to minimize the community's impact on energy use by reducing building energy use, providing on-site generation, and encouraging alternative forms of transportation. ARBI provided support to this project throughout the design and construction stages using BEopt software to identify the most appropriate energy efficiency package for the climate and maximize cost-effective, energy-efficient buildings. ARBI continues to be involved in the project to evaluate the field performance of a centralized HPWH serving the student apartments, and to compare BEopt-predicted energy use to measured use.

- *Maintenance of Existing Air Conditioners*: Spurred by observations that home performance contractors tend to ignore air conditioning systems if they are not replaced as part of home energy upgrades, an ARBI literature search revealed that cooling energy savings could average as high as 30% if proper maintenance procedures are applied. Further investigations revealed a lack of systematic diagnostic procedures that home performance contractors and HVAC technicians could apply. To fill this gap, ARBI worked with two experts in HVAC diagnostics to produce a guideline that provides a concise, easy-to-apply, two-step approach to diagnostics. The guideline allows contractors and technicians to quickly diagnose and correct such deficiencies as restricted ducts, undersized filters, incorrect refrigerant charges, refrigerant line restrictions, blocked coils, and even contaminated refrigerants. Training was provided to one large home performance contracting firm.

- *Home Energy Retrofits*: ARBI is involved in Whole Neighborhood Approach Pilot Programs in Los Angeles, Sonoma, and San Joaquin Counties through the Better Buildings Program and the California Energy Commission Public Interest Energy Research Program. The top five lessons learned from these retrofit programs that will help direct future program efforts are:
    - The use of professional, experienced sales personnel correlates closely with homeowner uptake.
    - Finding early adopters (the "right" homeowners) correlates much more closely with program uptake than does finding housing stock in great need of energy upgrades (the right houses).
    - Flexibility—for example, the ability to offer prescriptive versus performance paths—is key. Middle income homeowners are most likely to upgrade items that are either most pressing or most affordable.
    - Full-blown test-ins and assessments are too costly for homeowners and contractors.
    - Simplified financing is necessary to obtain homeowner participation.

3.4.3 Building America Retrofit Alliance (BARA)

- *Outreach Tasks and Knowledge Tools*: BARA established plans and content during 2012 to reach more than 400,000 industry professionals and millions of consumers. In 2012, BARA worked with media and industry partners to reach more than 150,000 industry professionals with technical research results. Work conducted in the fourth quarter of 2012 and into 2013 to promote the results of the BA meeting series, to promote the first "knowledge tool" (HVAC), and to promote BA technical research results will reach 400,000 or more industry professionals (remodelers, builders, contractors, and home energy professionals).

- *Las Vegas Community Scale Demonstration*: BARA is having a profound impact on a broad community-wide retrofit program designed to increase the efficiency of thousands of low and middle income homes in the greater Las Vegas area by 30% (see Figure 9). The program was piloted in 2011 and quickly went to scale with the endorsement and backing of Las Vegas Mayor Caroline Goodman. The total program goal is to have thousands of homes retrofitted to 30% efficiency in several cities within five years.

Figure 9. Old equipment removal from Las Vegas community-scale retrofit project

- *Cool Energy House Demonstration Project*: Through the development and implementation of the Cool Energy House Demonstration Project in Orlando, Florida, BARA cost-effectively took the demonstration of energy efficient retrofit practices to a new scale, providing a clear demonstration of whole-house strategies, extensive multimedia content, and outreach for the program and specific EEMs.

3.4.4 Building America Partnership for Improved Residential Construction (BA-PIRC)

- *Evaluation of Cost-Effectiveness of Home Energy Retrofits in Pre-Code Vintage Homes in the United States*: This analytical study examines the opportunities for cost-effective energy efficiency and renewable energy retrofits in residential archetypes constructed before 1980 (pre-code) in 14 U.S. cities. The energy efficiency levels of older, poorly insulated homes across U.S. climates can be dramatically improved. Moreover, with favorable economics, they can reach levels of performance close to zero energy when evaluated on an annual source energy basis. However, findings indicate that retrofit financing alternatives and whether equipment requires replacement have a quite large impact on the achievable source energy reduction in this cohort of residential building archetypes.

- *Best Practices Guidance for Retrofitting Foreclosed Homes*: With the prevalence of foreclosures on the market, and federal Neighborhood Stabilization Program (NSP) funds dispersed to local governments enabling their retrofit, BA-PIRC completed a project to develop best practices for incorporating systems engineered efficiency as part of the foreclosure retrofit process. This takes advantage of findings from other BA-PIRC analytical studies that show longer term financing provides great retrofit opportunities. The best practices focus on the hot-humid climate, and provide a package of cost-effective measures that can and should be applied to foreclosed homes, regardless of vintage, and without a costly test-in audit, that is a reasonable approach to 30% savings, depending on the home's condition. The best practices were developed by studying retrofits undertaken by partners on more than 100 foreclosed homes.

- *Side by Side Testing of Water Heating Systems*: Since 2009, FSEC has tested more than 15 different water heating systems in its laboratory (under realistic operating conditions), giving the industry and consumers a more accurate understanding of performance (see Figure 10). In 2012, the focus has been on "hybrid" systems that include a solar component combined with emerging tankless gas and HPWH technology. Recent data show that annual water heating energy use reductions of 80% or greater are possible over conventional, minimum code systems.

Figure 10. The FSEC water heating laboratory

- *Multifamily Deep Energy Retrofits in Marine and Mixed Climates*: BA-PIRC team member Newport Partners worked with the Maryland Energy Administration to devise and document a retrofit of a 1970s era multifamily building. The projected 52% annual energy use reduction at Bay Ridge in Annapolis, Maryland, comprises primarily space heating savings from high efficiency hybrid heat pump systems (heat pump with gas furnace backup) and an improved building envelope. Weather-normalized measurements (Btu/ft^2/heating degree day), taken to moderate the effect of milder post-retrofit weather on savings, indicate a 60% or greater reduction in space heating. BA-PIRC team member Washington State University worked with King County Housing Authority on the retrofit of Newporter Apartments, a 120-unit 1960s era multifamily apartment complex. Based on a post-retrofit energy analysis for the apartments using TREAT analysis software, annual whole-building site energy savings are estimated to be 30%, with measured annual energy savings for gas and electricity totaling $143.86 per apartment at current utility rates. The successful demonstration of this effort is scalable to other communities owned by the King County Housing Authority and other public housing authorities in Washington in need of retrofits to the envelope and systems. This research may also help inform efforts to improve U.S. Department of Energy (DOE) and state weatherization guidelines in multifamily projects throughout the Northwest.

- *Updating of the Gainesville, FL Multiple Listing Service*: The Multiple Listing Services is an important tool for the real estate industry in the marketing and selling of homes. Real estate agents use the service to locate properties that meet the homebuyers' needs and appraisers use it to find comparables to developing appraised market values. A feature that does not appear in the Multiple Listing Service is essentially hidden from the real estate market. As a result of the tireless efforts of BA-PIRC team member Ken Fonorow of Florida H.E.R.O., and area builders partners including Tommy Williams Homes, the Gainesville, Florida Multiple Listing Service now includes several BA systems innovations along with related whole-house performance indicators, including HERS Index and the DOE Challenge Home certification.

3.4.5 Building Science Corporation (BSC)

- *NIST Zero Energy Research Facility*: BSC provided design and technical support for the National Institute of Standards and Technology Net-Zero Energy Residential Test Facility (see Figure 11). This house will serve as a research facility where new mechanical and ventilation systems can be tested in a state-of-the-art building enclosure. The house is ultra airtight and super insulated, yet looks like a conventional residence. It uses advanced framing, continuous exterior insulation, unvented compact cathedral roof construction, high performance glazing, heat recovery ventilation, high efficiency lighting, appliances, air conditioning, heating, and domestic hot water. The enclosure follows the principles of the "Perfect Wall," which uses layers of continuous water control, air control, vapor control, and thermal control.

Figure 11. The National Institute of Standards and Technology Zero-Energy Test Facility

- *External Insulation of Masonry and Framed Walls*: Exterior insulation effectively increases the overall thermal resistance of wall assemblies, improves water management, and often increases building airtightness. However, the engineering basis and support for this work had not been conducted, resulting in obstacles for building official and building code acceptance. The water management and integration of window systems, door systems, decks, balconies, and roof-wall intersections had also not been adequately developed. This gap also stands in the way of wider deployment. This research project developed baseline engineering analysis to support the installation of thick layers of exterior insulation (2–8 in.) on existing masonry and wood-framed walls through the use of wood furring strips (fastened through the insulation back to the structure) as a cladding attachment location. Water management details necessary to connect the exterior insulated wall assemblies to roofs, balconies, decks, and windows were created to provide guidance on the integration of exterior insulation strategies with other enclosure elements.

3.4.6 Consortium for Advanced Residential Buildings (CARB)

- *Buried and/or Encapsulated HVAC Ducts Research*: CARB has been researching buried and/or encapsulated ducts (BEDs) for more than a decade in different climates and for new and existing homes (see Figure 12). As a result, buried ducts and encapsulated/buried ducts have been incorporated into several energy conservation codes and standards, including California's Title 24, the 2009 International Residential Code, and DOE's Challenge Home. The most recent research examined existing home application of encapsulated ducts and encapsulated/buried ducts in three homes in Jacksonville, Florida's hot-humid climate. A viable method for improving the performance of existing duct systems in unvented attics is a critical need. A final technical report on this research was submitted in June. CARB recently completed a draft measure guideline for BEDS. Existing homes and new construction are covered by the guideline and detailed step-by-step measure implementation instructions are provided for all BEDs methods.

Figure 12. Encapsulated duct

- *Validating and Optimizing Heat Pump Water Heaters*: CARB completed a field monitoring study of HPWH installations in 14 test homes in the Northeast and is currently drafting the technical report. In conjunction with this research, CARB is actively participating in the Northeast HPWH Advisory Committee to help guide proper adoption of this technology in cold climates. Steven Winter Associates has worked with several utility companies in the Northeast to develop a quality installation guide and an informational trifold for consumers. One key gap in current research is the space conditioning impact of these units. CARB has recently begun monitoring an HPWH in

Orlando, Florida. This unit has more extensive monitoring (additional temperature and RH sensors and condensate measurement) that help us understand the space conditioning impacts of this technology. CARB has been using this research to work on an HPWH performance model for various HPWH units and working with NREL to better understand how HPWHs are being modeled in BEopt. Work on the HPWH performance model and draw profile analysis is ongoing.

- *Optimizing Condensing Boilers*: When operating properly, the combination of a gas-fired condensing boiler with baseboard convectors and an indirect water heater is a low-cost option for high efficiency residential space heating in cold climates. However, previous CARB research revealed that these types of systems are typically not designed and installed to achieve maximum efficiency. Through modeling and monitoring, CARB is seeking to determine the optimal combinations of components—pumps, high efficiency heat sources, plumbing configurations, and controls—that will result in the highest overall efficiency for a hydronic system that uses baseboard convectors as the heat emitter. The impact of variable-speed pumps on energy use and performance is also being investigated, along with the effects of various control strategies and the introduction of mass on system performance. Monitoring has recently begun for three different system arrangements in three Ithaca, New York homes. A technical report summarizing the modeling results, preliminary cost analyses, and monitoring plan was submitted in June.

3.4.7 IBACOS

- *Heating and Cooling Guidelines*: In 2011 and 2012 IBACOS developed a series of BA guidelines on heating and cooling system sizing and design that complements Air Conditioning Contractors of America Manuals J, S, T, and D. These guidelines enable builders and mechanical system designers and installers to understand the implications of various oversizing issues, and they discuss the process of heating and cooling system design specifically in the context of houses that meet or exceed the energy efficiency requirements of the 2009 IECC, such as ENERGY STAR homes and DOE Challenge Homes. These guidelines were accompanied by a webinar with more than 700 participants and form the basis of a number of accepted or proposed presentations at building industry conferences. These guidelines are critical resources for builders and program implementers who need nonbiased, objective information on how energy efficient heating and cooling systems can be designed. The guidelines, which are available on the BA publications website, help to dispel myths and rules-of-thumb that are prevalent throughout the space conditioning industry.

- *Imagine Homes and Beazer Homes*: IBACOS has been working with Imagine Homes since 2007. They are currently collaborating on the design and construction of a 50% whole-house source energy savings occupied test house (see Figure 13), a step up from Imagine Homes' standard specification that is 15% above the BAB (B10). Imagine Homes works with IBACOS under BA to evaluate the cost effectiveness and field implementation issues associated with various high-R wall assemblies, air sealing strategies, HVAC system approaches, and renewable energy systems (solar thermal and PV). Imagine is a multiyear winner of the NAHB Green Building award (Production and Affordable categories), the Energy Value Housing Award, and the ENERGY STAR Leadership in Housing Award. Imagine Homes is partly owned by Beazer Homes (2011

Builder 100 ranking #9), which uses Imagine Homes as a "research and development lab" to roll out cost-effective energy efficiency strategies nationally. Beazer's calculation of energy savings is available on its website and states, "*Beazer Homes eSMART Energy Analysis* (October 2009), [was] prepared by using building assumptions established through the DOE Building America program."

Figure 13. Imagine Homes test house in San Antonio, Texas

- *K. Hovnanian Homes*: IBACOS has been working with K. Hovnanian Homes since 2008 to develop and test market-ready solutions for achieving 30% whole-house source energy savings in multiple CZs. Strategies that have been evaluated for both performance and cost effectiveness include HVAC system approaches, air sealing strategies, high-R wall and attic assemblies, and foundation insulation. Multiple generations of occupied test houses have contributed to the specifications reflected in K. Hovnanian Homes' High Performance Home program.

- *Interdisciplinary Collaborative Research*: BA funding helps manufacturers, builders, researchers, and installers create and validate the next generation of energy efficiency solutions in a collaborative environment. IBACOS has been working with United Technologies, Wathen-Castanos Hybrid Homes (2011 Builder 100 rank #129), S&A Homes (2011 Builder 100 Rank #86) Green Earth Equities, and NREL to build and evaluate houses with alternatives to traditional central forced air heating and cooling systems in an effort to understand the fundamental conditions needed to maintain occupant comfort in new and existing homes. This research helps to create the operational specifications for new product innovations at the manufacturer level and provides proven, low-risk solutions that production builders and energy upgrade contractors can use in energy-efficient new and existing homes.

3.4.8 National Association of Home Builders—Research Center (NAHB-RC)

- *New Construction High-R Walls*: In 2012, NAHB-RC developed an outline for design solutions based on discussions with builders about advanced 2 × 6 framing techniques and challenges related to out-of-plane wind loading performance (see Figure 14). NAHB focused primarily on developing integrated solutions for a variety of light-frame walls to achieve high R-values that have minimal transition costs for builders and ensure long-term performance.

Figure 14. Advanced framing structural testing

- *New Construction Test Home Research (NCTH)*: NAHB-RC continues to work with builders of NCTHs that advance BA goals.
    - **Maracay Homes:** This NCTH is in the planning phases in Phoenix, where the builder is looking at ways to approach a HERS index of 50 and 40% over the B10 BAB. The focus is on envelope and duct design.

  - **Nexus EnergyHomes:** This NCTH is an affordable infill project in Frederick, Maryland, in the mixed-humid climate leading to 50% savings over the BAB using structurally insulated panels, ground source heat pumps, and renewables.
  - **Lafayette Housing Authority:** Southface is working on this test house to develop framing and foundation details for 15 duplex structures in Lafayette, Georgia. With design guidance from A.O. Smith, the water heating system is a ducted HPWH that will draw air from and exhaust to the encapsulated attic space. This innovative approach to installing the HPWH system also presents opportunities to use this technology in multifamily homes and retrofits.
  - **Winchester Homes, K. Hovnanian Homes, Martin Dodson Homes, and TaC Studios:** Ongoing projects include measure evaluations for high-R wall designs, air sealing, and improved duct designs.

- *Greenbelt Homes*: NAHB-RC is also working on solutions for existing homes. In 2012, it continued to research large-scale multifamily efficiency solutions with Greenbelt Homes, Inc., a housing cooperative of 1,600 1940 era homes. The 28 pilot homes are currently being monitored for baseline energy use and BEopt models were developed to estimate energy savings for various levels of investment to select the most cost-effective solutions to upgrade the building envelopes. The project will consist of three phases: Phase I will collect baseline energy use data; Phase II will upgrade building envelopes and Phase III will upgrade HVAC systems. Phase II was divided into two parts: the crawlspace upgrades are being completed and planning for the second part is underway. Monitoring will continue through all phases to verify the actual savings of the energy upgrades.

- *Moisture Research*: In 2012, new construction wall systems in various CZs were monitored as part of ongoing research. The outcome will provide field data on the moisture performance of new construction high-R wall designs. The goal is to more accurately evaluate the risk of moisture problems when wall assemblies are constructed with high levels of insulation in various configurations, either through a retrofit of the wall assembly or as a new construction wall system.

The 2012 update to the ICC-700 National Green Building Standard (NGBS) is currently undergoing the first revision since its inception in 2008. All chapters are being addressed including Chapter 7, Energy Efficiency. Specific NGBS provisions and the associated point levels are under review. Because the baseline performance level for the NGBS is being updated, many similarities between the NGBS performance levels and the BA program savings goals can be made using the BEopt software analysis. In support of the revision process, the BA program is supporting simulation estimates from NAHB-RC of energy savings and a realignment of point values with energy savings levels.

3.4.9 NorthernSTAR

- *Integrated Space and Water Heating (Combi) Systems*: Even though the "combi system" has been used for more than two decades, the technology has been primarily targeted to low-load new homes. But the attractiveness of using a single heating plant to meet space heating and domestic hot water needs was extremely attractive to several weatherization programs in Minnesota. It can provide a very positive approach to minimizing combustion safety concerns with "orphaned" water heaters, deliver much higher water heating efficiencies, and meet program savings requirements. Unfortunately, the plant (boilers, tankless water heaters, and storage water heaters) and fan coil options were too numerous to evaluate and the lack of solid performance data made it difficult for typical weatherization operations to develop proper scopes of work and quality control measures. The BA funding allowed the Sustainable Resources Center and Center for Energy and Environment to set up a full-scale testing laboratory to establish clear performance parameters for a wide variety of plant and fan coil units (see Figure 15). These results were used to develop guidance for the proper installation of these systems, thus allowing the local weatherization assistance programs to install this technology with confidence in almost 400 low-income homes. This project has demonstrated that the technology can be deployed on a wide scale for existing homes and early field data corroborate the significant energy savings projected in the laboratory.

Figure 15. Integrated space and water heating test laboratory

- *Foundation Insulation*: Foundation insulation, especially for basements in cold climates, is an essential component for energy performance and comfort. Experts agree that foundation heat loss can be quite significant, especially once above-grade insulation and air sealing measures have been completed; however, the hygrothermal behavior for below-grade assemblies is not well understood. The models have not been sufficiently validated and in-situ performance data are limited. The NorthernSTAR team has focused on a series of projects to provide better tools, data, and guidance for foundation insulation for new and existing homes. These projects could lead to significant energy savings for the entire building stock.

- *Building Better Models*: The need for more realistic and accurate assessments of foundation insulation energy savings is becoming increasingly apparent. Also, proposed insulation strategies must be evaluated for long-term moisture, durability, and indoor air quality implications. This project initiated an experimental and theoretical investigation of the energy and hygrothermal performance of retrofit foundation insulation systems in

CZs 6 and 7. Interior foundation insulation retrofit systems have been identified in preparation for a planned experimental hygrothermal study in 2013.

- *Upgrade Below Grade*: The best method to insulate basements is with exterior waterproofing and insulation. However, using traditional excavation around an existing house is very expensive and many barriers (porches, landscaping, etc.) are in the way. This project investigated several new "excavationless" methods that will remove a small amount of soil from around the entire perimeter of a house. It also evaluated a number of pourable or sprayable insulation formulations that could be injected or inserted into the small cavity outboard of the foundation wall to completely fill it with effective insulation and waterproofing. The early results from our literature search, interviews, and energy modeling suggest this new approach could have widespread application for basements, crawlspaces, and slabs in colder climates.

- *Home Energy Audit and Assessment*: Being able to measure and predict energy savings is the key to cost-effective energy retrofits. This suite of projects has provided information on the best ways to approach this problem. The first project focused on energy assessment with a field test of several building performance models of varying complexity to evaluate their value as rating systems in the context of a residential retrofit program. One subset, conducted by the Center for Energy and Environment, examined and compared 50 homes selected from a DOE "Home Energy Score" pilot project to a full HERS rating and a newer reduced input tool called Simple. The second subset, conducted by the Energy Center of Wisconsin and Wisconsin Energy Conservation Corporation, evaluated two rating tools currently used by the "Focus on Energy" utility program, National Energy Audit Tool and Green Energy Compass, to a full HERS rating. For both subsets, actual utility bills were also collected, analyzed, and compared to the rating tool results. A second project focused on nonenergy performance concerns (health, safety, moisture, mold, and indoor air quality) with a comprehensive review of overall guidance, recommended protocols, and test procedures that could or should be used in a whole-house evaluation. The primary objective was to establish guidelines for assessing these important nonenergy performance parameters before and after an energy upgrade or remodeling effort.

3.4.10 Partnership for Advanced Residential Retrofit (PARR)

- *Developing Measure Packages for Targeted Housing Stock*: PARR is working with Illinois Home Performance with Energy Star to develop measure packages for the most common housing types. PARR's work includes energy modeling and monthly utility bill analysis for tens of thousands of homes across northern Illinois. From 15 housing types (e.g., bungalow), PARR selected the top three based on the cost effectiveness of retrofit (includes total energy use and cost effectiveness of energy efficiency improvements). These three packages are being applied to real homes through Illinois Home Performance with Energy Star. Results will be packaged as case studies in coordination with key partners to highlight the benefits of energy efficiency retrofits, a specific need identified by home performance contractors.

- *Steam System Balancing and Tuning: The Cornerstone of a Complete Energy Efficiency Retrofit*: Chicago's older multifamily housing stock is primarily heated by centrally metered steam or hydronic systems. Older heating systems often suffer from mis-investment—multiple contractors upgrading parts of systems in inadequate or inappropriate ways that reduce system functionality and efficiency. Based on significant field experience, the PARR team developed a steam balancing and tuning technical report addressing practical solutions to implementing system improvements across a large number of multifamily buildings, addressing space heating energy use in a significant and cost-effective manner (see Figure 16). PARR conducted a study to identify best practices for the methodology, typical costs, and energy savings associated with steam system balancing by looking at 10 test buildings. A package of common steam balancing measures was assembled and data were collected on the buildings before and after these retrofits were installed to provide building owners, contractors, and utility companies with a clear and concise understanding of the process and cost effectiveness of steam system balancing. Results reveal that on average, steam balancing measures will save approximately 14.2% of the natural gas used for heating and improve tenant comfort.

Figure 16. A typical building that could benefit from steam system balancing and tuning

- *Best Approach to Combustion Safety in a Direct Vent World*: The building science community holds varying opinions about the best overall value proposition (testing versus replacement) and the proper test procedures for verifying the combustion safety of draft hood-equipped appliances. Practitioners and codes differ in their recommendations for level of home depressurization and time required for cold vent establishment pressure. In addition, statistics on incidents and data collected from the field have not supported stringent testing requirements. GTI brought a diverse group together in a BA expert meeting to identify gaps and barriers that need to be addressed by future research and data-driven technical recommendations for code updates so all members of the building energy efficiency and code communities can adopt a common approach.

- *High Efficiency Combined Space and Water Heat*: PARR is supporting a pilot energy efficiency program for high efficiency condensing tankless driven combined water and forced air heat systems. PARR has developed a test plan to monitor several installed systems to determine efficiency, energy use and savings, and cost effectiveness. PARR will develop key installation and commissioning guidelines to help Nicor Gas and other utilities implement programs for combined systems that optimize efficiency and cost effectiveness. This project is a great example of leveraging strong partnerships and funding to provide real value to key industry partners and energy end users. PARR has been working closely with BA team NorthernSTAR to leverage lessons learned through previous combined systems research.

4 Multi-Year Research Plan and Critical Path Milestone

The BA strategic planning process provides the framework for the program's efforts to develop innovative integrated energy-saving solutions that achieve a 50% reduction in energy use in new and existing homes. This includes regular meetings of individual technical committees to identify specific gaps in our understanding of high performance building systems and three annual meetings directed at tracking progress in resolving stakeholder issues, technical issues, and policy issues. The program actively engages relevant industry stakeholders in the research planning process, primarily through STCs. The STCs focus on identifying and tracking progress on key technical issues that limit achievement of BA program goals.

The critical path milestones, summarized in Appendix D, represent the high level goals that the program must achieve for the successful development of BA system innovations leading to 50% savings in existing and new homes. The development of successful solutions will require crosscutting, multidisciplinary, and multiscale approaches that will involve multiple STCs.

The milestones were developed to define the key areas where the BA program can provide major contributions that significantly reduce home energy use and work in partnership with the residential construction industry. This work will provide significant benefits to industry via meaningful solutions for high performance homes. The milestones help focus BA resources on accelerating the resolution of key technical barriers that limit the broad, risk-free, reliable, cost-effective, safe, and rapid implementation of next-generation energy-efficient systems in all U.S. homes.

The STCs continuously assess research progress and identify new gaps as they relate to the BA critical path milestones. The milestones represent our current understanding of what is needed to achieve the BA goal of 50% energy savings, but they must be re-evaluated as new innovations emerge and the market responds.

5 Conclusions

During FY 2012 the BA program made significant progress toward achieving its initial goal of 30% savings. Key technical tools developed by the program include the BEopt tool, the National Measures Database, and the BA field Data Repository, including the extended HPXML standard that providers use to design the next generation of energy efficiency programs. A multi-year plan identifying the critical innovations required to achieve 50% savings was completed to ensure the program focuses on solutions that can be broadly adopted. Technical content and systems knowledge developed by the program will be integrated in real time with the BA Solution Center, an emerging online tool for all BA research content, to increase the rate of knowledge transfer to key stakeholder groups.

Appendix A: Comparing Building America Whole-House Savings Targets With the 2012 and 2015 International Energy Conservation Code Residential Energy Code Updates

DOE's Residential Energy Codes Program provides recommendations for potential improvements in residential building energy codes, including prescriptive and performance-related provisions. The BA program is an industry-driven, cost-sharing building energy research program that accelerates the development, adoption, and cost effectiveness of advanced energy technologies and building practices in new and existing homes. Both programs develop approaches to save energy in buildings and measure program effectiveness relative to a target. Current residential building energy codes do not include all end use loads that are included in BA performance targets and code improvement targets set by the DOE codes program and use a different baseline code reference (2006 IECC) than is used to set BA whole-house performance goals (2009 IECC).

The Building America Program

The BA program sets energy performance goals to track program progress and to measure energy savings and cost savings. Energy savings are calculated as source energy savings relative to the reference home. The reference home for "New Homes" program goals is the BAB home, which aligns with the prescriptive requirements of 2009 IECC. Using the source energy use of the BAB home as a baseline, energy savings from improvements to insulation, fenestration, and other technologies are evaluated using the Building America House Simulation Protocols.[12] In this system research framework, different combinations of EEMs and renewable energy measures that target all energy end uses can potentially be used to reach target levels of source energy savings. Cost effectiveness is evaluated using life cycle cost analysis. Table 1 shows that savings targets for the BA program are expressed in whole-house, source energy savings. Additionally, the scope of the BA energy savings targets includes retrofit savings targets for existing homes. The Residential Energy Code does not currently consider existing homes.

The Residential Energy Codes Program

The metric for setting goals for improvements in residential building energy codes is expressed in percentage cost savings relative to 2006 IECC.[13] Table 3 provides a summary of past code updates and savings targets.

[12] BA House Simulation Protocols ensure consistency of modeling results by defining a variety of simulation conditions, rules, and assumptions.
[13] http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/ns/webinar_residential_energycodes_20110222.pdf

Table 3. DOE Residential Energy Code Improvement Savings Targets

Year of IECC Code Update	End-Use Specific, Site Energy Cost Savings Relative to IECC 2006
2009	12%–15%
2012	30%
2015	50%

Savings are calculated using a subset of energy end uses and reference current National Appliance Energy Conservation Act requirements for appliance efficiency.[14] The energy cost savings are calculated using an end use-specific metric because of scope restrictions of the Residential Energy Code. Only end uses that are regulated by code are considered: space conditioning, lighting, and water heating. A new methodology for evaluating Residential Energy Code changes was published in April 2012.[15] For future Residential Energy Code updates, computer-simulated energy savings and life cycle cost will be used to evaluate the efficacy of proposed changes.

Comparing Building America Savings Goals and Codes Savings Goals

Table 4 summarizes the difference between the two approaches for metrics, baselines, and end uses for calculating savings targets in the two programs.

Table 4. Summary of Metrics, Baselines, and Scopes for BA and DOE Residential Energy Codes Savings Targets

	Building America Program	Residential Energy Codes
Metric	Source energy savings relative to BAB home.	Site energy cost for end uses regulated by code: space conditioning, lighting, and water heating.
Baseline	BAB home; Follows prescriptive requirements of IECC 2009 and is simulated under BA House Simulation Protocols	Follows prescriptive requirements of IECC 2006; considers only end uses regulated by code.
Scope	Energy efficiency (envelope, HVAC, water heaters) and renewable energy (PV and solar water heating)	End uses regulated by code.

The differences in approach result in some EEMs that are included for the BA program to be excluded in the Residential Energy Code. For example, BA's scope allows HVAC, water heaters, and renewable energy measures to be considered in achieving energy savings, whereas the Residential Energy Code's scope does not include these savings options.

Examples comparing BA savings and the Residential Energy Code savings are illustrated in Figure 17. Four prototype homes were simulated using BEopt1.3 E+: a two-story, 2,400-ft^2, all-

[14] http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/ns/webinar_residential_energycodes_20110222.pdf
[15] http://www.energycodes.gov/development/residential/methodology/

electric single-family home in Atlanta, Georgia, that is built to 2006 IECC, 2012 IECC, 2015 IECC,[16] and a home that achieves the BA 50% savings target. Figure 17 plots whole-house source energy savings in MMBtu relative to the 2006 IECC home (left axis) and energy cost savings in space conditioning, lighting, and water heating relative to 2006 IECC (right axis). The price of electricity is assumed to be $0.12/kWh.

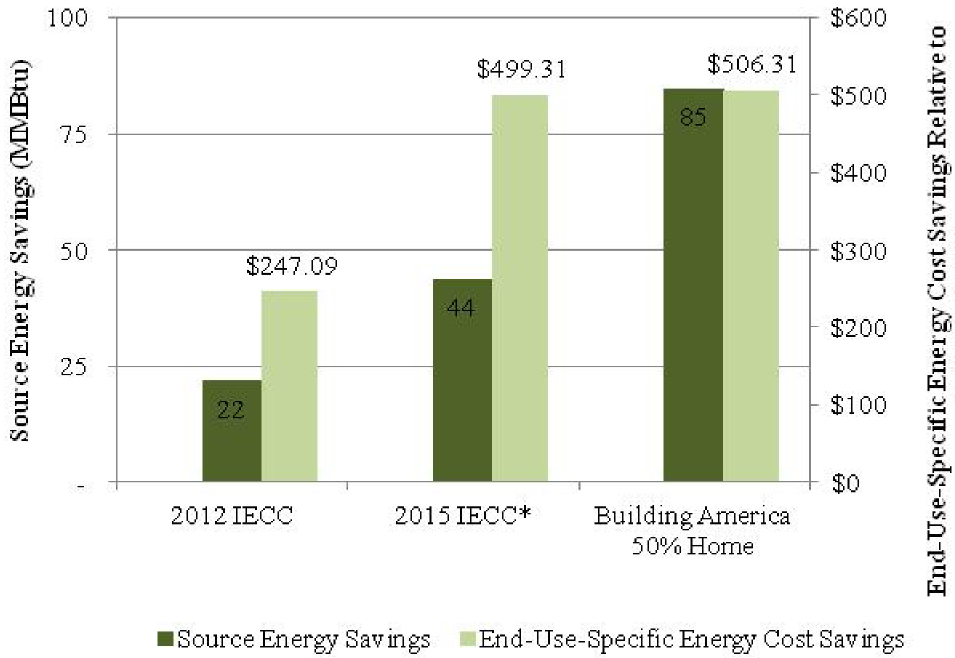

Figure 17. Source energy savings and end use-specific cost savings relative to 2006 IECC for three prototype buildings

The cost savings for the 2015 IECC and BA 50% home are nearly the same (~$500); the BA 50% home achieves nearly double the source energy savings of the 2015 IECC home because additional system design tradeoffs were included that cannot currently be considered in IECC codes. This is due to large energy savings from a high efficiency heat pump (seasonal energy efficiency ratio [SEER] 22/heating seasonal performance factor 10.0), use of ENERGY STAR appliances, and use of a 2.5-kW PV system, which are all currently outside the scope of the IECC Residential Energy Code.

[16] As of publication, the 2015 IECC code cycle has not yet completed. The 2015 IECC prototype home is defined such that the space heating, lighting, and hot water energy costs are roughly 50% of the 2006 IECC prototype home.

Appendix B: New Construction and Retrofit Energy Savings Measure Packages for Mixed Fuel and All-electric Prototypes

Overview

DOE and the BA program set energy savings goals for new and existing homes. Energy savings goals are climate specific and are met by cost-effectively integrating EEMs and renewable energy measures into packages. To identify the measures required to attain different levels of energy savings, NREL developed the publicly available BEopt software, an hourly building energy simulation tool.[17] BEopt models the interactive effects of combining measures, calculates the life cycle cost of implementing different measures, and generates a cost-optimal path to net-zero energy. A combination of measures on the cost-optimal path is an ESMP. ESMPs are representative measure packages that attain energy savings goals for specific prototype buildings. These packages are optimized for maximum energy cost savings to homeowners for source energy savings given the local energy costs, climates, and building characteristics such as foundation types.

Analysis

ESMPs are expressed as a percentage of savings relative to a case-specific reference home prototype.

To represent different availability of fuel types, two prototypes are created: an all-electric and a mixed fuel (electric and natural gas). The analysis period is 30 years with an inflation rate and discount rate of 3%. The retrofit measure capital costs are financed via a five-year loan at an interest rate of 7%. All measure costs are assumed to be installed capital costs taken from NREL's National Residential Efficiency Measures Database). All simulations are conducted using BEoptE+ version 1.3.

ESMP analysis is highly sensitive to the prototype building characteristics, economic assumptions, and operational inputs. A typical BEopt optimization contains thousands of combinations of EEMs and renewable energy measures. Though the ESMPs are optimal packages, near-optimal packages of measures may achieve nearly identical energy savings. As illustrated in Figure 18, a number of near-optimal ESMPs cluster about the optimal ESMPs.

[17] beopt.nrel.gov

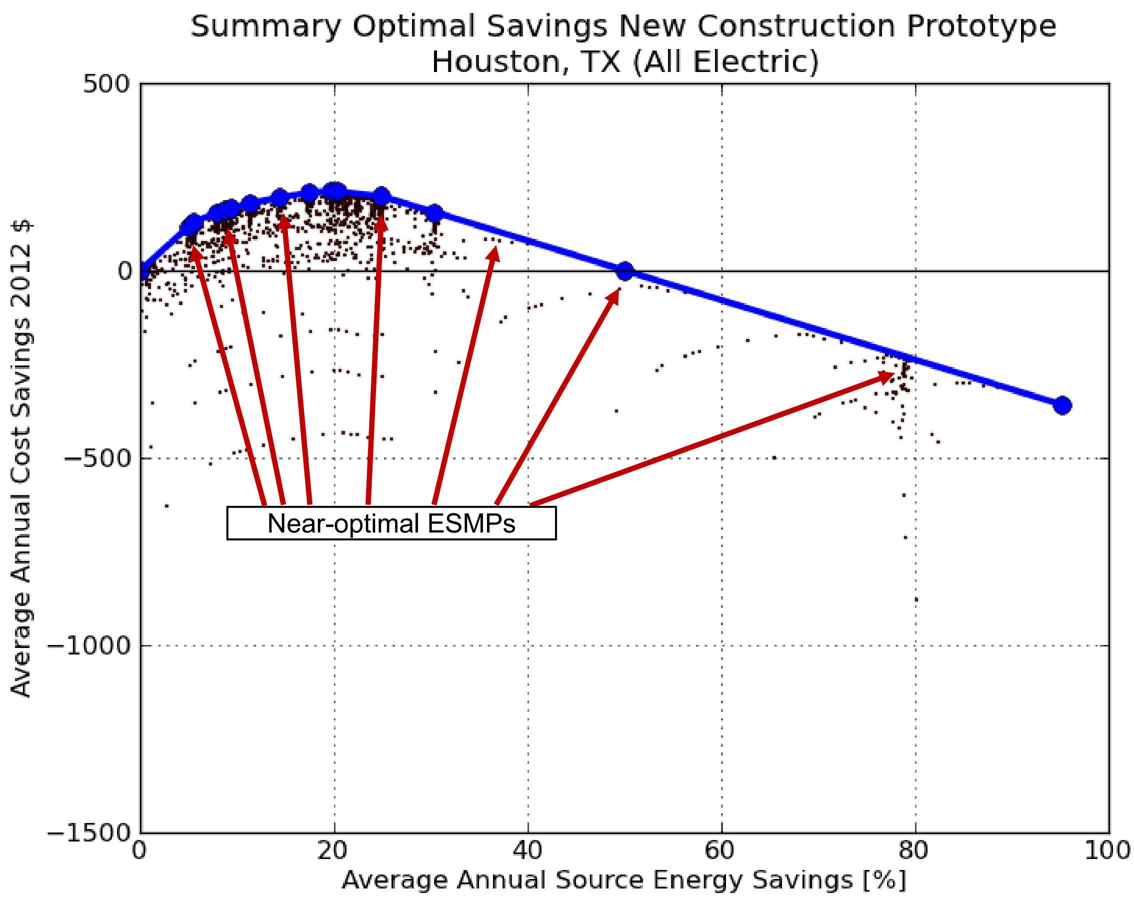

Figure 18. Near-optimal ESMPs should be explored for specific projects

We encourage users to explore the near-optimal ESMPs when interpreting this analysis. To facilitate this exploration, all BEoptE+ version 1.3 project files have been made available on the BEopt website. See Table 5 for direct links.

Table 5. BEopt ESMP Analysis Files

http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/NewConstruction_AllElectric_Atlanta.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/NewConstruction_AllElectric_Chicago.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/NewConstruction_AllElectric_Houston.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/NewConstruction_AllElectric_Phoenix.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/NewConstruction_AllElectric_Seattle.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/NewConstruction_MixedFuel_Atlanta.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/NewConstruction_MixedFuel_Chicago.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/NewConstruction_MixedFuel_Houston.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/NewConstruction_MixedFuel_Phoenix.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/NewConstruction_MixedFuel_Seattle.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_AllElectric_1990s_Atlanta.bpp

http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_AllElectric_1990s_Chicago.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_AllElectric_1990s_Houston.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_AllElectric_1990s_Phoenix.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_AllElectric_1990s_Seattle.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_AllElectric_1960s_Atlanta.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_AllElectric_1960s_Chicago.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_AllElectric_1960s_Houston.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_AllElectric_1960s_Phoenix.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_AllElectric_1960s_Seattle.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_MixedFuel_1990s_Atlanta.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_MixedFuel_1990s_Chicago.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_MixedFuel_1990s_Houston.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_MixedFuel_1990s_Phoenix.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_MixedFuel_1990s_Seattle.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_MixedFuel_1960s_Atlanta.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_MixedFuel_1960s_Chicago.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_MixedFuel_1960s_Houston.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_MixedFuel_1960s_Phoenix.bpp
http://beopt.nrel.gov/sites/beopt.nrel.gov/files/docs/Retrofit_MixedFuel_1960s_Seattle.bpp

Table 6 summarizes cost-effective ESMPs for new and existing homes to achieve 50% savings in six prototype buildings in five climates across the United States.

Table 6. Summary of ESMP Prototype Buildings

Construction Type	Construction Era	Type	Locations
New Construction	N/A	All-electric	Atlanta, Georgia Chicago, Illinois Houston, Texas Phoenix, Arizona Seattle, Washington
Retrofit	1960s		
Retrofit	1990s	Mixed fuel	

Simulation inputs for new construction and retrofit prototype buildings are provided in Table 7 and Table 8, respectively.

Table 7. Summary of BEopt Inputs for New Construction ESMP Prototype Buildings

Simulation Input	Value
Conditioned Floor Area	2,400 ft^2
Above-Grade Stories	2
Footprint	Rectangular (40 ft × 30 ft)
Garage (Attached)	Two-car (20 ft × 20 ft)
Orientation	North
Neighbors	At 15 ft
Number of Bedrooms	3
Number of Baths	2
Window Areas	Total window area: 301 ft^2
Window Directional Distributions (% of Total)	N: 20%, S: 40%, E: 20%, W: 20%

Table 8. Summary of BEopt Simulation Inputs for Retrofit ESMP Prototype Buildings

Simulation Input	Value
Conditioned Floor Area	1,280 ft^2
Above-Grade Stories	1
Footprint	Rectangular (40 ft × 32 ft)
Garage (Attached)	One-car (20 ft × 10 ft)
Orientation	North
Neighbors	At 15 ft
Number of Bedrooms	3
Number of Baths	2
Window Areas	Total window area: 148 ft^2
Window Directional Distributions (% of Total)	N: 20%, S: 40%, E: 20%, W: 20%

Table 9. Summary of Measures Modeled in New Construction All-Electric ESMPs

Category	Reference	Options Modeled							
Foundation: Basement	Chicago: R-10 Rigid, 8 ft	R-15 Rigid, 8 ft	R-20 Rigid, 8 ft						
Foundation: Crawlspace Wall	Atlanta: R-5 Rigid Seattle: R-10 Rigid	R-10 Rigid	R-15 Rigid	R-20 Rigid					
Foundation: Slab	Houston: Uninsulated Phoenix: Uninsulated	R-5 Rigid 2 ft	R-5 Rigid 4 ft	R-10 Rigid 2 ft	R-10 Rigid 4 ft	Whole Slab R10 R5 Gap			
Exterior Walls	Atlanta: R-13 2x4 16 in o.c. Phoenix: R-13 2x4 16 in o.c. Chicago: R-13 2x4 16 in o.c.+ 1 in foam Seattle: R-13 2x4 16 in o.c.+ 1 in foam	R-13 2x4 16 in o.c. (+ 1 in foam)	R-19 2x6 24 in o.c. (+ 1 in foam) (+ 2 in foam)	R-21 2x4 16 in o.c. (+ 1 in foam)					
Interzonal Walls	R-19 2x6 24 in o.c.	R-19 2x6 24 in o.c. + 1 in foam							
Unfinished Attic	Atlanta, Houston, Phoenix: R-30 Seattle, Chicago: R-38	R-38	R-49	R-60					
Windows	Atlanta: U=0.37|SHGC=0.30 Chicago: U=0.35|SHGC=0.44 Houston: U=0.37|SHGC=0.30 Phoenix: U=0.37|SHGC=0.30 Seattle: U=0.35|SHGC=0.44	U=0.34 SHGC=0.29	U=0.29 SHGC=0.56	U=0.27 SHGC=0.46	U=0.26 SHGC=0.31	U=0.28 SHGC=0.38	U=0.27 SHGC=0.25	U=0.18 SHGC=0.40	U=0.17 SHGC=0.27
Infiltration	7 ACH @ 50Pa	4 ACH @ 50Pa	2 ACH @ 50Pa						
Heat Pump	SEER 13 HSPF 7.7	SEER 14 HSPF 8.2	SEER 15 HSPF 8.5	SEER 16 HSPF 8.6	SEER 17 HSPF 8.7	SEER 18 HSPF 9.3	SEER 19 HSPF 9.5	SEER 22 HSPF 10.0	
Ducts	Atlanta: Typical, R-6 Seattle: Typical, R-6 Chicago: Typical, R-6 Houston, Phoenix: Typical, R-8	Typical, R-6	Typical, R-8	Tight, R-8	In Finished Space				
Water Heater	EF = 0.92	EF = 0.95	HP, 50 gal	HP, 80 gal					
Lighting	BA Benchmark	20% CFL	40% CFL	60% CFL	80% CFL	100% CFL			
Refrigerator	Standard 480 kWh	EnergyStar 374 kWh							
Cooking Range	Standard 500 kWh	Induction 473 kWh							
Dishwasher	Standard 318 kWh	EnergyStar 290 kWh							
Clothes Washer	Standard 1.41 MEF	EnergyStar 2.47 MEF							
Hot Water Pipe Insulation	Uninsulated	R-2	R-2 Recirc Pump	R-5	R-5 Recirc Pump				
Solar Hot Water	None	40 sq ft Closed Loop	64 sq ft Closed Loop						
PV	None	1 kW 1.5 kW	2 kW 2.5 kW	3 kW 3.5 kW	4 kW 4.5 kW	5 kW 5.5 kW	6 kW 6.5 kW	7 kW 7.5 kW	8 kW

Table 10. 30% ESMPs—New Construction All-Electric Prototype

30% Energy Savings Measure Packages - New Construction Prototype All Electric	Atlanta, GA	Chicago, IL	Houston, TX	Phoenix, AZ	Seattle, WA
Clothes Washer: EnergyStar	X	X	X	X	X
Dishwasher: EnergyStar	X	X	X	X	X
DHW Piping: R2, TrunkBranch, PEX, Demand	X	X	X	X	X
Water Heater: Electric Premium	X	X		X	X
Refrigerator: EnergyStar	X		X	X	X
Walls: R-19 Batt, 2x6, 24"o.c., 2" Foam	X	X			X
Attic: Ceiling R-38, Vented	X	X		X	
Heat Pump: SEER 22, HSPF 10.	X	X			X
PV System: 0.5 kW	X			X	X
Ducts: In Finished Space		X	X	X	
Air Sealing: 2 ACH@50Pa	X	X			
Windows: 2 Pane (U=0.341, SHGC=0.297)			X	X	
Walls: R-13 Batt, 2x4, 16"o.c., 1" Foam			X	X	
Air Sealing: 4 ACH@50Pa			X	X	
Heat Pump: SEER 19, HSPF 9.5			X	X	
Windows: 2 Pane (U=0.368, SHGC=0.300)		X			
Interzonal Walls: R-19 Batt, 2x6, 24"o.c.		X			
Water Heater: Heat Pump Water			X		
Crawlspace: Wall R15 Rigid					X
Windows: 2 Pane (U=0.291, SHGC=0.559)					X
Attic: Ceiling R-49, Vented					X
Exposed Floor: 20% Exposed					X
Interzonal Walls: R-19 Batt, 2x6, 24"o.c., 1" Foam					X

Table 11. 50% ESMPs—New Construction All-Electric Prototype

50% Energy Savings Measure Packages - New Constrution Prototype All Electric	Atlanta, GA	Chicago, IL	Houston, TX	Phoenix, AZ	Seattle, WA
Clothes Washer: EnergyStar	X	X	X	X	X
Dishwasher: EnergyStar	X	X	X	X	X
Refrigerator: EnergyStar	X	X	X	X	X
DHW Piping: R2, TrunkBranch, PEX, Demand	X	X	X	X	X
Water Heater: Electric Premium	X			X	X
Walls: R-19 Batt, 2x6, 24"o.c., 2" Foam	X	X			X
Heat Pump: SEER 22, HSPF 10.	X	X			X
Attic: Ceiling R-38, Vented	X			X	
Air Sealing: 2 ACH@50Pa	X	X			
PV System: 4.0 kW	X			X	
Interzonal Walls: R-19 Batt, 2x6, 24"o.c., 1" Foam		X			X
Attic: Ceiling R-49, Vented		X			X
Water Heater: Heat Pump Water		X	X		
Windows: 2 Pane (U=0.291, SHGC=0.559)		X			X
Ducts: In Finished Space			X	X	
Windows: 2 Pane (U=0.341, SHGC=0.297)			X	X	
Walls: R-13 Batt, 2x4, 16"o.c., 1" Foam			X	X	
Air Sealing: 4 ACH@50Pa			X	X	
Heat Pump: SEER 19, HSPF 9.5			X	X	
Unfinished Basement: Wall 8ft R15 Rigid		X			
Ducts: Typical, R6 Insulation		X			
PV System: 3.0 kW		X			
PV System: 3.5 kW			X		
Crawlspace: Wall R15 Rigid					X
Exposed Floor: 20% Exposed					X
PV System: 0.5 kW					X
PV System: 6.0 kW					X

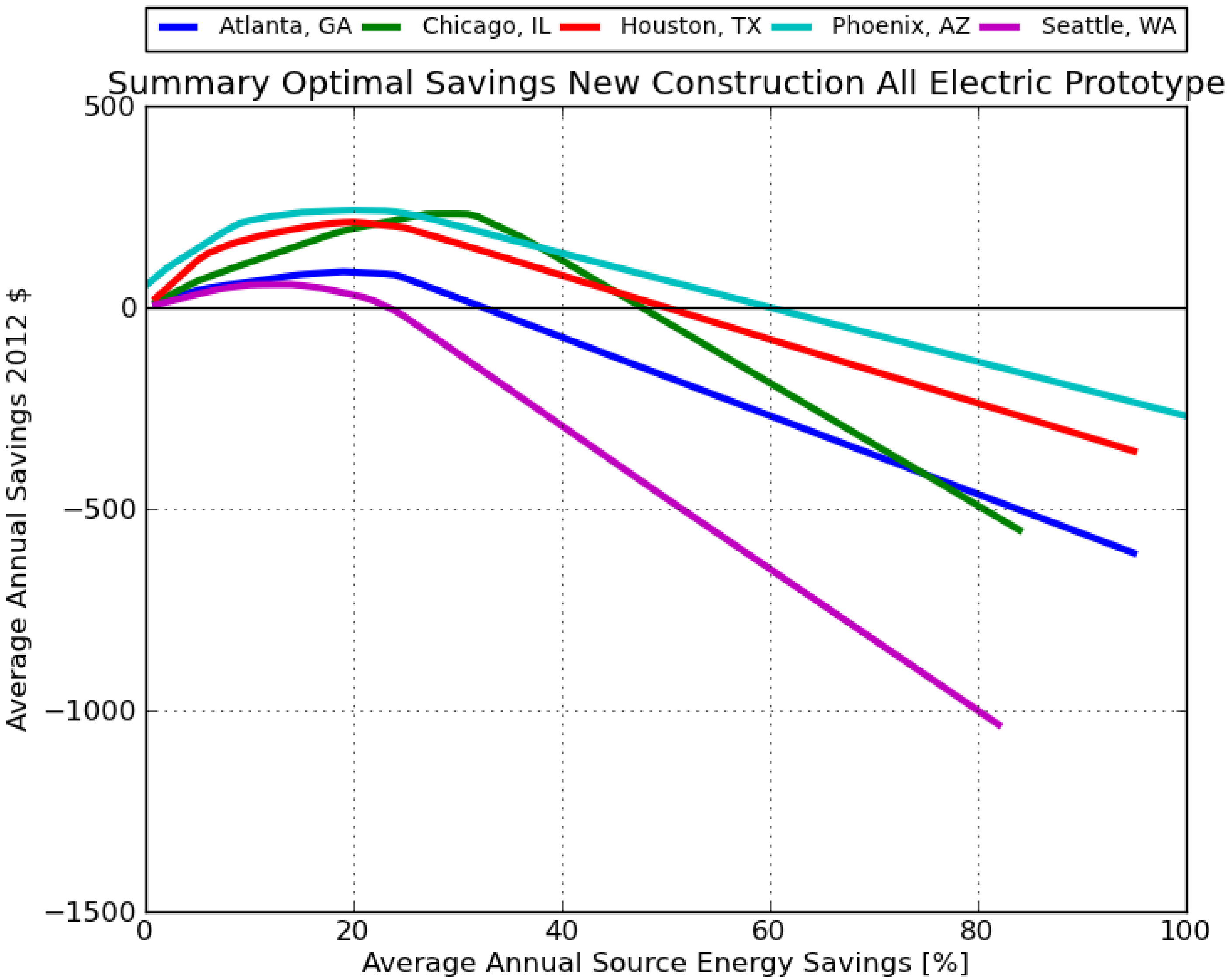

Figure 19. Summary of optimal savings—new construction all-electric prototype

Table 12. ESMPs for New Construction All-Electric Prototype—Atlanta

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	Clothes Washer: EnergyStar	Water Heater: Electric Premium	Dishwasher: EnergyStar	Heat Pump: SEER 14, HSPF 8.2 (29.91 kBtu/hr) (2.31 tons)	Walls: R-19 Batt, 2x6, 24"o.c., 2" Foam	Attic: Ceiling R-38, Vented	Refrigerator: EnergyStar	DHW Piping: R2, TrunkBranch, PEX, Demand	Heat Pump: SEER 15, HSPF 8.5 (24.97 kBtu/hr) (2.0 tons)	Walls: R-21 Batt, 2x6, 24"o.c., 1" Foam	Refrigerator: Standard, Top Mount Freezer	Heat Pump: SEER 22, HSPF 10.0 (25.5 kBtu/hr) (1.99 tons)	Air Sealing: 2 ACH@50Pa	PV System: 0.5 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
5	40	X																
5	45	X	X															
6	48	X	X	X														
8	57	X	X	X	X													
15	81	X	X	X	X	X	X	X										
18	87	X	X	X	X	X	X	X	X									
19	89	X	X	X		X	X	X	X	X								
24	82	X	X	X			X		X		X	X	X					
24	78	X	X	X			X	X	X		X		X					
28	47	X	X	X		X	X	X	X				X	X				
30	24	X	X	X		X	X	X	X				X	X	X			
50	-171	X	X	X		X	X	X	X				X	X		X		
79	-453	X	X	X		X	X	X	X				X	X			X	
96	-619	X	X	X		X	X	X	X				X	X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

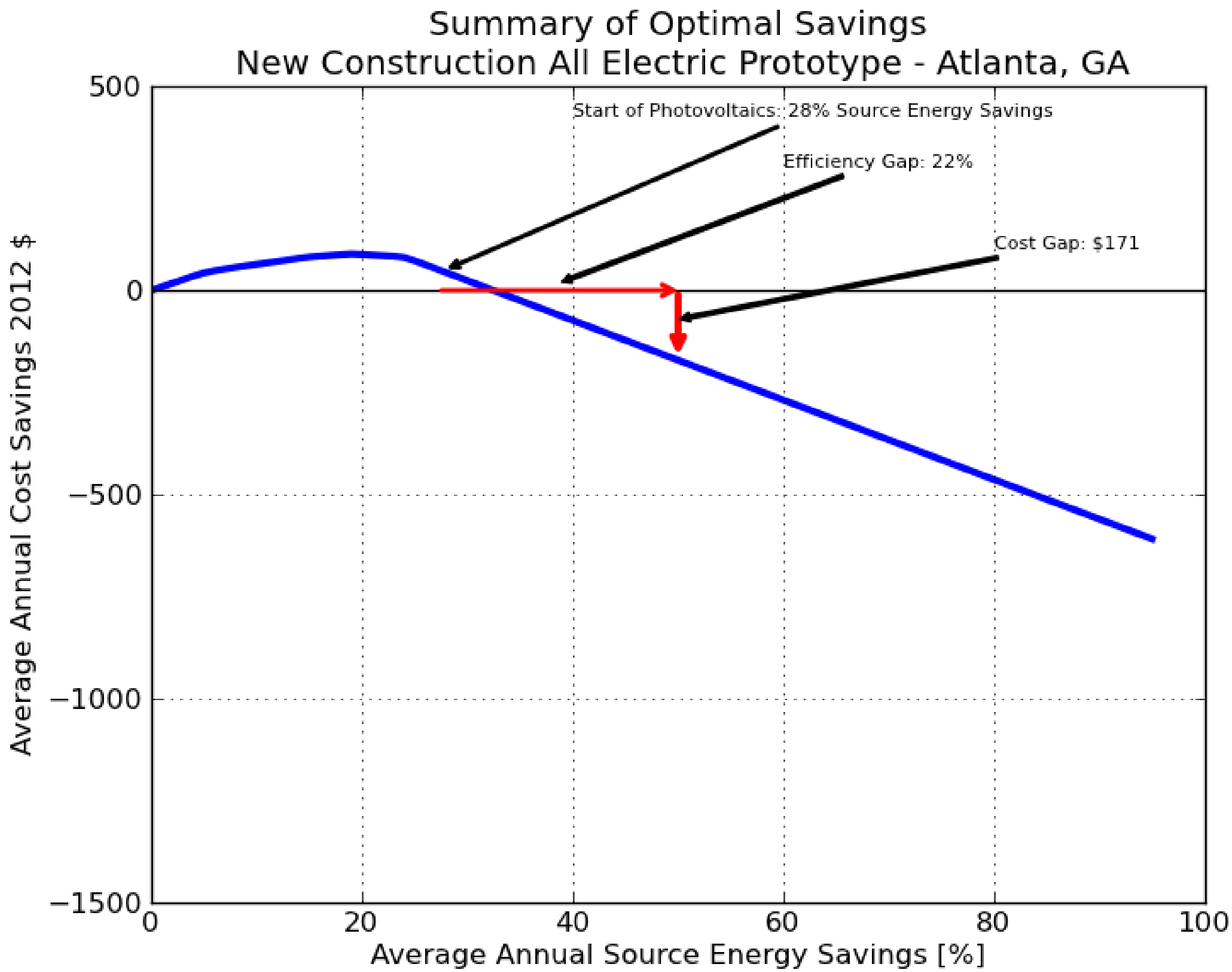

Figure 20. Summary of optimal savings new construction all-electric prototype—Atlanta

Table 13. ESMPs for New Construction All-Electric Prototype—Chicago

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	Clothes Washer: EnergyStar	Water Heater: Electric Premium	Heat Pump: SEER 14, HSPF 8.2 (44.46 kBtu/hr) (2.49 tons)	Walls: R-21 Batt, 2x6, 24"o.c., 1" Foam	Air Sealing: 4 ACH@50Pa	Dishwasher: EnergyStar	Walls: R-19 Batt, 2x6, 24"o.c., 2" Foam	Interzonal Walls: R-19 Batt, 2x6, 24"o.c., 1" Foam	Windows: 2 Pane (U=0.368, SHGC=0.300)	Air Sealing: 2 ACH@50Pa	Heat Pump: SEER 15, HSPF 8.5 (25.41 kBtu/hr) (1.5 tons)	Ducts: In Finished Space	DHW Piping: R2, TrunkBranch, PEX, Demand	Attic: Ceiling R-49, Vented	Interzonal Walls: R-19 Batt, 2x6, 24"o.c.	Attic: Ceiling R-38, Vented	Heat Pump: SEER 22, HSPF 10.0 (25.77 kBtu/hr) (1.5 tons)	Unfinished Basement: Wall 8ft R15 Rigid	Refrigerator: EnergyStar	Water Heater: Heat Pump Water Heater 50 gal	Windows: 2 Pane (U=0.291, SHGC=0.559)	Ducts: Typical, R6 Insulation	PV System: 3.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
5	67	X																								
6	73	X	X																							
8	97	X	X	X																						
18	183	X	X	X	X	X																				
19	188	X	X	X	X	X	X																			
20	194	X	X	X		X	X	X																		
24	218	X	X				X	X	X	X	X	X	X													
27	232	X	X				X	X	X	X	X	X	X	X												
28	233	X	X				X	X	X	X	X	X	X	X	X											
30	233	X	X				X	X		X	X		X	X		X	X	X								
31	232	X	X				X	X	X	X	X		X	X			X	X								
31	232	X	X				X	X	X	X	X		X	X	X			X								
32	229	X	X				X	X	X	X	X		X	X	X			X	X							
36	172	X					X	X	X	X	X		X	X	X			X	X	X	X					
39	134	X					X	X	X		X			X	X			X	X	X	X	X	X			
50	-35	X					X	X	X		X			X	X			X	X	X	X	X	X	X		
73	-384	X					X	X	X		X			X	X			X	X	X	X	X	X		X	
84	-556	X					X	X	X		X			X	X			X	X	X	X	X	X			X

(blue)	30% Energy Savings
(green)	50% Energy Savings

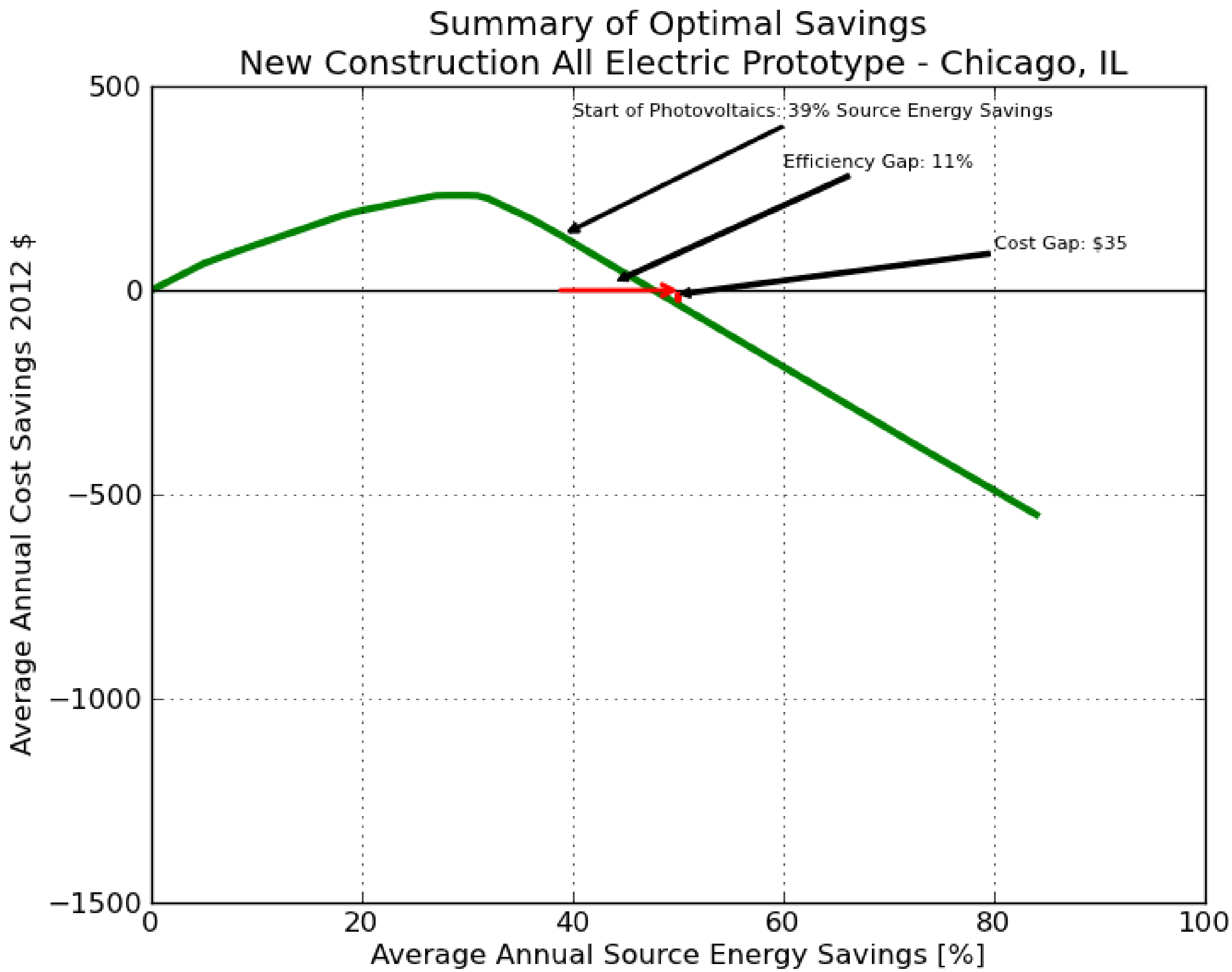

Figure 21. Summary of optimal savings new construction all-electric prototype—Chicago

Table 14. ESMPs for New Construction All-Electric Prototype—Houston

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	Windows: 2 Pane (U=0.376, SHGC=0.437)	Ducts: In Finished Space	Windows: 2 Pane (U=0.341, SHGC=0.297)	Clothes Washer: EnergyStar	Water Heater: Electric Premium	Dishwasher: EnergyStar	Heat Pump: SEER 14, HSPF 8.2 (23.06 kBtu/hr) (2.47 tons)	Heat Pump: SEER 16, HSPF 8.6 (23.06 kBtu/hr) (2.34 tons)	DHW Piping: R2, TrunkBranch, PEX, Demand	Heat Pump: SEER 18, HSPF 9.3 (23.06 kBtu/hr) (2.36 tons)	Refrigerator: EnergyStar	Walls: R-13 Batt, 2x4, 16"o.c., 1" Foam	Air Sealing: 4 ACH@50Pa	Heat Pump: SEER 19, HSPF 9.5 (16.85 kBtu/hr) (1.88 tons)	Water Heater: Heat Pump Water Heater 50 gal	PV System: 3.5 kW	PV System: 6.0 kW	PV System: 8.0 kW
5	117	X	X																
6	129		X	X															
8	155		X	X	X														
9	161		X	X	X	X													
9	166		X	X	X	X	X												
11	179		X	X	X	X	X	X											
14	195		X	X	X	X	X		X										
17	208		X	X	X	X	X		X	X									
20	212		X	X	X	X	X			X	X								
20	211		X	X	X	X	X			X	X	X							
25	199		X	X	X	X	X			X		X	X	X	X				
30	156		X	X	X		X			X		X	X	X	X	X			
50	0		X	X	X		X			X		X	X	X	X	X	X		
79	-229		X	X	X		X			X		X	X	X	X	X		X	
95	-356		X	X	X		X			X		X	X	X	X	X			X

(blue)	30% Energy Savings
(green)	50% Energy Savings

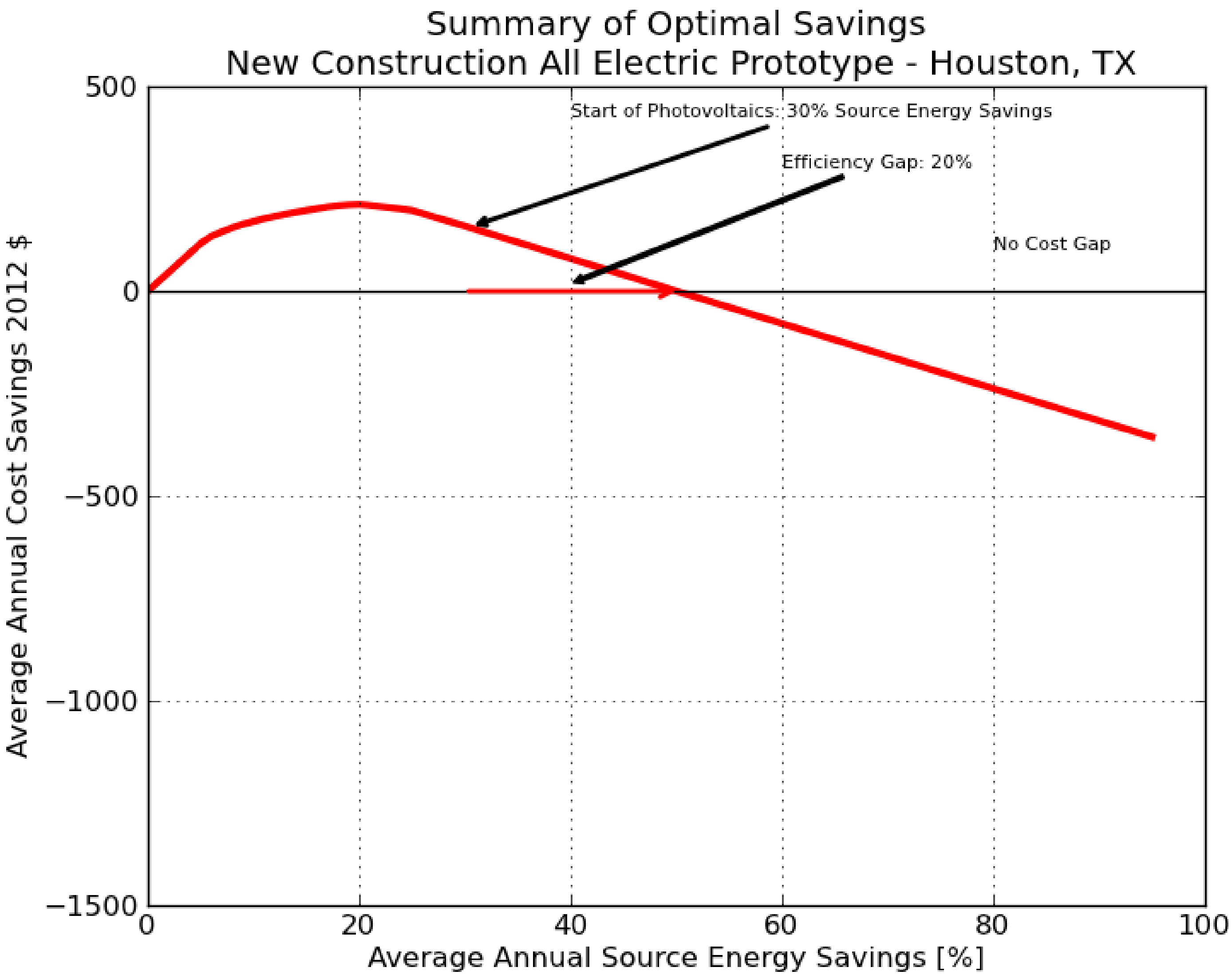

Figure 22. Summary of optimal savings new construction all-electric prototype—Houston

Table 15. ESMPs for New Construction All-Electric Prototype—Phoenix

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	Attic: Roof R-19, Closed	Windows: 2 Pane (U=0.376, SHGC=0.437)	Windows: 2 Pane (U=0.341, SHGC=0.297)	Ducts: In Finished Space	Attic: Ceiling R-60, Vented	Attic: Ceiling R-49, Vented	Clothes Washer: EnergyStar	Water Heater: Electric Premium	Heat Pump: SEER 14, HSPF 8.2 (15.5 kBtu/hr) (3.0 tons)	Dishwasher: EnergyStar	Heat Pump: SEER 15, HSPF 8.5 (15.5 kBtu/hr) (3.0 tons)	Walls: R-13 Batt, 2x4, 16"o.c., 1" Foam	Attic: Ceiling R-30, Vented	DHW Piping: R2, TrunkBranch, PEX, Demand	Heat Pump: SEER 18, HSPF 9.3 (14.21 kBtu/hr) (2.82 tons)	Refrigerator: EnergyStar	Air Sealing: 4 ACH@50Pa	Heat Pump: SEER 19, HSPF 9.5 (11.8 kBtu/hr) (2.47 tons)	Attic: Ceiling R-38, Vented	PV System: 0.5 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	45	X	X																					
2	99	X		X	X																			
8	188			X	X	X																		
9	211			X	X		X	X																
10	215			X	X		X	X	X															
12	226			X	X		X	X	X	X														
13	228			X	X		X	X	X	X	X													
15	236			X	X		X	X	X		X	X												
17	239			X	X			X	X		X	X	X	X										
20	241			X	X			X	X		X	X	X	X	X									
24	240			X	X			X	X		X		X	X	X	X								
24	237			X	X			X	X		X		X	X	X	X	X							
26	226			X	X			X	X		X		X	X	X		X	X	X					
27	224			X	X			X	X		X		X		X		X	X	X	X				
30	205			X	X			X	X		X		X		X		X	X	X	X	X			
50	69			X	X			X	X		X		X		X		X	X	X	X		X		
85	-165			X	X			X	X		X		X		X		X	X	X	X			X	
104	-294			X	X			X	X		X		X		X		X	X	X	X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

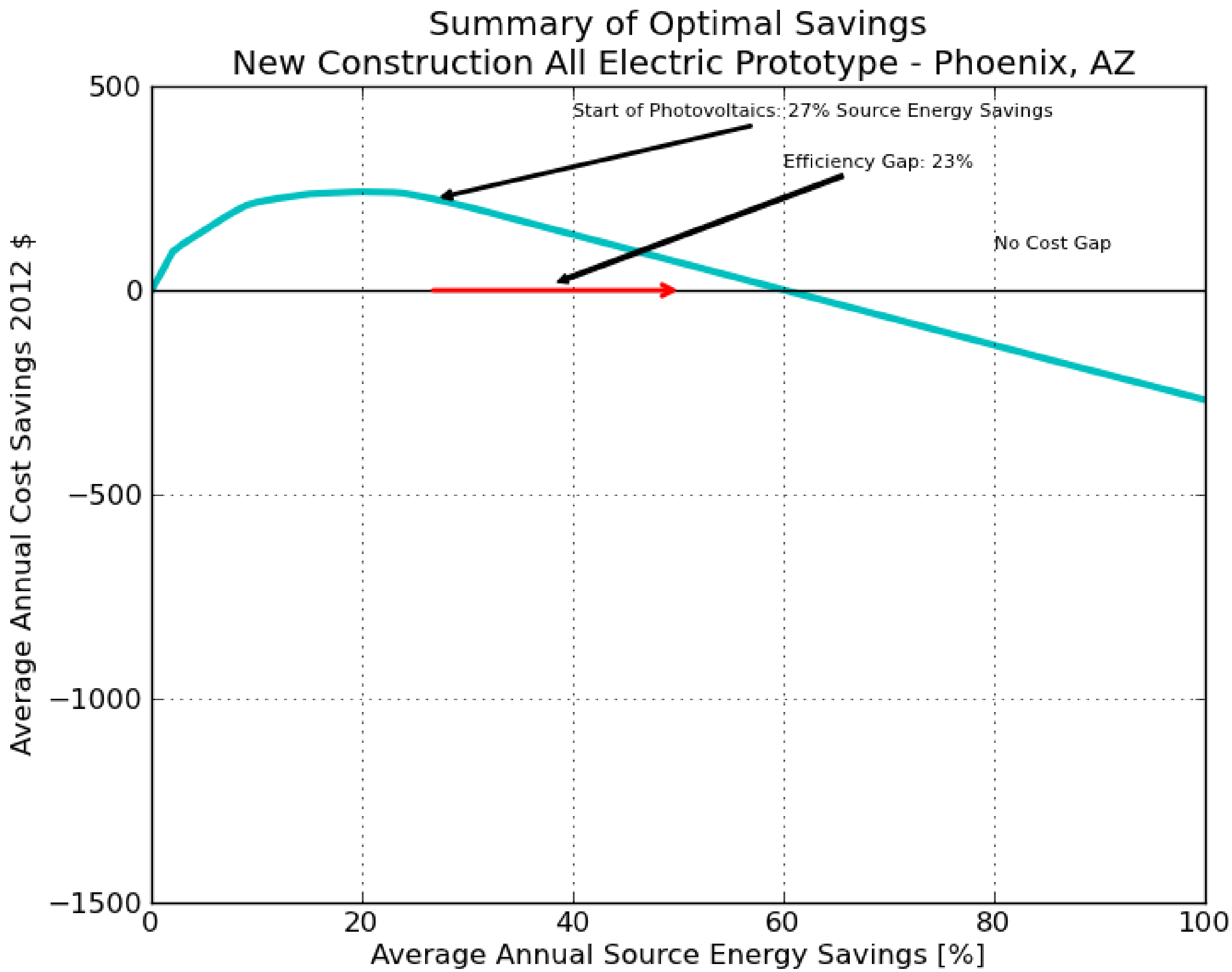

Figure 23. Summary of optimal savings new construction all-electric prototype—Phoenix

Table 16. ESMPs for New Construction All-Electric Prototype—Seattle

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	Clothes Washer: EnergyStar	Water Heater: Electric Premium	Heat Pump: SEER 14, HSPF 8.2 (21.15 kBtu/hr) (1.31 tons)	Dishwasher: EnergyStar	DHW Piping: R2, TrunkBranch, PEX, Demand	Heat Pump: SEER 15, HSPF 8.5 (21.15 kBtu/hr) (1.31 tons)	Walls: R-19 Batt, 2x6, 24"o.c., 2" Foam	Crawlspace: Wall R15 Rigid	Heat Pump: SEER 22, HSPF 10.0 (19.56 kBtu/hr) (1.14 tons)	Exposed Floor: 100% Exposed	Windows: 2 Pane (U=0.291, SHGC=0.559)	Refrigerator: EnergyStar	Attic: Ceiling R-49, Vented	Exposed Floor: 20% Exposed	Interzonal Walls: R-19 Batt, 2x6, 24"o.c., 1" Foam	PV System: 0.5 kW	PV System: 6.0 kW	PV System: 7.0 kW	PV System: 8.0 kW
7	44	X																		
8	49	X	X																	
10	54	X	X	X																
10	56	X	X	X	X															
14	57	X	X	X	X	X														
15	55	X	X		X	X	X													
17	47	X	X		X	X	X	X												
22	22	X	X		X	X		X	X	X										
24	-11	X	X		X	X		X	X	X	X	X	X							
25	-16	X	X		X	X		X	X	X		X	X	X	X					
25	-19	X	X		X	X		X	X	X		X	X	X	X	X				
30 (30% Energy Savings)	-104	X	X		X	X		X	X	X		X	X	X	X	X	X			
50 (50% Energy Savings)	-466	X	X		X	X		X	X	X		X	X	X	X	X	X	X		
65	-728	X	X		X	X		X	X	X		X	X	X	X	X			X	
78	-964	X	X		X	X		X	X	X		X	X	X	X	X				X

Blue	30% Energy Savings
Green	50% Energy Savings

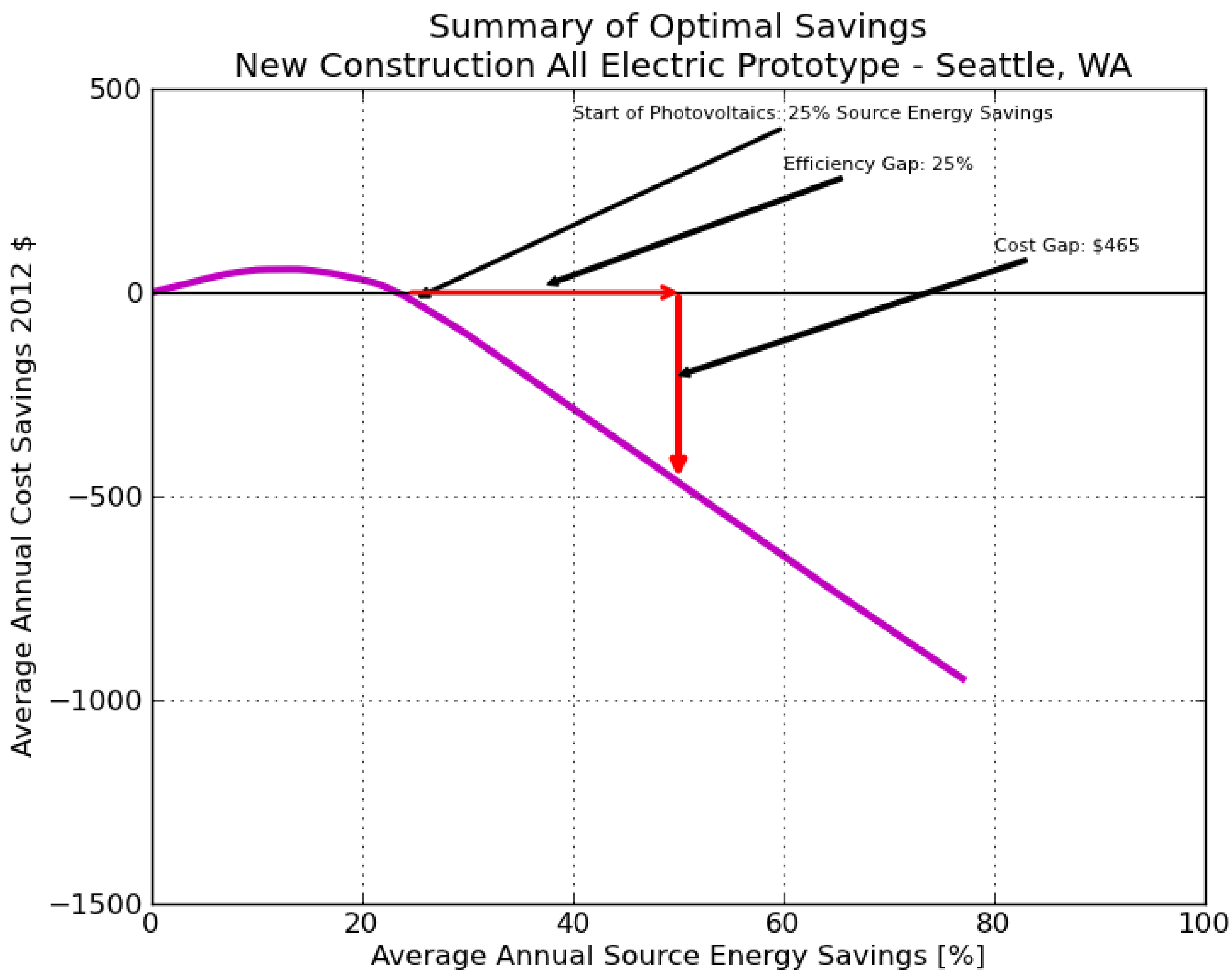

Figure 24. Summary of optimal savings new construction all-electric prototype—Seattle

Table 17. Summary of Measures Modeled in New Construction Mixed Fuel ESMPs

Category	Reference	Options Modeled							
Foundation: Basement	Chicago: R-10 Rigid, 8 ft	R-15 Rigid, 8 ft	R-20 Rigid, 8 ft						
Foundation: Crawlspace Wall	Atlanta: R-5 Rigid Seattle: R-10 Rigid	R-10 Rigid	R-15 Rigid	R-20 Rigid					
Foundation: Slab	Houston: Uninsulated Phoenix: Uninsulated	R-5 Rigid 2 ft	R-5 Rigid 4 ft	R-10 Rigid 2 ft	R-10 Rigid 4 ft	Whole Slab R10 R5 Gap			
Exterior Walls	Atlanta: R-13 2x4 16 in o.c. Phoenix: R-13 2x4 16 in o.c. Chicago: R-13 2x4 16 in o.c.+ 1 in foam Seattle: R-13 2x4 16 in o.c.+ 1 in foam	R-13 2x4 16 in o.c. (+ 1 in foam)	R-19 2x6 24 in o.c. (+ 1 in foam) (+ 2 in foam)	R-21 2x4 16 in o.c. (+ 1 in foam)					
Interzonal Walls	R-19 2x6 24 in o.c.	R-19 2x6 24 in o.c. + 1 in foam							
Unfinished Attic	Atlanta, Houston, Phoenix: R-30 Seattle, Chicago: R-38	R-38	R-49	R-60					
Windows	Atlanta: U=0.37|SHGC=0.30 Chicago: U=0.35|SHGC=0.44 Houston: U=0.37|SHGC=0.30 Phoenix: U=0.37|SHGC=0.30 Seattle: U=0.35|SHGC=0.44	U=0.34 SHGC=0.29	U=0.29 SHGC=0.56	U=0.27 SHGC=0.46	U=0.26 SHGC=0.31	U=0.28 SHGC=0.38	U=0.27 SHGC=0.25	U=0.18 SHGC=0.40	U=0.17 SHGC=0.27
Infiltration	7 ACH @ 50Pa	4 ACH @ 50Pa	2 ACH @ 50Pa						
Furnace	Gas, AFUE 78%	Gas, AFUE 92.5%							
Air Conditioner	SEER 13	SEER 14	SEER 15	SEER 16	SEER 16 (2-Stage)	SEER 17	SEER 18	SEER 21	SEER 24
Ducts	Atlanta: Typical, R-6 Seattle: Typical, R-6 Chicago: Typical, R-6 Houston, Phoenix: Typical, R-8	Typical, R-6	Typical, R-8	Tight, R-8	In Finished Space				
Water Heater	Gas, Standard EF = 0.59	Gas, Premium EF = 0.67	Gas, Tankless EF = 0.82	Gas, Tankless Condensing EF = 0.96					
Lighting	BA Benchmark	20% CFL	40% CFL	60% CFL	80% CFL	100% CFL			
Refrigerator	Standard 480 kWh	EnergyStar 374 kWh							
Dishwasher	Standard 318 kWh	EnergyStar 290 kWh							
Clothes Washer	Standard 1.41 MEF)	EnergyStar 2.47 MEF							
Hot Water Pipe Insulation	Uninsulated	R-2	R-2 Recirc Pump	R-5	R-5 Recirc Pump				
Solar Hot Water	None	40 sq ft Closed Loop	64 sq ft Closed Loop						
PV	None	1 kW 1.5 kW	2 kW 2.5 kW	3 kW 3.5 kW	4 kW 4.5 kW	5 kW 5.5 kW	6 kW 6.5 kW	7 kW 7.5 kW	8 kW

Table 18. 30% ESMPs—New Construction Mixed Fuel Prototype

30% Energy Savings Measure Packages - New Construction Prototype Mixed Fuel	Atlanta, GA	Chicago, IL	Houston, TX	Phoenix, AZ	Seattle, WA
Clothes Washer: EnergyStar	X	X	X	X	X
Dishwasher: EnergyStar	X	X	X	X	X
Refrigerator: EnergyStar	X	X	X	X	X
Water Heater: Gas Tankless	X	X	X	X	
Walls: R-19 Batt, 2x6, 24"o.c., 2" Foam	X	X		X	X
Attic: Ceiling R-49, Vented	X	X			X
Furnace: Gas, AFUE 92	X	X			X
DHW Piping: R2, TrunkBranch, PEX, Demand	X	X			X
Interzonal Walls: R-19 Batt, 2x6, 24"o.c., 1" Foam	X	X			X
Air Conditioner: SEER 21	X		X	X	
Windows: 2 Pane (U=0.341, SHGC=0.297)	X			X	
PV System: 0.5 kW	X		X		
Ducts: In Finished Space			X	X	
Air Sealing: 4 ACH@50Pa			X		X
Windows: 2 Pane (U=0.368, SHGC=0.300)		X			
Air Sealing: 2 ACH@50Pa		X			
Air Conditioner: SEER 16		X			
Interzonal Walls: R-19 Batt, 2x6, 24"o.c.			X		
Walls: R-13 Batt, 2x4, 16"o.c., 1" Foam			X		
Attic: Ceiling R-30, Vented				X	
Roofing Material: Metal, White				X	
Windows: 2 Pane (U=0.291, SHGC=0.559)					X
Water Heater: Gas Tankless, Condensing					X
Crawlspace: Wall R20 Rigid					X

Table 19. 50% ESMPs—New Construction Mixed Fuel Prototype

50% Energy Savings Measure Packages - New Construction Prototype Mixed Fuel	Atlanta, GA	Chicago, IL	Houston, TX	Phoenix, AZ	Seattle, WA
Clothes Washer: EnergyStar	X	X	X	X	X
Dishwasher: EnergyStar	X	X	X	X	X
Refrigerator: EnergyStar	X	X	X	X	X
Water Heater: Gas Tankless	X	X	X	X	
Walls: R-19 Batt, 2x6, 24"o.c., 2" Foam	X	X		X	X
PV System: 4.0 kW	X		X	X	X
Attic: Ceiling R-49, Vented	X	X			X
Furnace: Gas, AFUE 92	X	X			X
DHW Piping: R2, TrunkBranch, PEX, Demand	X	X			X
Interzonal Walls: R-19 Batt, 2x6, 24"o.c., 1" Foam	X	X			X
Air Conditioner: SEER 21	X		X	X	
Windows: 2 Pane (U=0.341, SHGC=0.297)	X			X	
Ducts: In Finished Space			X	X	
Air Sealing: 4 ACH@50Pa			X		X
Windows: 2 Pane (U=0.368, SHGC=0.300)		X			
Air Sealing: 2 ACH@50Pa		X			
Air Conditioner: SEER 16		X			
PV System: 3.5 kW		X			
Interzonal Walls: R-19 Batt, 2x6, 24"o.c.			X		
Walls: R-13 Batt, 2x4, 16"o.c., 1" Foam			X		
Attic: Ceiling R-30, Vented				X	
Roofing Material: Metal, White				X	
Windows: 2 Pane (U=0.291, SHGC=0.559)					X
Water Heater: Gas Tankless, Condensing					X
Crawlspace: Wall R20 Rigid					X

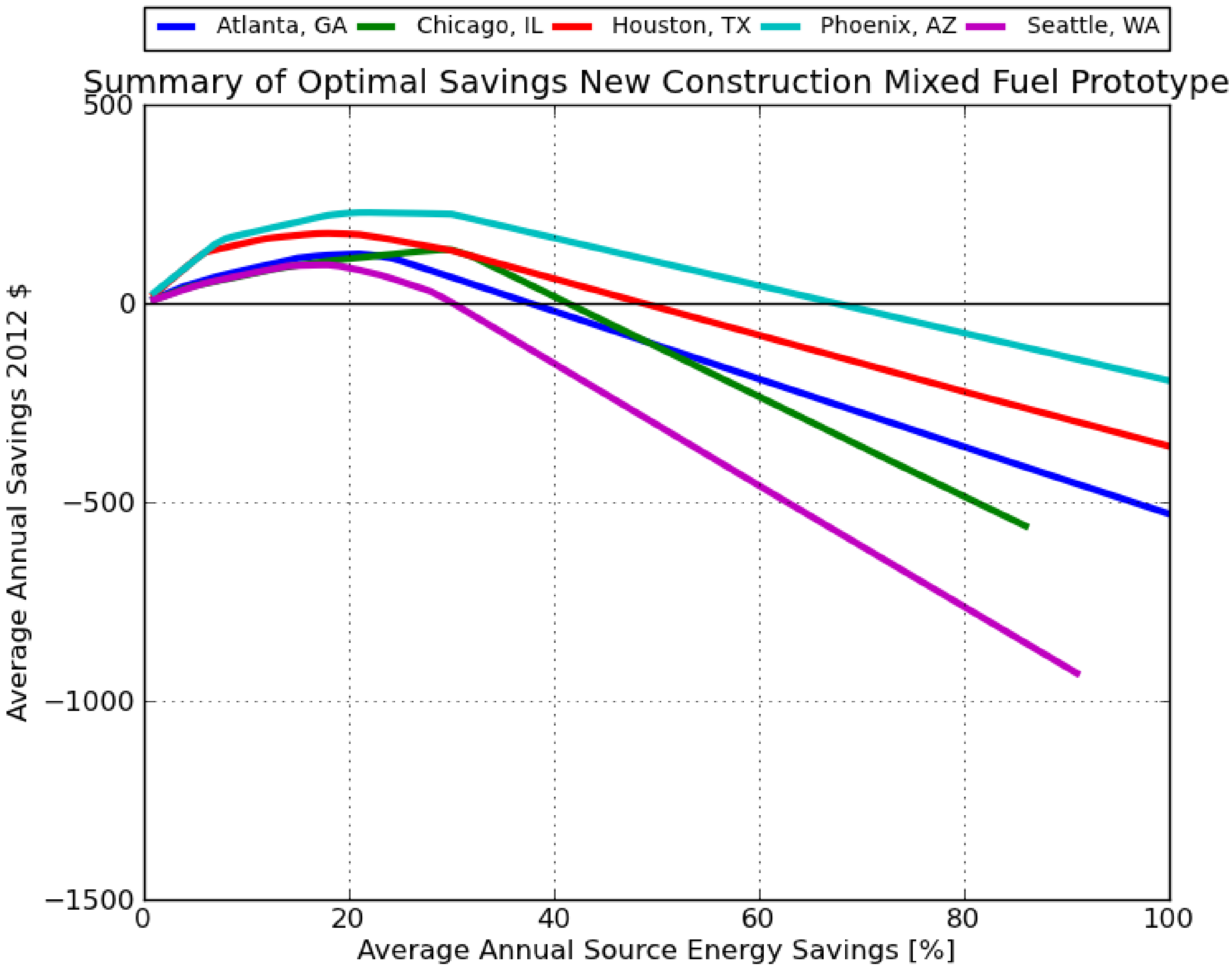

Figure 25. Summary of optimal savings—new construction mixed fuel prototype

Table 20. ESMPs for New Construction Mixed Fuel Prototype—Atlanta

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	Clothes Washer: EnergyStar	Water Heater: Gas Tankless	Windows: 2 Pane (U=0.376, SHGC=0.437)	Walls: R-21 Batt, 2x6, 24"o.c., 1" Foam	Attic: Ceiling R-49, Vented	Windows: 2 Pane (U=0.341, SHGC=0.297)	Furnace: Gas, AFUE 92.5% (25.23 kBtu/hr)	Dishwasher: EnergyStar	Air Conditioner: SEER 16 (2 Stage) (2.0 tons)	Walls: R-19 Batt, 2x6, 24"o.c., 2" Foam	DHW Piping: R2, TrunkBranch, PEX, Demand	Air Conditioner: SEER 17 (1.98 tons)	Interzonal Walls: R-19 Batt, 2x6, 24"o.c., 1" Foam	Refrigerator: EnergyStar	Air Conditioner: SEER 18 (1.96 tons)	Air Conditioner: SEER 21 (1.96 tons)	PV System: 0.5 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
4	43	X																			
8	70	X	X																		
8	72	X	X	X																	
15	114	X	X		X	X	X														
17	119	X	X		X	X	X	X													
18	120	X	X		X	X	X	X	X												
21	125	X	X		X	X	X	X	X	X											
21	124	X	X			X	X	X	X	X	X										
23	119	X	X			X	X	X	X	X	X	X									
24	117	X	X			X	X	X	X		X	X	X								
25	111	X	X			X	X	X	X		X	X	X	X	X						
25	108	X	X			X	X	X	X		X	X		X	X	X					
26	97	X	X			X	X	X	X		X	X		X	X		X				
30	66	X	X			X	X	X	X		X	X		X	X		X	X			
50	-105	X	X			X	X	X	X		X	X		X	X		X		X		
85	-404	X	X			X	X	X	X		X	X		X	X		X			X	
103	-559	X	X			X	X	X	X		X	X		X	X	X					X

(blue)	30% Energy Savings
(green)	50% Energy Savings

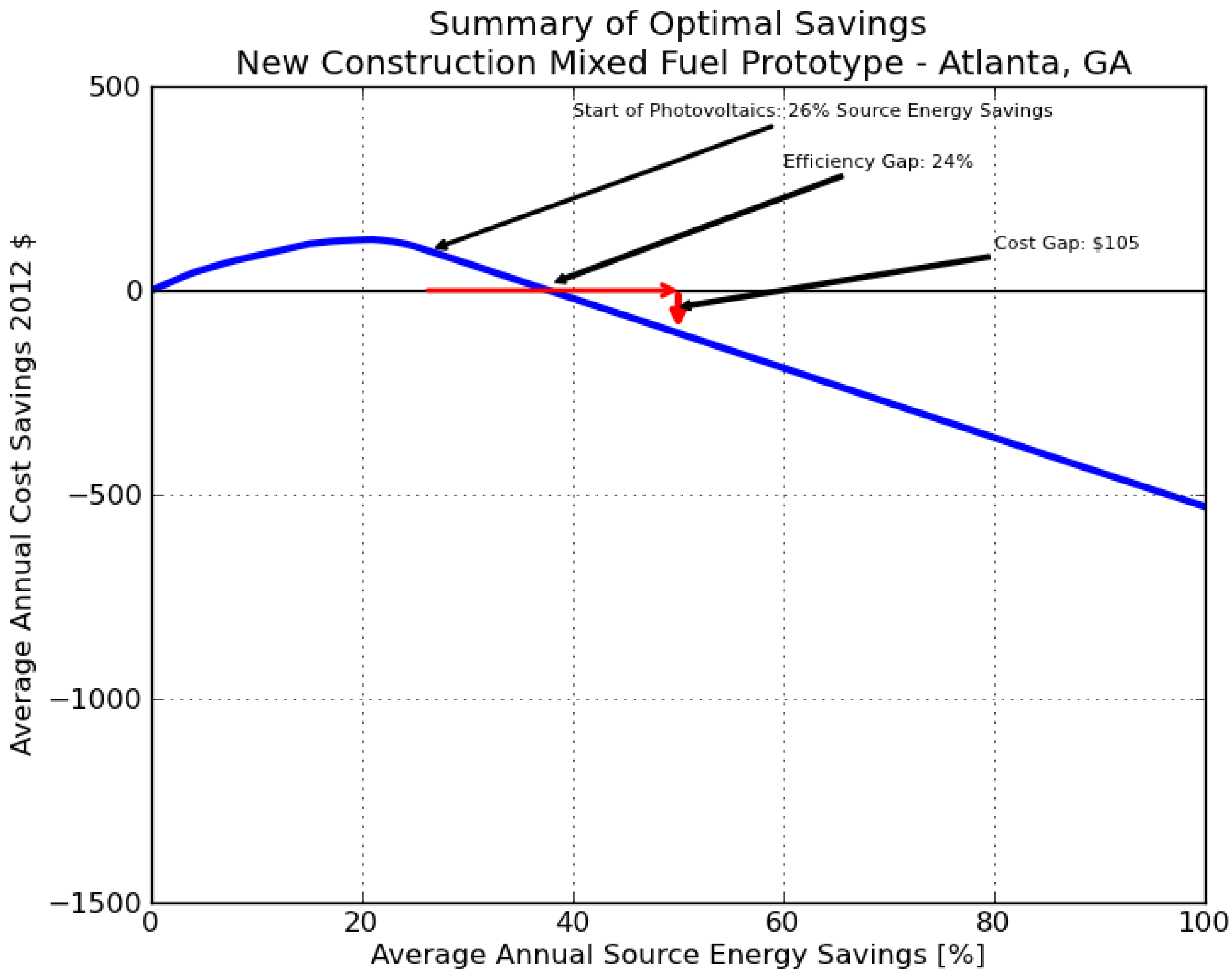

Figure 26. Summary of optimal savings new construction mixed fuel prototype—Atlanta

Table 21. ESMPs for New Construction Mixed Fuel Prototype—Chicago

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	Clothes Washer: EnergyStar	Interzonal Walls: R-19 Batt, 2x6, 24"o.c., 1" Foam	Air Sealing: 4 ACH@50Pa	Furnace: Gas, AFUE 92.5% (34.16 kBtu/hr)	Walls: R-21 Batt, 2x6, 24"o.c., 1" Foam	Attic: Ceiling R-49, Vented	Windows: 2 Pane (U=0.368, SHGC=0.300)	Air Sealing: 2 ACH@50Pa	Air Conditioner: SEER 16 (2 Stage) (1.5 tons)	Water Heater: Gas Tankless	Walls: R-19 Batt, 2x6, 24"o.c., 2" Foam	Dishwasher: EnergyStar	Refrigerator: EnergyStar	DHW Piping: R2, TrunkBranch, PEX, Demand	PV System: 3.5 kW	PV System: 6.0 kW	PV System: 8.0 kW
5	42	X																
13	89	X	X	X														
18	106	X	X	X	X													
26	129	X	X		X	X	X	X	X	X								
29	134	X	X		X	X	X	X	X	X	X							
30	135	X	X		X		X	X	X	X	X	X						
30	135	X	X		X		X	X	X	X	X	X	X					
32	121	X	X		X		X	X	X	X	X	X	X	X	X			
50	-109	X	X		X		X	X	X	X	X	X	X	X	X	X		
73	-397	X	X		X		X	X	X	X	X	X	X	X	X		X	
87	-569	X	X		X		X	X	X	X	X	X	X	X	X			X

(blue)	30% Energy Savings
(green)	50% Energy Savings

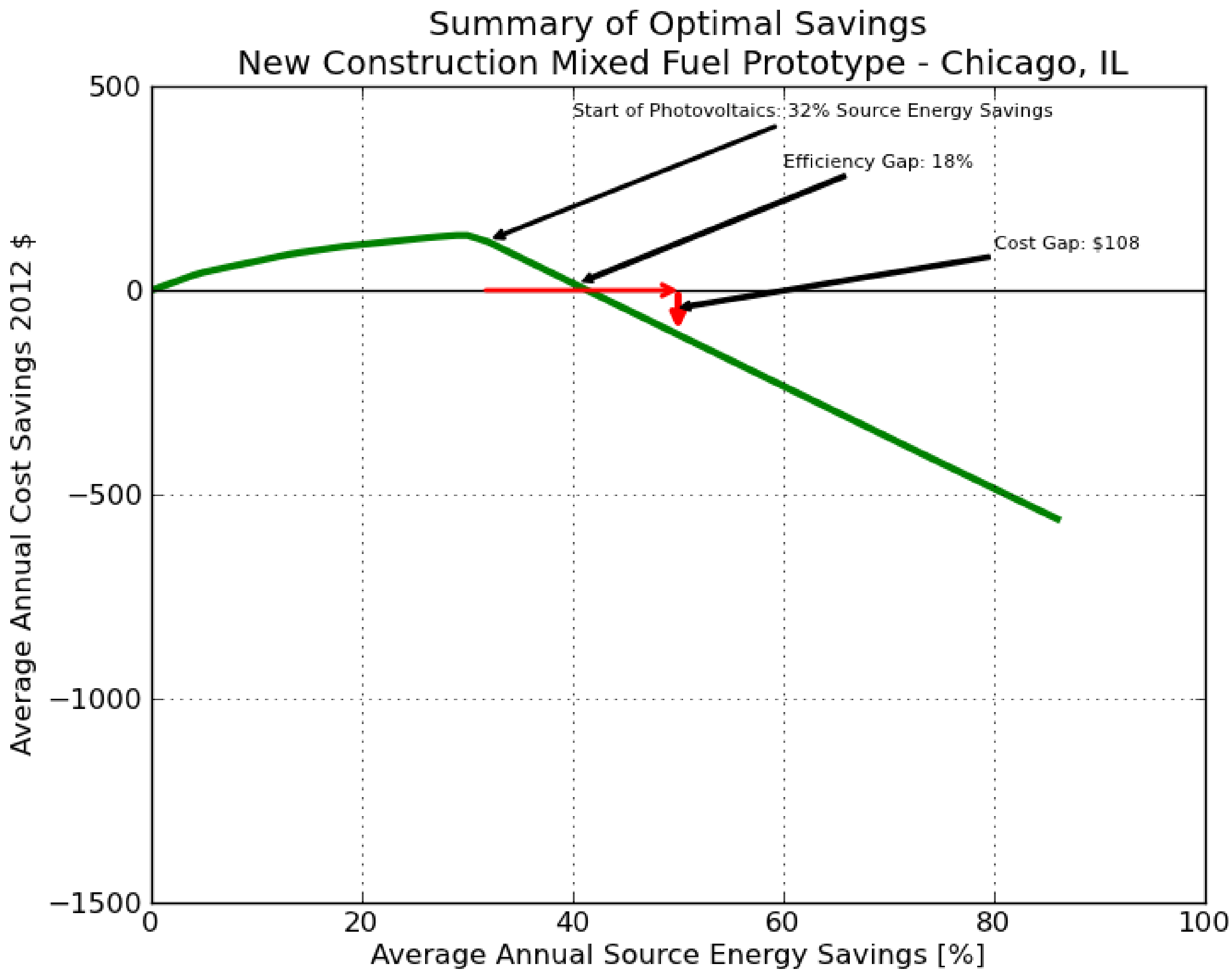

Figure 27. Summary of optimal savings new construction mixed fuel prototype—Chicago

Table 22. ESMPs for New Construction Mixed Fuel Prototype—Houston

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	Interzonal Walls: R-19 Batt, 2x6, 24"o.c.	Ducts: In Finished Space	Air Conditioner: SEER 16 (2 Stage) (2.34 tons)	Clothes Washer: EnergyStar	Air Conditioner: SEER 17 (2.33 tons)	Water Heater: Gas Tankless	Air Conditioner: SEER 18 (2.33 tons)	Dishwasher: EnergyStar	Air Conditioner: SEER 21 (2.33 tons)	Refrigerator: EnergyStar	Walls: R-13 Batt, 2x4, 16"o.c., 1" Foam	Air Sealing: 4 ACH@50Pa	PV System: 0.5 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
6	127	X	X														
11	157	X	X	X													
12	163	X	X	X	X												
13	167	X	X		X	X											
17	175	X	X		X	X	X										
18	176	X	X		X		X	X									
18	176	X	X		X		X	X	X								
20	174	X	X		X		X		X	X							
21	173	X	X		X		X		X	X	X						
24	163	X	X		X		X		X	X	X	X					
26	152	X	X		X		X		X	X	X	X	X				
30	133	X	X		X		X		X	X	X	X	X	X			
50	-9	X	X		X		X		X	X	X	X	X		X		
82	-233	X	X		X		X		X	X	X	X	X			X	
100	-360	X	X		X		X		X	X	X	X	X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

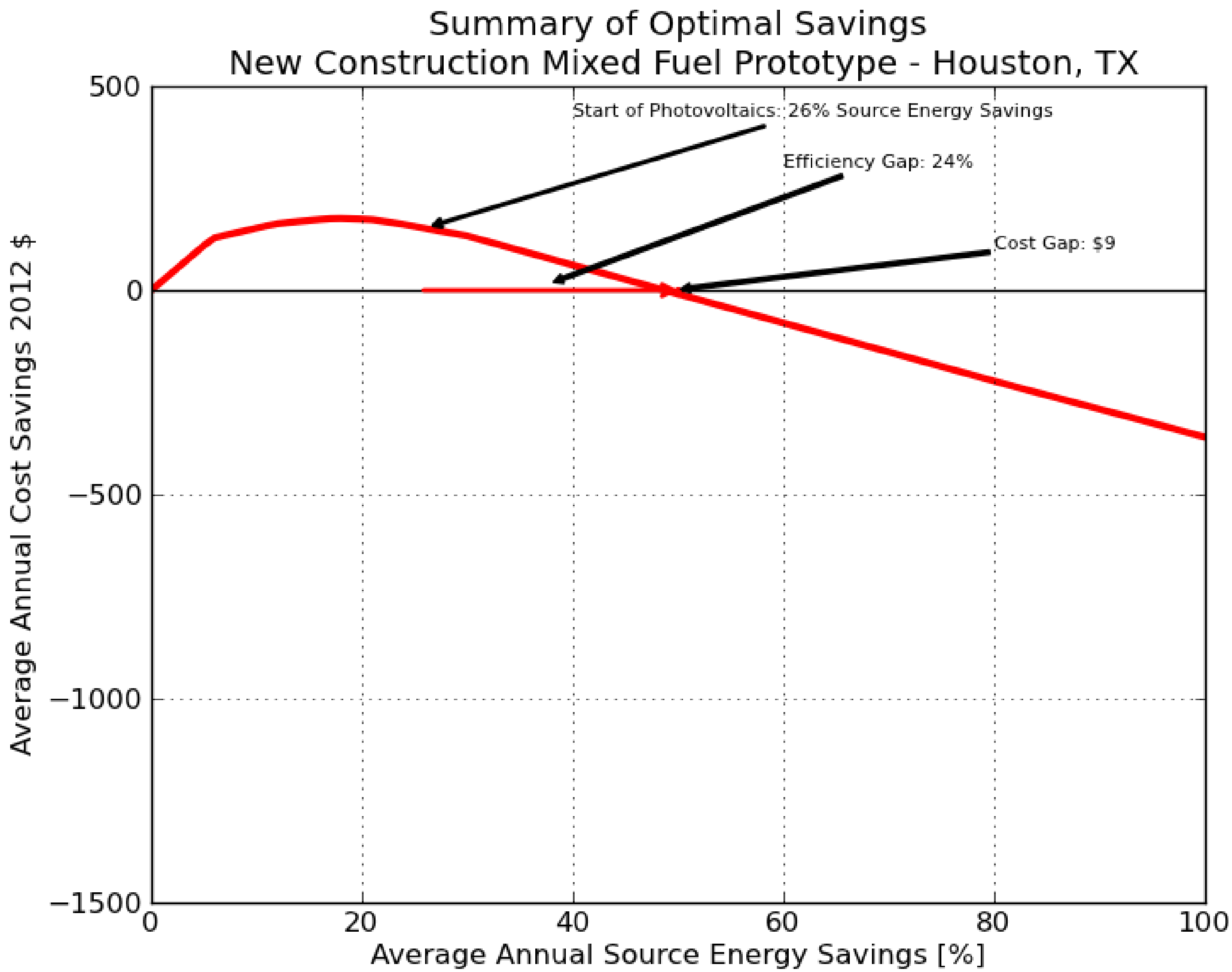

Figure 28. Summary of optimal savings new construction mixed fuel prototype—Houston

Table 23. ESMPs for New Construction Mixed Fuel Prototype—Phoenix

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	Attic: Roof R-19, Closed	Windows: 2 Pane (U=0.376, SHGC=0.437)	Attic: Ceiling R-49, Vented	Windows: 2 Pane (U=0.341, SHGC=0.297)	Ducts: In Finished Space	Clothes Washer: EnergyStar	Water Heater: Gas Tankless	Air Conditioner: SEER 16 (2 Stage) (2.98 tons)	Air Conditioner: SEER 17 (2.98 tons)	Air Conditioner: SEER 18 (2.98 tons)	Dishwasher: EnergyStar	Walls: R-19 Batt, 2x6, 24"o.c., 2" Foam	Attic: Ceiling R-30, Vented	Roofing Material: Metal, White	Refrigerator: EnergyStar	Air Conditioner: SEER 21 (2.5 tons)	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	27	X	X																	
7	158			X	X	X														
8	166			X	X	X	X													
11	182			X	X	X	X	X												
18	221			X	X	X	X	X	X											
20	227			X	X	X	X	X		X										
21	229			X	X	X	X	X			X									
21	229			X	X	X	X	X			X	X								
27	226				X	X	X	X			X	X	X	X	X	X				
30	224				X	X	X	X				X	X	X	X	X	X			
50	105				X	X	X	X				X	X	X	X	X	X	X		
95	-164				X	X	X	X				X	X	X	X	X	X		X	
117	-293				X	X	X	X				X	X	X	X	X	X			X

(blue)	30% Energy Savings
(green)	50% Energy Savings

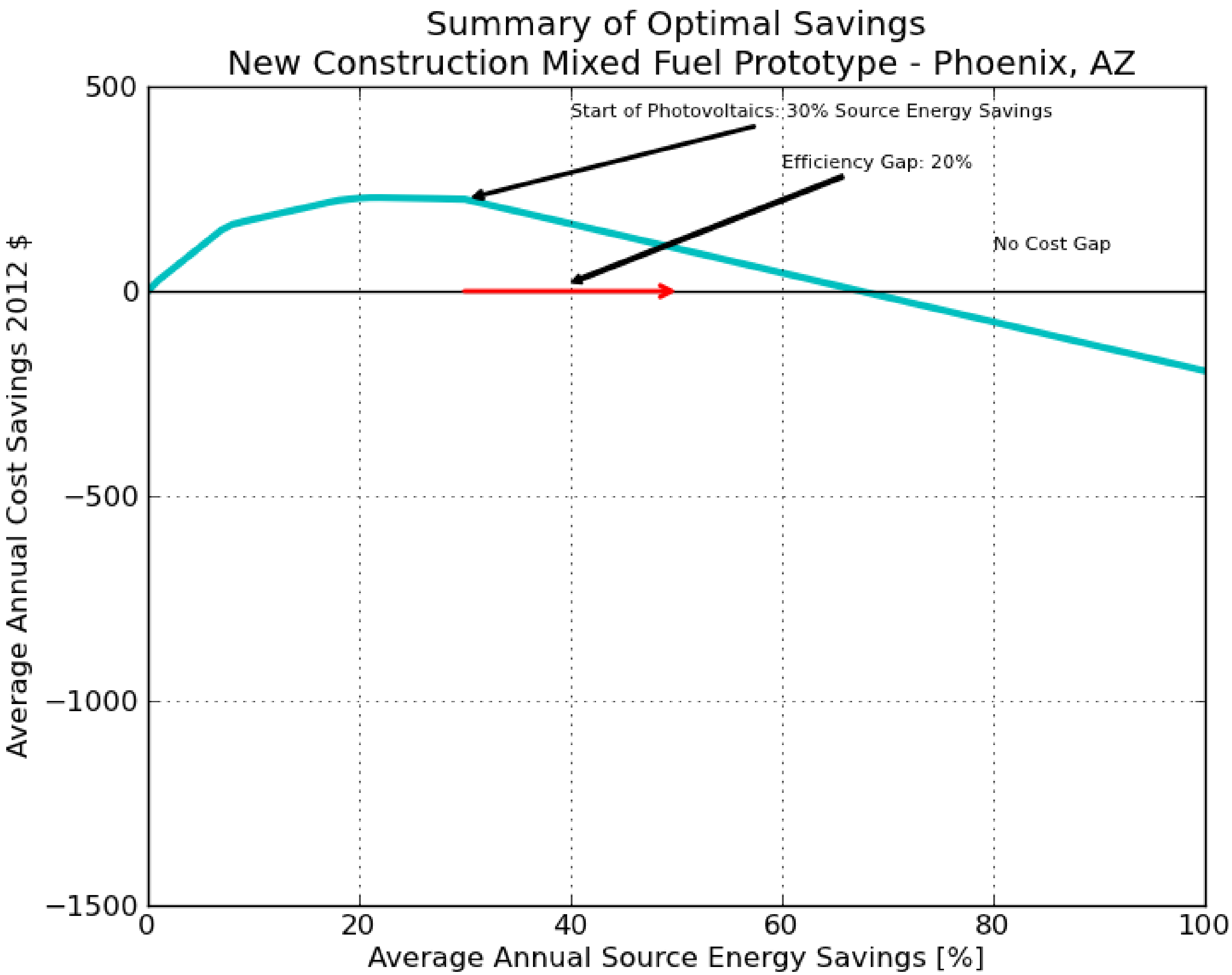

Figure 29. Summary of optimal savings new construction mixed fuel prototype—Phoenix

Table 24. ESMPs for New Construction Mixed Fuel Prototype—Seattle

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	Clothes Washer: EnergyStar	Water Heater: Gas Tankless	Furnace: Gas, AFUE 92.5% (21.21 kBtu/hr)	Walls: R-19 Batt, 2x6, 24"o.c., 2" Foam	Dishwasher: EnergyStar	Crawlspace: Wall R15 Rigid	Attic: Ceiling R-49, Vented	Interzonal Walls: R-19 Batt, 2x6, 24"o.c., 1" Foam	DHW Piping: R2, TrunkBranch, PEX, Demand	Windows: 2 Pane (U=0.291, SHGC=0.559)	Air Sealing: 4 ACH@50Pa	Refrigerator: EnergyStar	Water Heater: Gas Tankless, Condensing	Crawlspace: Wall R20 Rigid	PV System: 4.0 kW	PV System: 5.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
6	48	X																	
10	73	X	X																
14	95	X	X	X															
17	97	X	X	X	X														
18	97	X	X	X	X	X													
18	97	X	X	X	X	X	X												
19	95	X	X	X	X	X	X	X											
19	94	X	X	X	X	X	X	X	X										
21	86	X	X	X	X	X	X	X	X	X									
23	71	X	X	X	X	X	X	X	X	X	X								
28	34	X	X	X	X	X	X	X	X	X	X	X							
28	28	X	X	X	X	X	X	X	X	X	X	X	X						
29	14	X		X	X	X	X	X	X	X	X	X	X	X					
30	10	X		X	X	X		X	X	X	X	X	X	X	X				
50	-305	X		X	X	X		X	X	X	X	X	X	X	X	X			
60	-463	X		X	X	X		X	X	X	X	X	X	X	X		X		
76	-699	X		X	X	X		X	X	X	X	X	X	X	X			X	
91	-935	X		X	X	X		X	X	X	X	X	X	X	X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

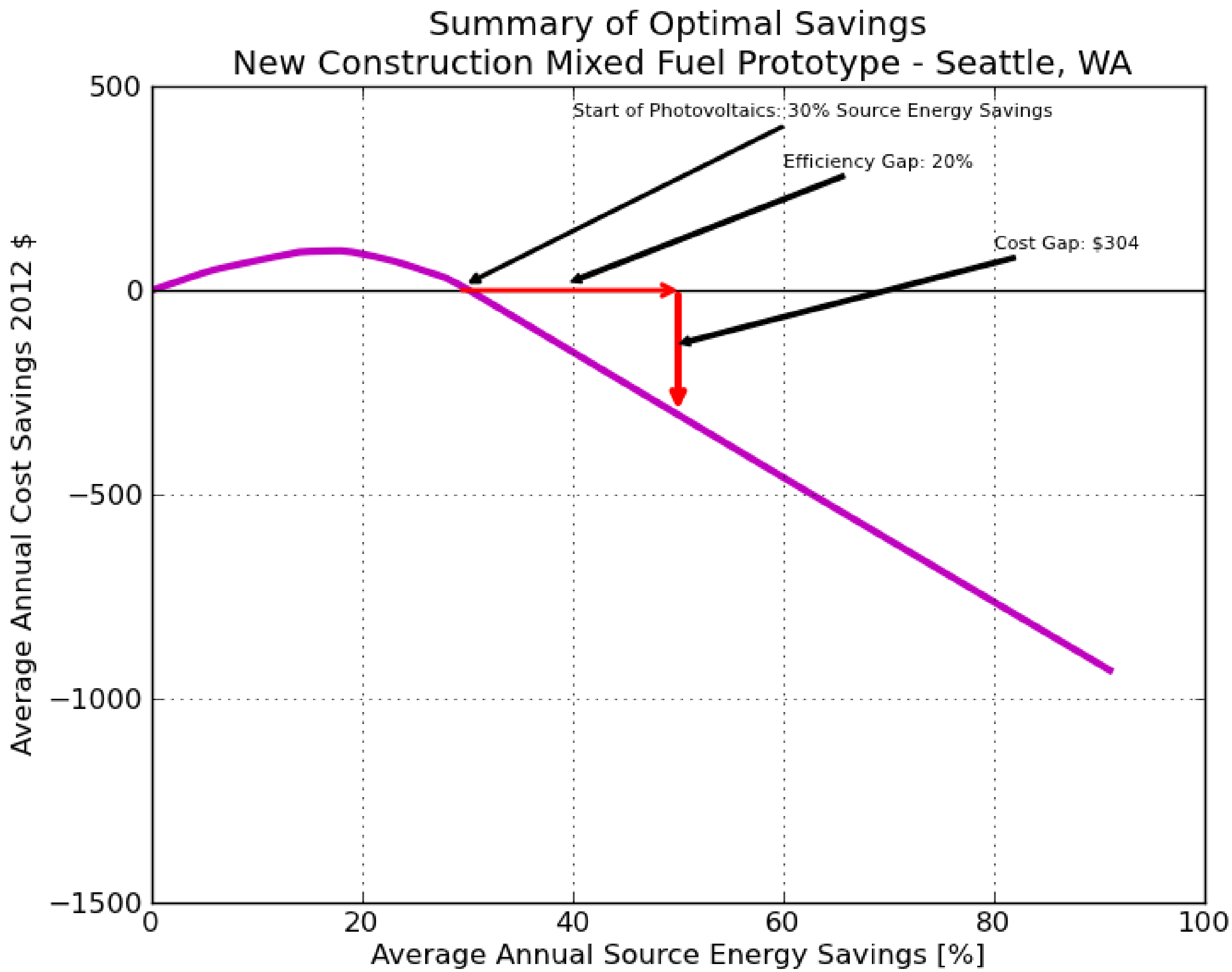

Figure 30. Summary of optimal savings new construction mixed fuel prototype—Seattle

Table 25. Summary of Measures Modeled in Retrofit 1960s All-Electric Prototype ESMPs

Category	Reference	Options Modeled							
Foundation: Basement	Chicago: Uninsulated	R-5 Rigid, 8 ft	R-10 Rigid, 8 ft	R-15 Rigid, 8 ft	R-20 Rigid, 8 ft				
Foundation: Crawlspace Wall	Atlanta: Vented|Uninsulated Seattle: Vented|Uninsulated	Vented R-13 Ceil	Vented R-19 Ceil	Vented R-30 Ceil	Vented R-38 Ceil	Closed R-5 Rigid	Closed R-10 Rigid	Closed R-15 Rigid	Closed R-20 Rigid
Foundation: Slab	Houston: Uninsulated Phoenix: Uninsulated	R-5 Rigid 2 ft	R-5 Rigid 4 ft	R-10 Rigid 2 ft	R-10 Rigid 4 ft				
Exterior Walls	R-7 Batts	Drill and Fill to R-13							
Unfinished Attic	Atlanta, Houston, Phoenix: R-11 Seattle, Chicago: R-19	R-30	R-38	R-49	R-60				
Windows	1 Pane M Frame U=1.16|SHGC=0.76	Window Film High-Tvis U=1.09|SHGC=0.43	Window Film Low-Tvis U=1.14|SHGC=0.37	Storm Window Clear U=0.78|SHGC=0.68	Storm Window Low-e U=0.69|SHGC=0.59	2 Pane NM Frame U=0.37|SHGC=0.53 U=0.35|SHGC=0.44 U=0.34|SHGC=0.30	2 Pane INS Frame U=0.29|SHGC=0.56 U=0.27|SHGC=0.25 U=0.26|SHGC=0.31	3 Pane NM Frame U=0.29|SHGC=0.38 U=0.27|SHGC=0.26	3 Pane INS Frame U=0.18|SHGC=0.40 U=0.17|SHGC=0.27
Infiltration	18 ACH @ 50Pa	14 ACH @ 50Pa	10 ACH @ 50Pa	7 ACH @ 50Pa					
Heat Pump	10 SEER HSPF 6.2	13 SEER HSPF 7.7	14 SEER HSPF 8.6	15 SEER HSPF 8.8	16 SEER HSPF 8.4	17 SEER HSPF 8.6	18 SEER HSPF 9.2	19 SEER HSPF 9.5	22 SEER HSPF 10.0
Ducts	Leaky (30%) Uninsulated	Leaky (30%) R-6	Leaky (30%) R-8	Typical (15%) Uninsulated	Typical(15%) R-6	Typical(15%) R-8	Tight(7.5%) Uninsulated	Tight(7.5%) R-6	Tight(7.5%) R-8
Water Heater	EF = 0.92	EF = 0.95	HPWH, 50 gal	HPWH, 80 gal					
Lighting	20% CFL	40% CFL	60% CFL	80% CFL	100% CFL				
Refrigerator	Standard 480 kWh	EnergyStar 374 kWh							
Dishwasher	Standard 318 kWh	EnergyStar 290 kWh							
Clothes Washer	Standard 1.41 MEF	EnergyStar 2.47 MEF							
Hot Water Pipe Insulation	Uninsulated	R-2							
Solar Hot Water	None	32 ft2 ICS	40 ft2 Closed Loop	64 ft2 Closed Loop					
PV	None	1 kW 1.5 kW	2 kW 2.5 kW	3 kW 3.5 kW	4 kW 4.5 kW	5 kW 5.5 kW	6 kW 6.5 kW	7 kW 7.5 kW	8 kW

Table 26. 30% ESMPs—Retrofit 1960s All-Electric Prototype

30% Energy Savings Measure Packages - Retrofit 1960s Prototype All Electric	Atlanta, GA	Chicago, IL	Houston, TX	Phoenix, AZ	Seattle, WA
MHWL: Low-Flow Showers & Sinks	X	X	X	X	X
Lighting: 100% CFL	X	X	X	X	X
Clothes Washer: EnergyStar - Cold Only	X	X	X		X
Walls: Drill and Fill to R-13	X		X	X	
Attic: Ceiling R-30, Vented	X		X	X	
DHW Piping: R-2, Copper		X			X
Ceiling Fan: Whole-house coverage, 20W			X	X	
Crawlspace: Wall R5 Rigid	X				
Unfinished Basement: Wall 4ft R5 Rigid		X			
Air Sealing: 10 ACH@50Pa		X			
Attic: Ceiling R-49, Vented		X			
Ducts: Leaky, R6 Insulation		X			
Windows: 2 Pane (U=0.389, SHGC=0.528)		X			
Ducts: Typical, Uninsulated				X	
Attic: Ceiling R-38, Vented					X
Crawlspace: Wall R10 Rigid					X
Heat Pump: SEER 15, HSPF 8.5					X

Table 27. 50% ESMPs—Retrofit 1960s All-Electric Prototype

50% Energy Savings Measure Packages - Retrofit 1960s Prototype All Electric	Atlanta, GA	Chicago, IL	Houston, TX	Phoenix, AZ	Seattle, WA
MHWL: Low-Flow Showers & Sinks	X	X	X	X	X
Lighting: 100% CFL	X	X	X	X	X
Clothes Washer: EnergyStar - Cold Only	X	X	X	X	X
Walls: Drill and Fill to R-13	X	X	X	X	
Attic: Ceiling R-49, Vented	X	X		X	X
DHW Piping: R-5, Copper, Timer	X	X	X		X
PV System: 1.5 kW	X	X	X	X	
Ceiling Fan: Whole-house coverage, 20W	X		X	X	
Ducts: Leaky, R6 Insulation		X			X
Heat Pump: SEER 22, HSPF 10.		X			X
Water Heater: Electric Premium		X			X
Windows: 2 Pane (U=0.368, SHGC=0.300)			X	X	
Crawlspace: Wall R5 Rigid	X				
Air Sealing: 14 ACH@50Pa	X				
Windows: 2 Pane (U=0.376, SHGC=0.437)	X				
Air Sealing: 10 ACH@50Pa		X			
Unfinished Basement: Wall 4ft R10 Rigid		X			
Windows: 2 Pane (U=0.389, SHGC=0.528)		X			
Ducts: Typical, Uninsulated			X		
Attic: Ceiling R-38, Vented			X		
DHW Piping: R-2, Copper				X	
Ducts: Typical, R6 Insulation				X	
Crawlspace: Wall R15 Rigid					X
PV System: 2.0 kW					X

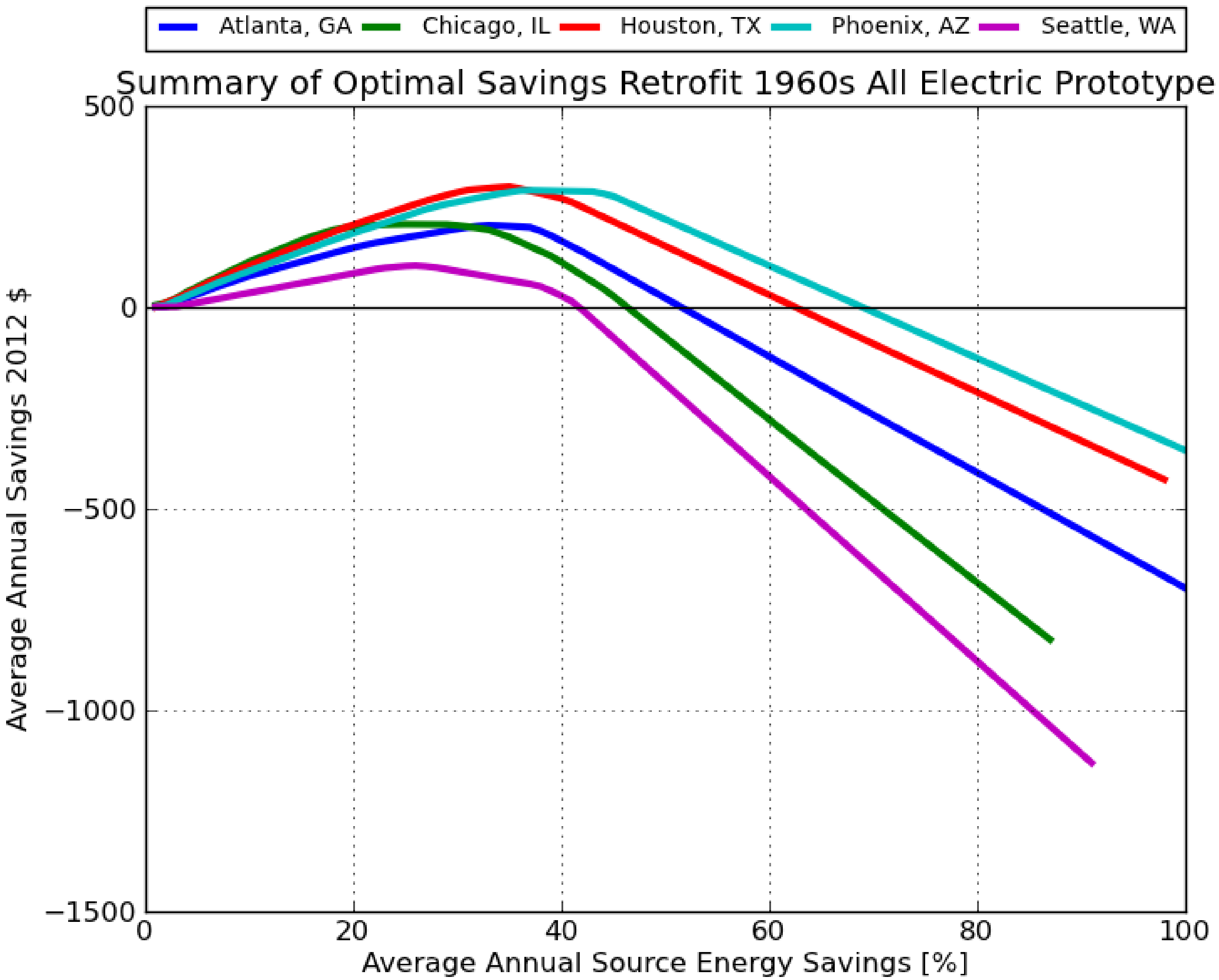

Figure 31. Summary of optimal savings—retrofit 1960s all-electric prototype

Table 28. ESMPs for Retrofit 1960s All-Electric Prototype—Atlanta

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Sinks	MHWL: Low-Flow Showers & Sinks	Lighting: 100% CFL	Attic: Ceiling R-19, Vented	Walls: Drill and Fill to R-13	Attic: Ceiling R-30, Vented	Clothes Washer: EnergyStar - Cold Only	Crawlspace: Wall R5 Rigid	Air Sealing: 14 ACH@50Pa	DHW Piping: R-2, Copper	Attic: Ceiling R-38, Vented	Ceiling Fan: Whole-house coverage, 20W	Attic: Ceiling R-49, Vented	DHW Piping: R-5, Copper, Timer	Windows: 2 Pane (U=0.389, SHGC=0.528)	Windows: 2 Pane (U=0.376, SHGC=0.437)	PV System: 1.5 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
2	1	X																			
4	22		X																		
6	43		X	X																	
10	76		X	X	X																
20	146		X	X	X	X															
22	158		X	X		X	X														
24	169		X	X		X	X	X													
31	199		X	X		X	X	X	X												
32	203		X	X		X	X	X	X	X											
33	204		X	X		X	X	X	X	X	X										
34	204		X	X		X		X	X	X	X	X									
37	199		X	X		X	X	X	X	X	X		X								
37	198		X	X		X		X	X	X	X	X	X								
39	178		X	X		X		X	X	X			X	X	X						
42	134		X	X		X		X	X	X			X	X	X	X					
42	133		X	X		X		X	X	X			X	X	X		X				
50	23		X	X		X		X	X	X			X	X	X		X	X			
72	-293		X	X		X		X	X	X			X	X	X		X		X		
87	-505		X	X		X		X	X	X			X	X	X		X			X	
101	-717		X	X		X		X	X	X			X	X	X		X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

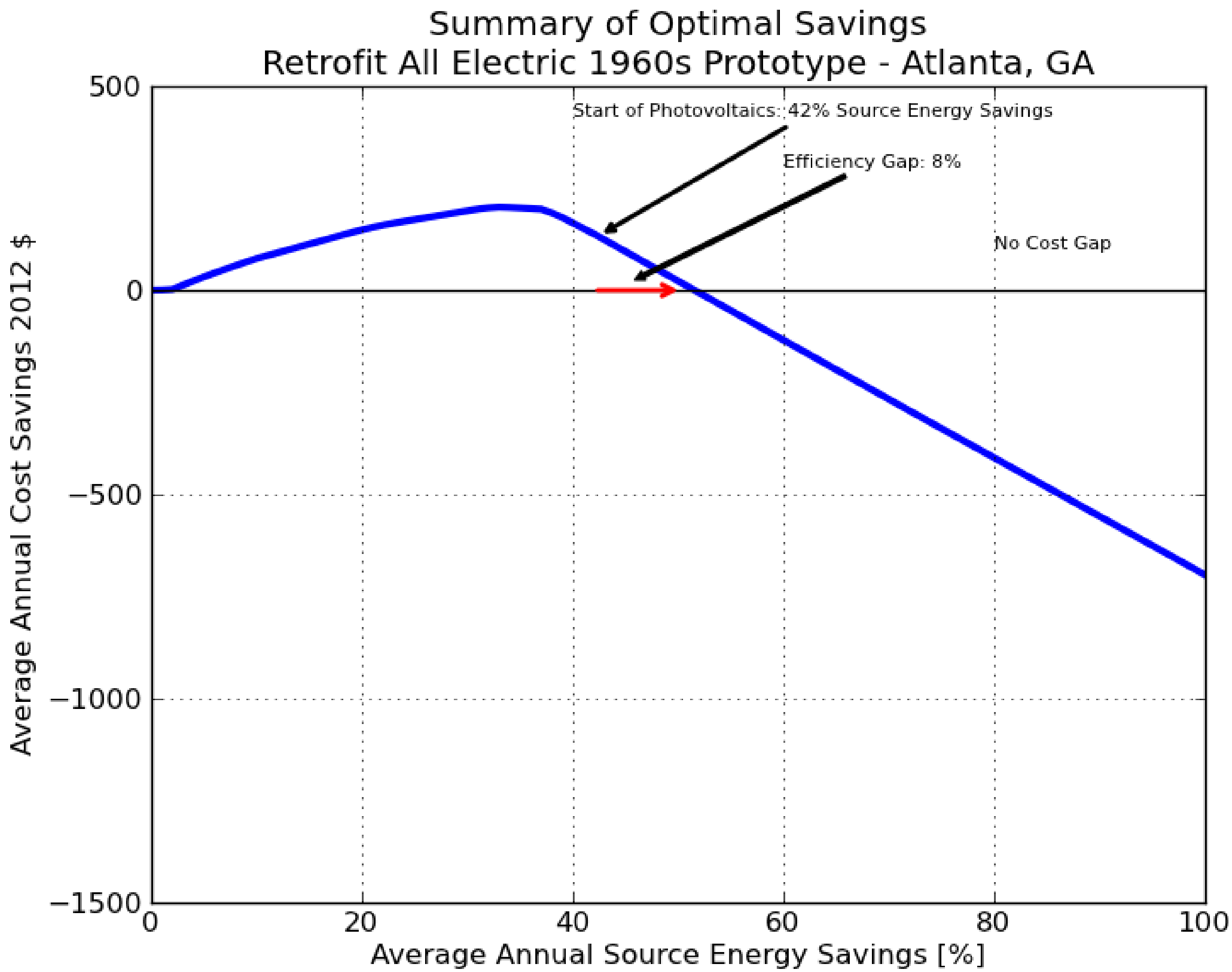

Figure 32. Summary of optimal savings retrofit all-electric 1960s prototype—Atlanta

Table 29. ESMPs for Retrofit 1960s All-Electric Prototype—Chicago

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Sinks	MHWL: Low-Flow Showers & Sinks	Air Sealing: 14 ACH@50Pa	Lighting: 100% CFL	Attic: Ceiling R-30, Vented	Unfinished Basement: Wall 4ft R5 Rigid	Clothes Washer: EnergyStar - Cold Only	Attic: Ceiling R-38, Vented	DHW Piping: R-2, Copper	Air Sealing: 10 ACH@50Pa	DHW Piping: Uninsulated	Attic: Ceiling R-49, Vented	Ducts: Leaky, R6 Insulation	Unfinished Basement: Wall 4ft R10 Rigid	Windows: 2 Pane (U=0.389, SHGC=0.528)	Ducts: Leaky, Uninsulated	Walls: Drill and Fill to R-13	DHW Piping: R-5, Copper, Timer	Attic: Ceiling R-60, Vented	Heat Pump: SEER 15, HSPF 8.5 (83.09 kBtu/hr) (3.97 tons)	Heat Pump: SEER 22, HSPF 10.0 (83.09 kBtu/hr) (3.97 tons)	Water Heater: Electric Premium	PV System: 1.5 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
2	13	X																									
4	43		X																								
10	115		X	X	X																						
13	141		X	X	X	X																					
15	171		X	X	X	X	X																				
18	191		X	X	X	X	X	X																			
19	196		X	X	X		X	X	X																		
19	197		X	X	X		X	X	X	X																	
22	203		X		X		X	X	X		X	X															
22	205		X		X		X	X	X	X	X																
23	206		X		X		X	X		X	X		X														
25	207		X		X		X	X		X	X		X	X													
29	206		X		X			X		X	X		X		X	X	X										
30	203		X		X		X	X		X	X		X	X		X											
32	198		X		X			X		X	X		X		X	X	X	X									
33	192		X		X			X		X	X		X	X	X	X		X									
34	181		X		X			X			X		X	X	X	X		X	X								
35	177		X		X			X			X			X	X	X		X	X	X							
39	124		X		X			X			X		X	X	X	X		X	X		X						
40	119		X		X			X			X			X	X	X		X	X	X	X						
44	47		X		X			X			X		X	X	X	X		X	X			X					
45	36		X		X			X			X		X	X	X	X		X	X			X	X				
50	-74		X		X			X			X		X	X	X	X		X	X			X	X	X			
66	-401		X		X			X			X		X	X	X	X		X	X			X	X		X		
77	-619		X		X			X			X		X	X	X	X		X	X			X	X			X	
88	-837		X		X			X			X		X	X	X	X		X	X			X	X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

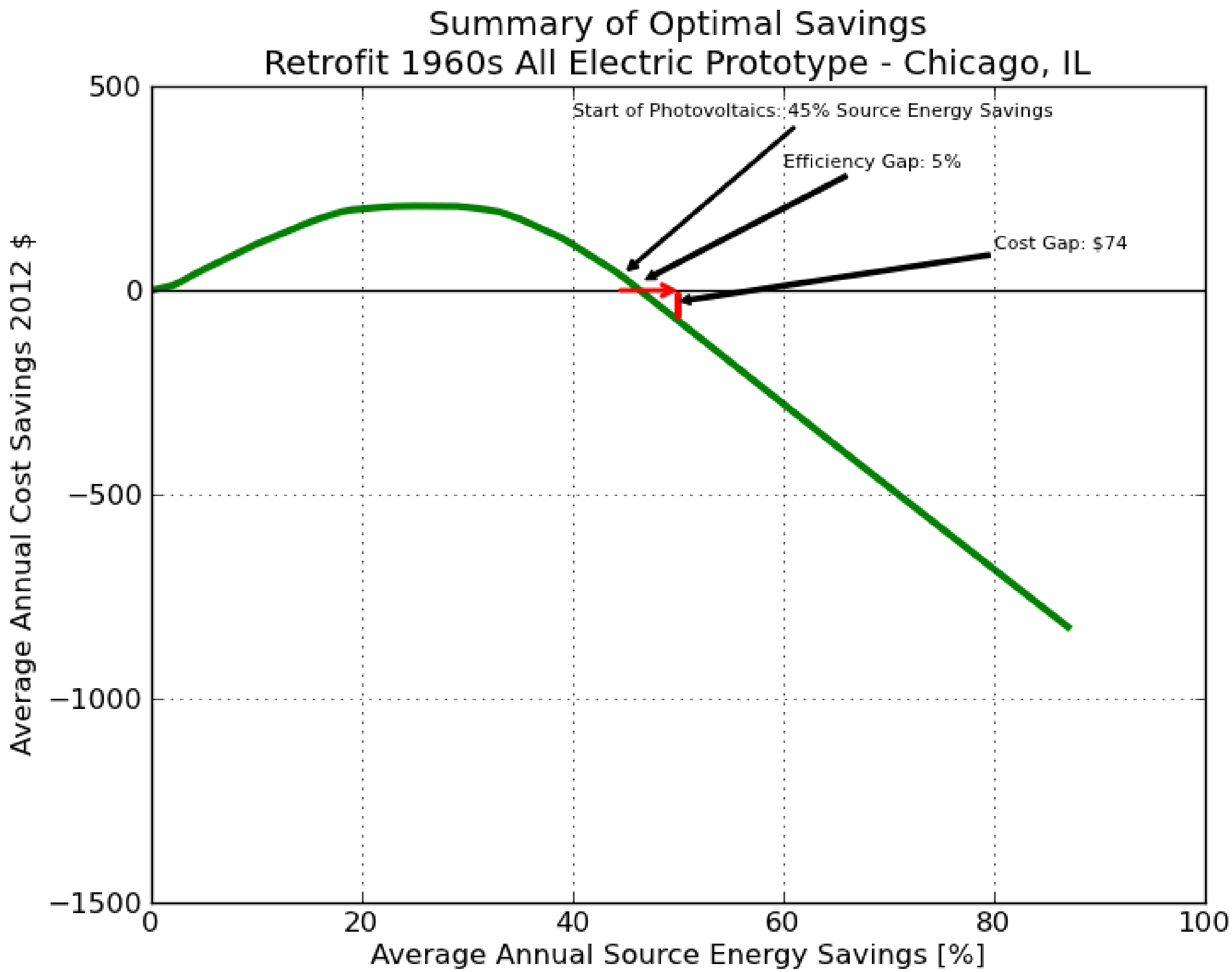

Figure 33. Summary of optimal savings retrofit 1960s all-electric prototype—Chicago

Table 30. ESMPs for Retrofit 1960s All-Electric Prototype—Houston

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Showers	MHWL: Low-Flow Showers & Sinks	Lighting: 100% CFL	Attic: Ceiling R-19, Vented	Ceiling Fan: Whole-house coverage, 20W	Walls: Drill and Fill to R-13	Clothes Washer: EnergyStar - Cold Only	Attic: Ceiling R-30, Vented	DHW Piping: R-2, Copper	Ducts: Typical, Uninsulated	Attic: Ceiling R-38, Vented	Windows: 2 Pane (U=0.368, SHGC=0.300)	DHW Piping: R-5, Copper, Timer	PV System: 1.5 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	1	X																
3	25		X															
6	60		X	X														
9	91		X	X	X													
19	200		X	X	X	X												
27	262		X	X	X	X	X											
29	280		X	X	X	X	X	X										
30	289		X	X		X	X	X	X									
31	292		X	X		X	X	X	X	X								
35	300		X	X		X	X	X	X	X	X							
35	299		X	X		X	X	X		X	X	X						
40	273		X	X		X	X	X		X	X	X	X					
41	263		X	X		X	X	X			X	X	X	X				
50	152		X	X		X	X	X			X	X	X	X	X			
70	-86		X	X		X	X	X			X	X	X	X		X		
84	-259		X	X		X	X	X			X	X	X	X			X	
98	-432		X	X		X	X	X			X	X	X	X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

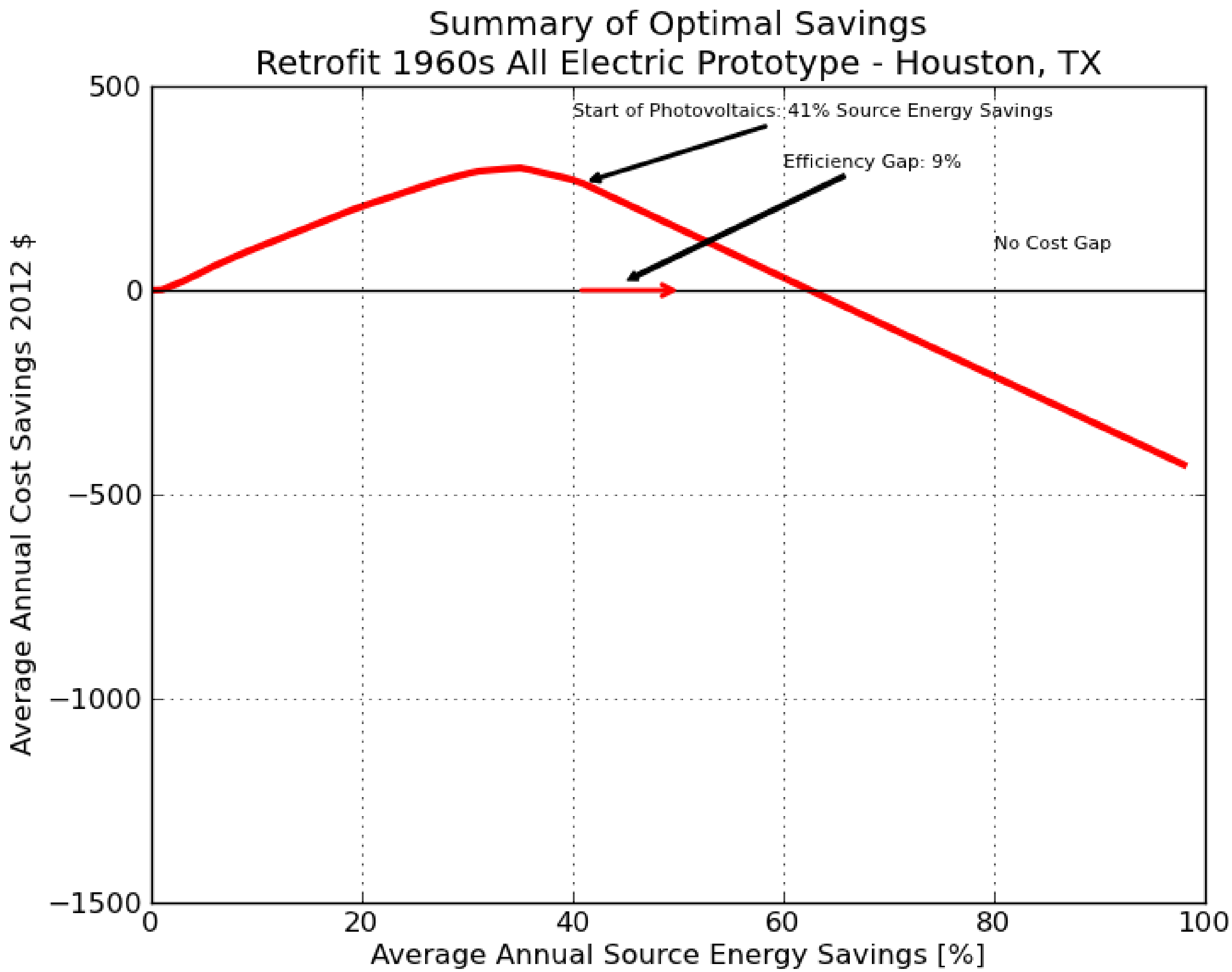

Figure 34. Summary of optimal savings retrofit 1960s all-electric prototype—Houston

Table 31. ESMPs for Retrofit 1960s All-Electric Prototype—Phoenix

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Showers	MHWL: Low-Flow Showers & Sinks	Lighting: 100% CFL	Attic: Ceiling R-19, Vented	Walls: Drill and Fill to R-13	Ceiling Fan: Whole-house coverage, 20W	Attic: Ceiling R-30, Vented	Ducts: Typical, Uninsulated	Clothes Washer: EnergyStar - Cold Only	DHW Piping: R-2, Copper	Attic: Ceiling R-38, Vented	Windows: 2 Pane (U=0.368, SHGC=0.300)	Ducts: Typical, R6 Insulation	Attic: Ceiling R-49, Vented	PV System: 1.5 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	1	X																	
2	3		X																
4	31		X	X															
7	64		X	X	X														
18	169		X	X	X	X													
27	245		X	X	X	X	X												
29	255		X	X		X	X	X											
34	283		X	X		X	X	X	X										
36	290		X	X		X	X	X	X	X									
37	291		X	X		X	X	X	X	X	X								
37	291		X	X		X	X		X	X	X	X							
43	288		X	X		X	X		X	X	X	X	X						
45	278		X	X		X	X			X	X	X	X	X					
45	274		X	X		X	X			X	X		X	X	X				
50	219		X	X		X	X			X	X		X	X	X	X			
76	-77		X	X		X	X			X	X		X	X	X		X		
91	-252		X	X		X	X			X	X		X	X	X			X	
106	-427		X	X		X	X			X	X		X	X	X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

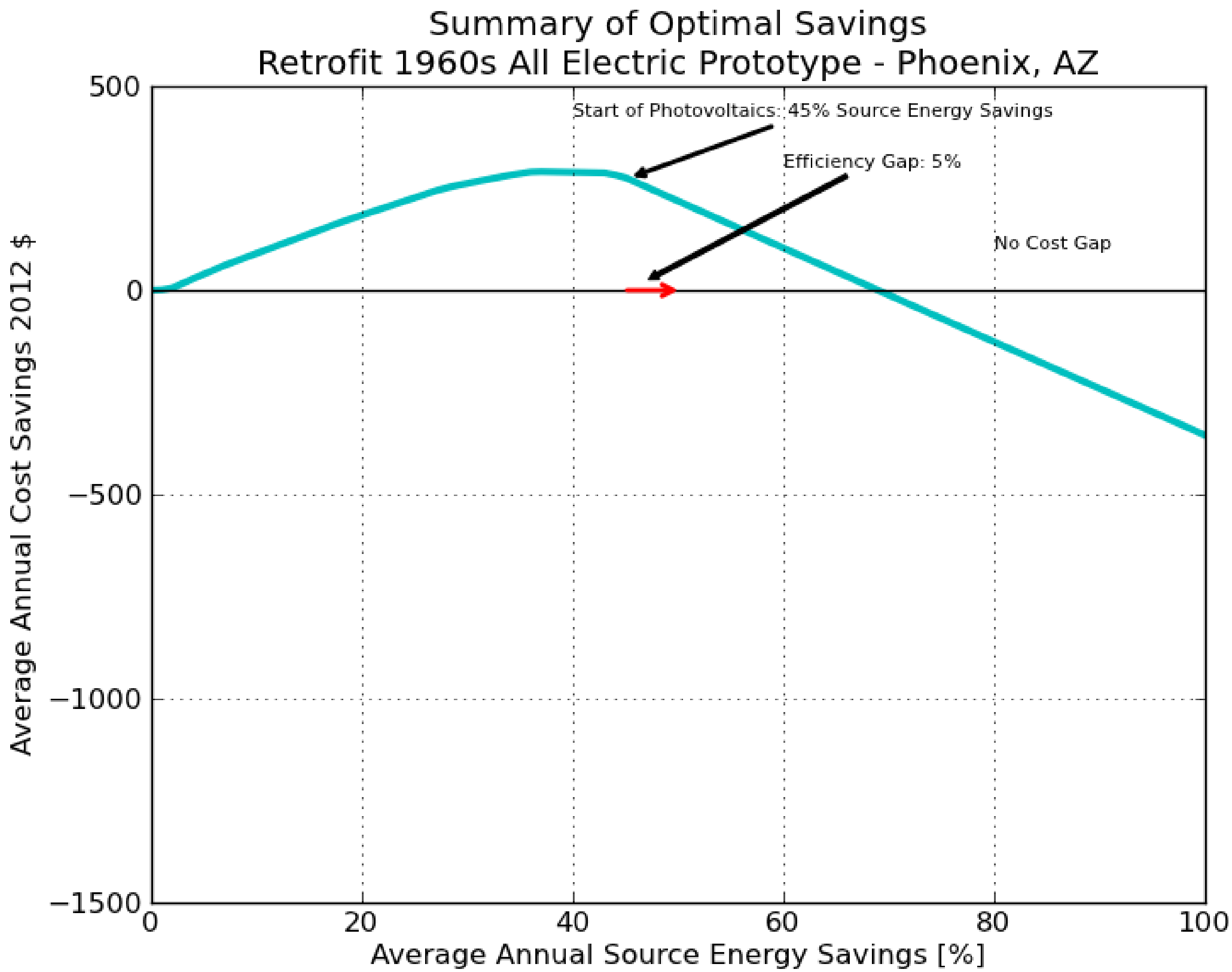

Figure 35. Summary of optimal savings retrofit 1960s all-electric prototype—Phoenix

Table 32. ESMPs for Retrofit 1960s All-electric Prototype—Seattle

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Sinks	MHWL: Low-Flow Showers & Sinks	Lighting: 100% CFL	Crawlspace: Wall R5 Rigid	Clothes Washer: EnergyStar - Cold Only	Attic: Ceiling R-38, Vented	Crawlspace: Wall R10 Rigid	DHW Piping: R-2, Copper	Crawlspace: Wall R15 Rigid	Heat Pump: SEER 15, HSPF 8.5 (40.65 kBtu/hr) (1.45 tons)	Attic: Ceiling R-30, Vented	Heat Pump: SEER 22, HSPF 10.0 (40.65 kBtu/hr) (1.45 tons)	Ducts: Leaky, R6 Insulation	DHW Piping: R-5, Copper, Timer	Water Heater: Electric Premium	Attic: Ceiling R-49, Vented	PV System: 2.0 kW	PV System: 2.5 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	1	X																				
3	2		X																			
5	11		X	X																		
23	97		X	X	X																	
26	104		X	X	X	X																
27	103		X	X	X	X	X															
27	101		X	X		X	X	X														
28	99		X	X		X	X	X	X													
29	97		X	X		X	X		X	X												
32	81		X	X		X	X	X	X		X											
38	55		X	X	X	X			X			X	X	X								
38	51		X	X	X	X	X		X				X	X								
39	46		X	X		X	X	X	X				X	X								
40	29		X	X		X	X	X					X	X	X							
41	15		X	X		X	X	X					X	X	X	X						
41	11		X	X		X	X			X			X	X	X	X						
42	3		X	X		X				X			X	X	X	X	X					
50	-190		X	X		X				X			X	X	X	X	X	X				
54	-282		X	X		X				X			X	X	X	X	X		X			
66	-566		X	X		X				X			X	X	X	X	X			X		
79	-851		X	X		X				X			X	X	X	X	X				X	
91	-1136		X	X		X				X			X	X	X	X	X					X

(blue)	30% Energy Savings
(green)	50% Energy Savings

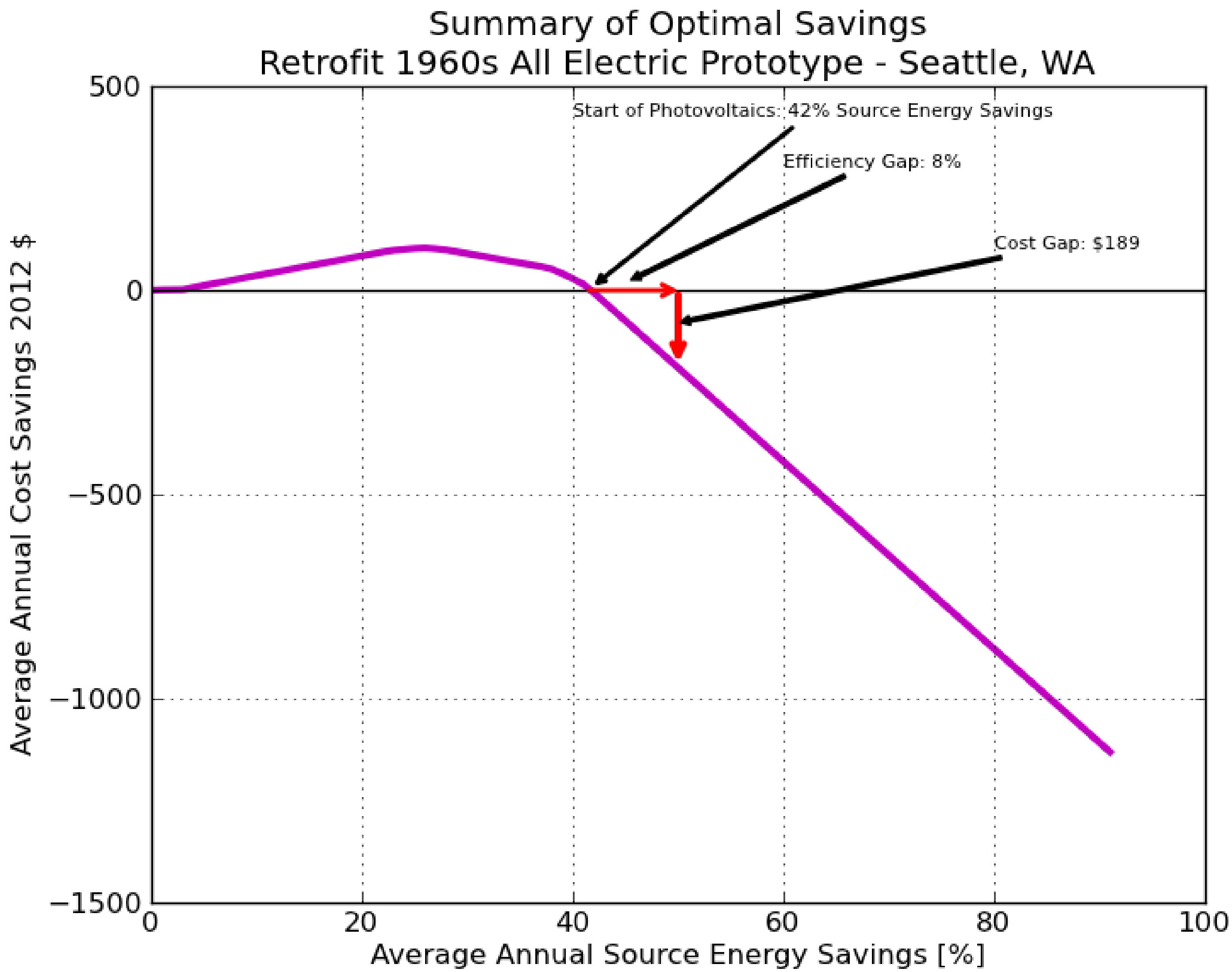

Figure 36. Summary of optimal savings retrofit 1960s all-electric prototype—Seattle

Table 33. Summary of Measures Modeled in Retrofit 1960s Mixed Fuel Prototype ESMPs

<table>
<tr><th>Category</th><th>Reference</th><th>Options Modeled</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></tr>
<tr><td>Foundation:
Basement</td><td>Chicago: Uninsulated</td><td>R-5 Rigid, 8 ft</td><td>R-10 Rigid, 8 ft</td><td>R-15 Rigid, 8 ft</td><td>R-20 Rigid, 8 ft</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Foundation:
Crawlspace Wall</td><td>Atlanta: Vented|Uninsulated
Seattle: Vented|Uninsulated</td><td>Vented
R-13 Ceil</td><td>Vented
R-19 Ceil</td><td>Vented
R-30 Ceil</td><td>Vented
R-38 Ceil</td><td>Closed
R-5 Rigid</td><td>Closed
R-10 Rigid</td><td>Closed
R-15 Rigid</td><td>Closed
R-20 Rigid</td><td></td></tr>
<tr><td>Foundation:
Slab</td><td>Houston: Uninsulated
Phoenix: Uninsulated</td><td>R-5 Rigid
2 ft</td><td>R-5 Rigid
4 ft</td><td>R-10 Rigid
2 ft</td><td>R-10 Rigid
4 ft</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Exterior Walls</td><td>R-7 Batts</td><td>Drill and Fill to R-13</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Unfinished Attic</td><td>Atlanta, Houston, Phoenix: R-11
Seattle, Chicago: R-19</td><td>R-30</td><td>R-38</td><td>R-49</td><td>R-60</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Windows</td><td>1 Pane M Frame
U=1.16|SHGC=0.76</td><td>Window Film
High-Tvis
U=1.09|SHGC=0.43</td><td>Window Film
Low-Tvis
U=1.14|SHGC=0.37</td><td>Storm Window
Clear
U=0.78|SHGC=0.68</td><td>Storm Window
Low-e
U=0.69|SHGC=0.59</td><td>2 Pane NM Frame
U=0.37|SHGC=0.53
U=0.35|SHGC=0.44
U=0.34|SHGC=0.30</td><td>2 Pane INS Frame
U=0.29|SHGC=0.56
U=0.27|SHGC=0.25
U=0.26|SHGC=0.31</td><td>3 Pane NM Frame
U=0.29|SHGC=0.38
U=0.27|SHGC=0.26</td><td>3 Pane INS Frame
U=0.18|SHGC=0.40
U=0.17|SHGC=0.27</td><td></td></tr>
<tr><td>Infiltration</td><td>18 ACH @ 50Pa</td><td>14 ACH @ 50Pa</td><td>10 ACH @ 50Pa</td><td>7 ACH @ 50Pa</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Furnace</td><td>Gas, AFUE 78%</td><td>Gas, AFUE 92.5%</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Air Conditioner</td><td>SEER 10</td><td>SEER 13</td><td>SEER 14</td><td>SEER 15</td><td>SEER 16</td><td>SEER 16 (2-Stage)</td><td>SEER 17</td><td>SEER 18</td><td>SEER 21</td><td>SEER 24</td></tr>
<tr><td>Ducts</td><td>Leaky (30%)
Uninsulated</td><td>Leaky (30%)
R-8</td><td>Leaky (30%)
R-8</td><td>Typical (15%)
Uninsulated</td><td>Typical(15%)
R-6</td><td>Typical(15%)
R-8</td><td>Tight(7.5%)
Uninsulated</td><td>Tight(7.5%)
R-6</td><td>Tight(7.5%)
R-8</td><td></td></tr>
<tr><td>Water Heater</td><td>Gas, Standard
EF = 0.59</td><td>Gas, Premium
EF = 0.67</td><td>Gas, Tankless
EF = 0.82</td><td>Gas, Tankless
Condensing
EF = 0.96</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Lighting</td><td>20% CFL</td><td>40% CFL</td><td>60% CFL</td><td>80% CFL</td><td>100% CFL</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Refrigerator</td><td>Standard
480 kWh</td><td>EnergyStar
374 kWh</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Dishwasher</td><td>Standard
318 kWh</td><td>EnergyStar
290 kWh</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Clothes Washer</td><td>Standard
1.41 MEF</td><td>EnergyStar
2.47 MEF</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Hot Water
Pipe Insulation</td><td>Uninsulated</td><td>R-2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Solar Hot Water</td><td>None</td><td>40 sq ft
Closed Loop</td><td>64 sq ft
Closed Loop</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>PV</td><td>None</td><td>1 kW
1.5 kW</td><td>2 kW
2.5 kW</td><td>3 kW
3.5 kW</td><td>4 kW
4.5 kW</td><td>5 kW
5.5 kW</td><td>6 kW
6.5 kW</td><td>7 kW
7.5 kW</td><td>8 kW</td><td></td></tr>
</table>

Table 34. 30% ESMPs—Retrofit 1960s Mixed Fuel Prototype

30% Energy Savings Measure Packages - Retrofit 1960s Prototype Mixed Fuel	Atlanta, GA	Chicago, IL	Houston, TX	Phoenix, AZ	Seattle, WA
MHWL: Low-Flow Showers & Sinks	X	X	X	X	X
Water Heater: Gas Tankless	X	X	X	X	X
Lighting: 100% CFL	X	X	X	X	X
Walls: Drill and Fill to R-13	X	X	X	X	
Attic: Ceiling R-30, Vented	X		X	X	
Air Sealing: 14 ACH@50Pa	X				X
Clothes Washer: EnergyStar - Cold Only		X			X
Ceiling Fan: Whole-house coverage, 20W			X	X	
Crawlspace: Wall R5 Rigid	X				
Attic: Ceiling R-49, Vented		X			
Air Sealing: 10 ACH@50Pa		X			
Windows: 2 Pane (U=0.389, SHGC=0.528)		X			
Unfinished Basement: Wall 4ft R10 Rigid		X			
Attic: Ceiling R-38, Vented					X
Crawlspace: Wall R15 Rigid					X

Table 35. 50% ESMPs—Retrofit 1960s Mixed Fuel Prototype

50% Energy Savings Measure Packages - Retrofit 1960s Prototype Mixed Fuel	Atlanta, GA	Chicago, IL	Houston, TX	Phoenix, AZ	Seattle, WA
MHWL: Low-Flow Showers & Sinks	X	X	X	X	X
Walls: Drill and Fill to R-13	X	X	X	X	X
Water Heater: Gas Tankless	X	X	X	X	X
Lighting: 100% CFL	X	X	X	X	X
Clothes Washer: EnergyStar - Cold Only	X	X	X	X	X
Ceiling Fan: Whole-house coverage, 20W	X	X	X	X	
DHW Piping: R-2, Copper	X		X	X	X
PV System: 1.5 kW	X	X	X	X	
Windows: 2 Pane (U=0.389, SHGC=0.528)	X	X			X
Attic: Ceiling R-60, Vented	X	X			X
Air Sealing: 14 ACH@50Pa	X				X
Furnace: Gas, AFUE 92		X			X
Windows: 2 Pane (U=0.368, SHGC=0.300)			X	X	
Crawlspace: Wall R5 Rigid	X				
Air Sealing: 10 ACH@50Pa		X			
Unfinished Basement: Wall 4ft R10 Rigid		X			
Ducts: Leaky, R6 Insulation		X			
Ducts: Typical, Uninsulated			X		
Attic: Ceiling R-38, Vented			X		
Ducts: Typical, R6 Insulation				X	
Attic: Ceiling R-49, Vented				X	
Ducts: Leaky, Uninsulated					X
Crawlspace: Wall R20 Rigid					X
PV System: 2.0 kW					X

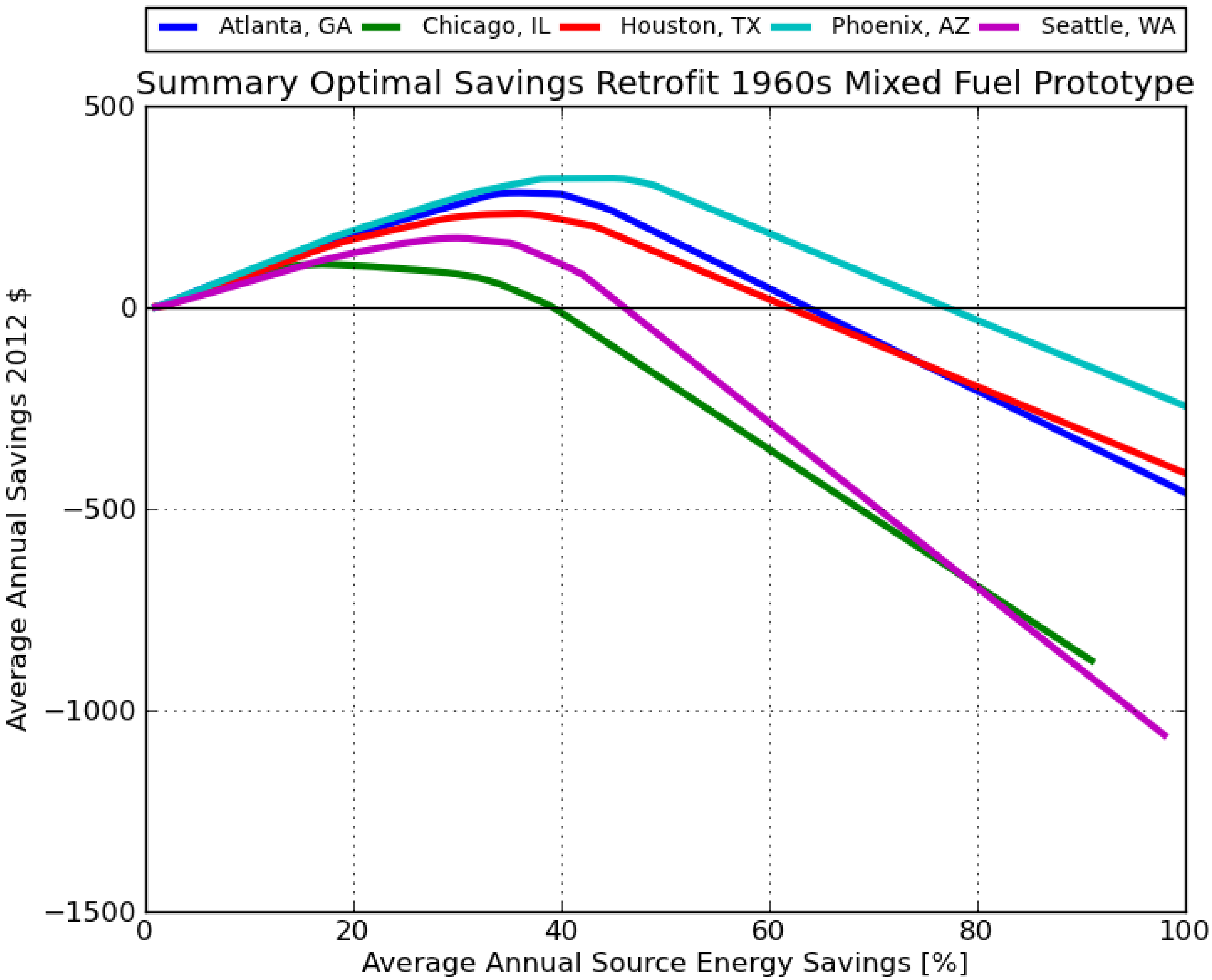

Figure 37. Summary of optimal savings—retrofit 1960s mixed fuel prototype

Table 36. ESMPs for Retrofit 1960s Mixed Fuel Prototype—Atlanta

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Sinks	MHWL: Low-Flow Showers & Sinks	Attic: Ceiling R-19, Vented	Walls: Drill and Fill to R-13	Attic: Ceiling R-30, Vented	Water Heater: Gas Tankless	Lighting: 100% CFL	Crawlspace: Wall R5 Rigid	Air Sealing: 14 ACH@50Pa	Attic: Ceiling R-38, Vented	Clothes Washer: EnergyStar - Cold Only	Ceiling Fan: Whole-house coverage, 20W	Attic: Ceiling R-49, Vented	DHW Piping: R-2, Copper	Windows: 2 Pane (U=0.389, SHGC=0.528)	DHW Piping: Uninsulated	Attic: Ceiling R-60, Vented	PV System: 1.5 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	1	X																				
1	1		X																			
5	45		X	X																		
17	154		X	X	X																	
19	172		X		X	X																
22	196		X		X	X	X															
25	216		X		X	X	X	X														
34	282		X		X	X	X	X	X	X												
34	284		X		X		X	X	X	X	X											
36	285		X		X		X	X	X	X	X	X										
40	282		X		X		X	X	X	X	X	X	X									
40	278		X		X		X	X	X	X		X	X	X								
41	276		X		X		X	X	X	X		X	X	X	X							
44	245		X		X		X	X	X	X		X	X	X		X	X					
45	243		X		X		X	X	X	X		X	X	X	X	X						
45	238		X		X		X	X	X	X		X	X		X	X		X				
50	175		X		X		X	X	X	X		X	X		X	X		X	X			
78	-187		X		X		X	X	X	X		X	X		X	X		X		X		
95	-399		X		X		X	X	X	X		X	X		X	X		X			X	
112	-611		X		X		X	X	X	X		X	X		X	X		X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

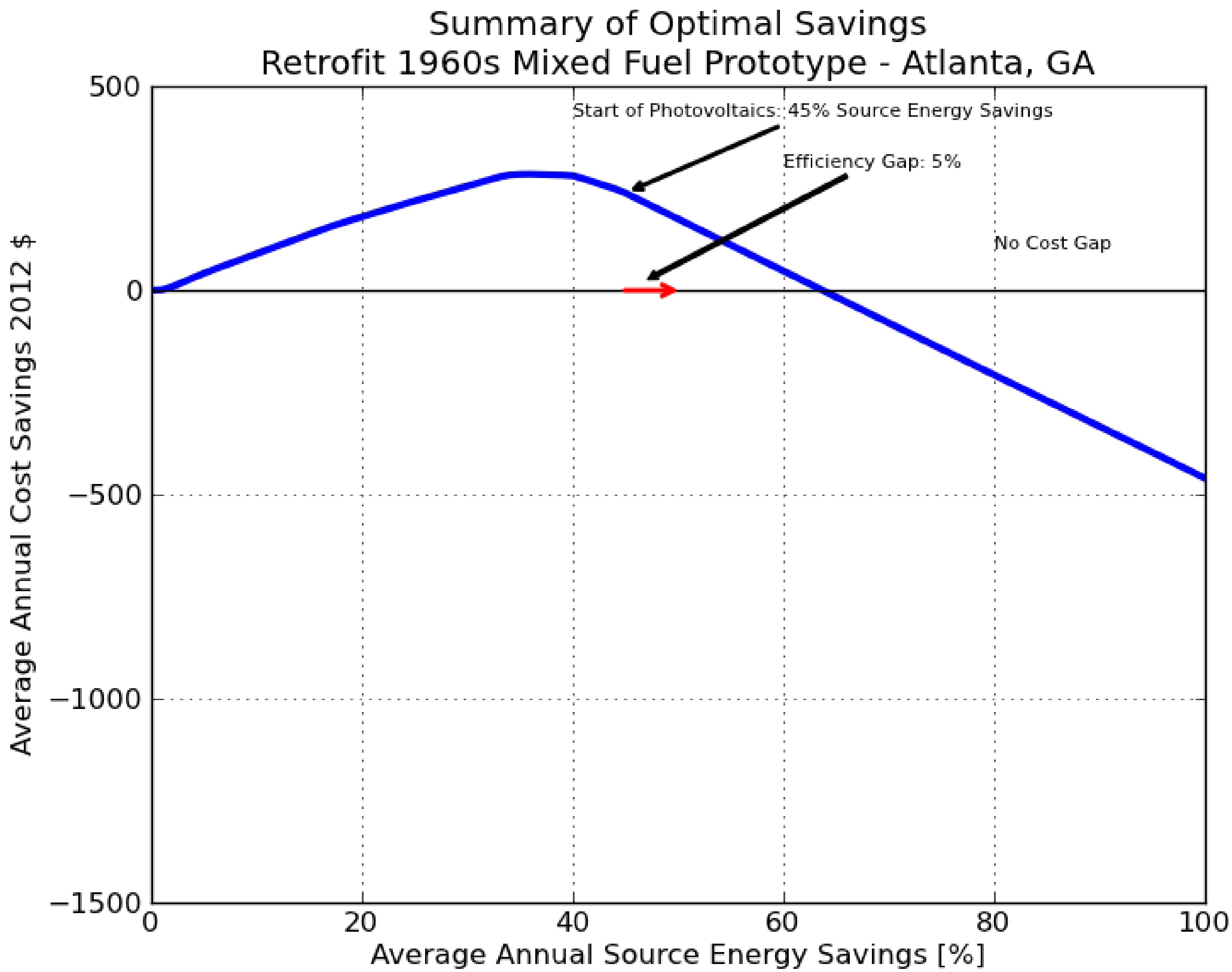

Figure 38. Summary of optimal savings retrofit 1960s mixed fuel prototype—Atlanta

Table 37. ESMPs for Retrofit 1960s Mixed Fuel Prototype—Chicago

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	Lighting: 100% CFL	MHWL: Low-Flow Showers	MHWL: Low-Flow Showers & Sinks	Air Sealing: 14 ACH@50Pa	Attic: Ceiling R-30, Vented	Unfinished Basement: Wall 4ft R5 Rigid	Attic: Ceiling R-38, Vented	Water Heater: Gas Tankless	Attic: Ceiling R-49, Vented	Air Sealing: 10 ACH@50Pa	Windows: 2 Pane (U=0.389, SHGC=0.528)	Clothes Washer: EnergyStar - Cold Only	Unfinished Basement: Wall 4ft R10 Rigid	Walls: Drill and Fill to R-13	Ducts: Leaky, R6 Insulation	Attic: Ceiling R-60, Vented	Furnace: Gas, AFUE 92.5% (82.55 kBtu/hr)	Ceiling Fan: Whole-house coverage, 20W	PV System: 1.5 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	1	X																					
2	9	X	X																				
4	25	X		X																			
8	60	X		X	X																		
11	79	X		X	X	X																	
14	101	X		X	X	X	X																
15	105	X		X	X		X	X															
17	107	X		X	X		X	X	X														
18	106	X		X	X		X		X	X													
21	102	X		X			X		X	X	X												
27	90	X		X			X		X	X	X	X											
29	87	X		X			X		X	X	X	X	X										
29	86	X		X					X	X	X	X	X	X									
32	73	X		X					X	X	X	X	X	X	X								
34	61	X		X					X	X	X	X	X	X	X	X							
34	56	X		X					X		X	X	X	X	X	X	X						
38	11	X		X					X	X	X	X	X	X	X	X		X					
39	5	X		X					X		X	X	X	X	X	X	X	X					
41	-21	X		X					X		X	X	X	X	X	X	X	X	X				
50	-183	X		X					X		X	X	X	X	X	X	X	X	X	X			
66	-458	X		X					X		X	X	X	X	X	X	X	X	X		X		
79	-676	X		X					X		X	X	X	X	X	X	X	X	X			X	
92	-894	X		X					X		X	X	X	X	X	X	X	X	X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

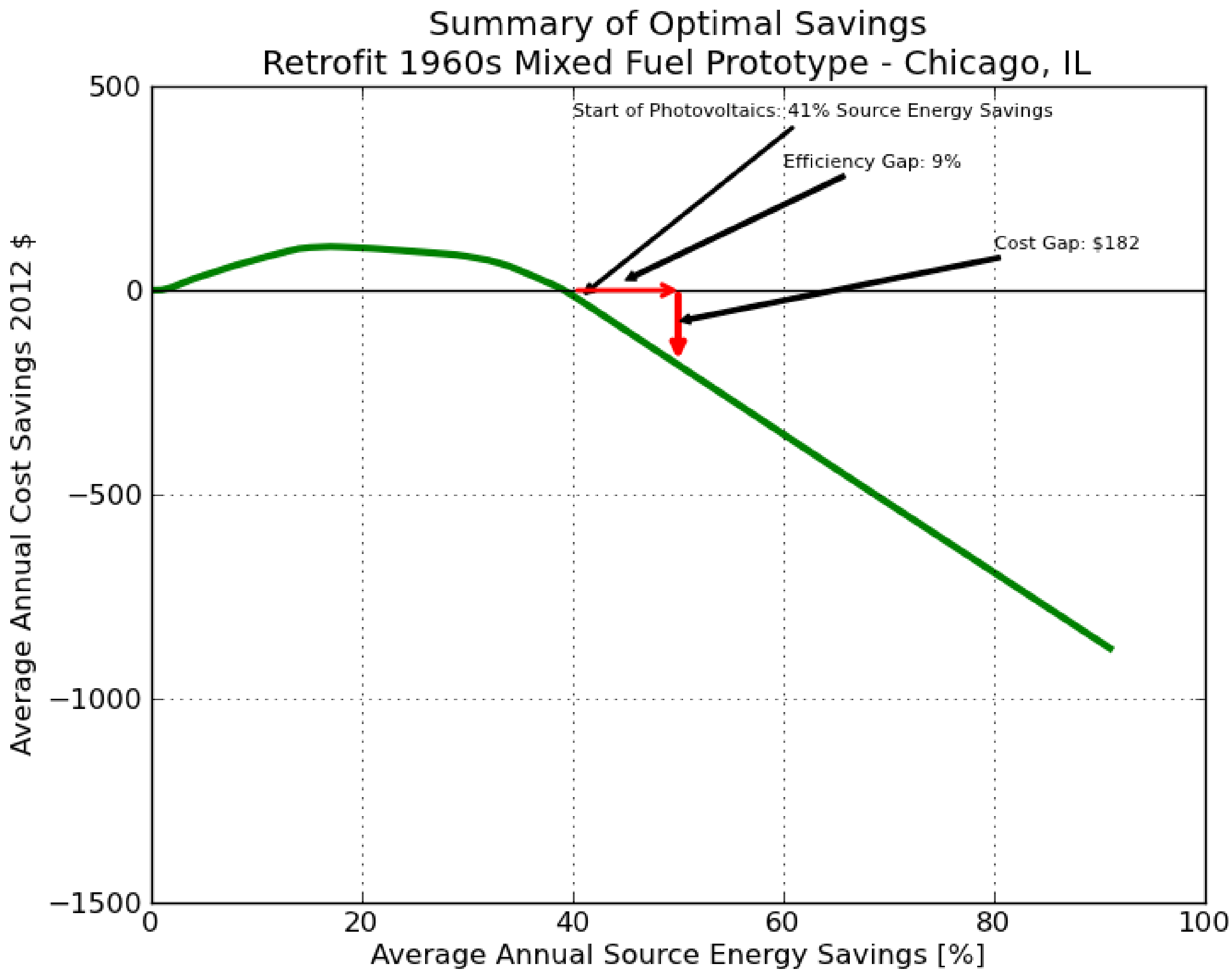

Figure 39. Summary of optimal savings retrofit 1960s mixed fuel prototype—Chicago

Table 38. ESMPs for Retrofit 1960s Mixed Fuel Prototype—Houston

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	Lighting: 100% CFL	MHWL: Low-Flow Showers	MHWL: Low-Flow Showers & Sinks	Ceiling Fan: Whole-house coverage, 20W	Attic: Ceiling R-19, Vented	Walls: Drill and Fill to R-13	Attic: Ceiling R-30, Vented	Water Heater: Gas Tankless	Ducts: Typical, Uninsulated	Attic: Ceiling R-38, Vented	Clothes Washer: EnergyStar - Cold Only	Windows: 2 Pane (U=0.368, SHGC=0.300)	DHW Piping: R-2, Copper	PV System: 1.5 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
2	3	X																
3	12	X	X															
4	23	X		X														
17	142	X		X	X													
19	166	X		X	X	X												
28	215	X		X	X	X	X											
29	222	X		X	X		X	X										
32	231	X		X	X		X	X	X									
37	233	X		X	X		X	X	X	X								
37	232	X		X	X		X		X	X	X							
38	228	X		X	X		X		X	X	X	X						
43	202	X		X	X		X		X	X	X	X	X					
43	199	X		X	X		X		X	X	X	X	X	X				
50	128	X		X	X		X		X	X	X	X	X	X	X			
76	-149	X		X	X		X		X	X	X	X	X	X		X		
92	-322	X		X	X		X		X	X	X	X	X	X			X	
108	-496	X		X	X		X		X	X	X	X	X	X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

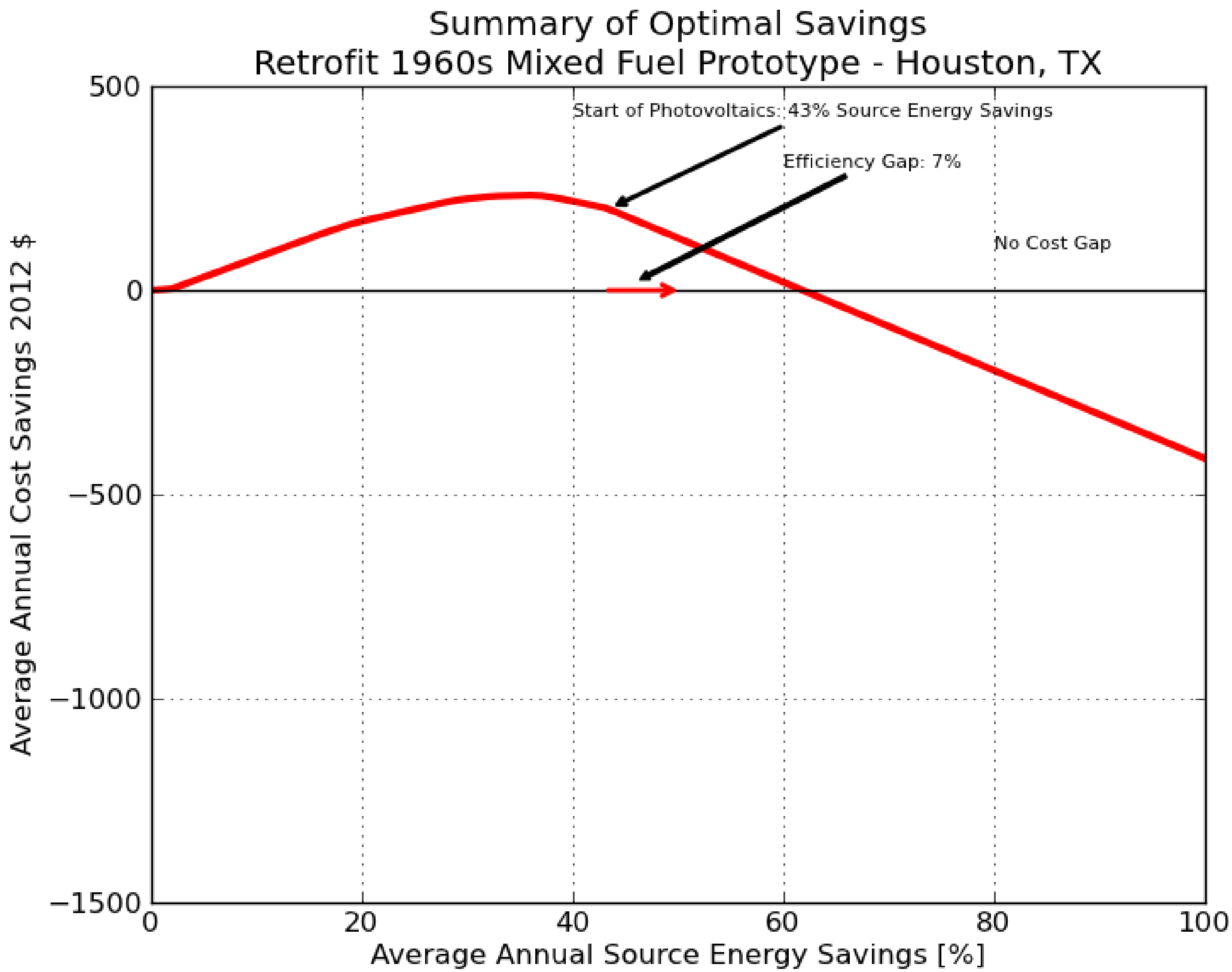

Figure 40. Summary of optimal savings retrofit 1960s mixed fuel prototype—Houston

Table 39. ESMPs for Retrofit 1960s Mixed Fuel Prototype—Phoenix

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Sinks	MHWL: Low-Flow Showers & Sinks	Attic: Ceiling R-19, Vented	Lighting: 100% CFL	Walls: Drill and Fill to R-13	Attic: Ceiling R-30, Vented	Ceiling Fan: Whole-house coverage, 20W	Water Heater: Gas Tankless	Ducts: Typical, Uninsulated	Attic: Ceiling R-38, Vented	Windows: 2 Pane (U=0.368, SHGC=0.300)	Clothes Washer: EnergyStar - Cold Only	Ducts: Typical, R6 Insulation	DHW Piping: R-2, Copper	Attic: Ceiling R-49, Vented	PV System: 1.5 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	1	X																		
1	1		X																	
4	26		X	X																
6	54		X	X	X															
18	176		X	X	X	X														
20	193		X		X	X	X													
28	258		X	X	X	X		X												
30	271		X		X	X	X	X												
32	287		X		X	X	X	X	X											
38	319		X		X	X	X	X	X	X										
39	320		X		X	X		X	X	X	X									
46	321		X		X	X		X	X	X	X	X								
46	318		X		X	X		X	X	X	X	X	X							
48	310		X		X	X		X	X		X	X	X	X						
48	308		X		X	X		X	X		X	X	X	X	X					
49	304		X		X	X		X	X			X	X	X	X	X				
50	291		X		X	X		X	X			X	X	X	X	X	X			
81	-47		X		X	X		X	X			X	X	X	X	X		X		
98	-222		X		X	X		X	X			X	X	X	X	X			X	
114	-396		X		X	X		X	X			X	X	X	X	X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

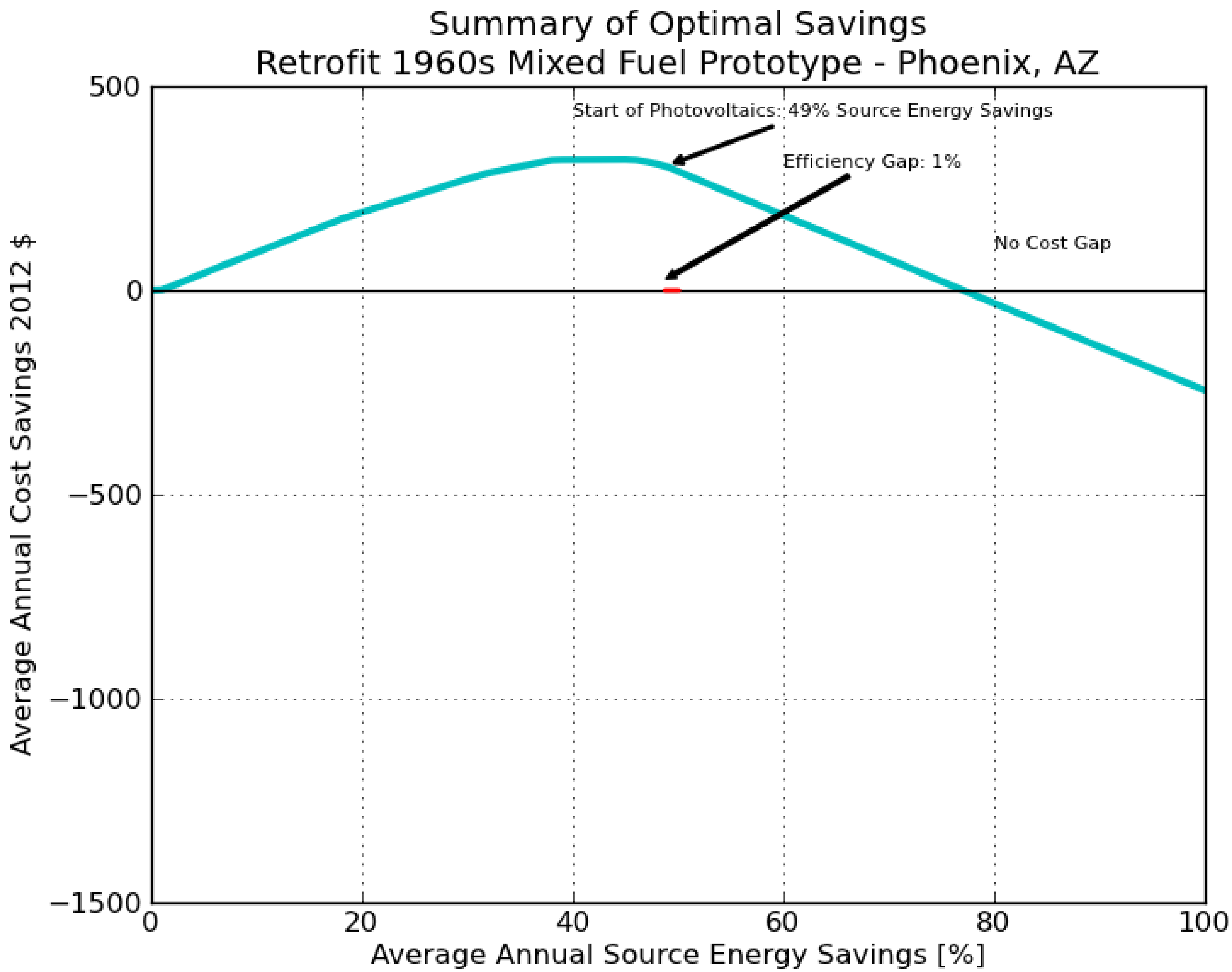

Figure 41. Summary of optimal savings retrofit 1960s mixed fuel prototype—Phoenix

Table 40. ESMPs for Retrofit 1960s Mixed Fuel Prototype—Seattle

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Sinks	MHWL: Low-Flow Showers & Sinks	Crawlspace: Ceiling R13, Vented	Crawlspace: Wall R5 Rigid	Attic: Ceiling R-30, Vented	Air Sealing: 14 ACH@50Pa	Water Heater: Gas Tankless	Lighting: 100% CFL	Crawlspace: Wall R10 Rigid	Attic: Ceiling R-38, Vented	Crawlspace: Wall R15 Rigid	Clothes Washer: EnergyStar - Cold Only	Furnace: Gas, AFUE 92.5% (48.6 kBtu/hr)	Attic: Ceiling R-49, Vented	Ducts: Leaky, R6 Insulation	Windows: 2 Pane (U=0.389, SHGC=0.528)	Ducts: Leaky, Uninsulated	Walls: Drill and Fill to R-13	Crawlspace: Wall R20 Rigid	Attic: Ceiling R-60, Vented	DHW Piping: R-2, Copper	PV System: 2.0 kW	PV System: 2.5 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	1	X																									
1	1		X																								
6	31		X	X																							
17	117		X		X																						
19	130		X		X	X																					
21	141		X		X	X	X																				
25	159		X		X	X	X	X																			
27	167		X		X	X	X	X	X																		
28	170		X			X	X	X	X	X																	
29	171		X				X	X	X	X	X																
30	172		X				X	X	X		X	X															
31	171		X				X	X	X		X	X	X														
35	160		X				X	X	X		X	X	X	X													
36	156		X				X	X	X			X	X	X	X												
37	141		X				X	X	X			X	X	X	X	X											
40	112		X				X	X	X			X	X	X	X		X	X									
42	88		X				X	X	X			X	X	X	X		X	X	X								
42	84		X				X	X	X				X	X	X		X	X	X	X							
42	77		X				X	X	X				X	X			X	X	X	X	X						
43	73		X				X	X	X				X	X			X	X	X	X	X	X					
50	-81		X				X	X	X				X	X			X	X	X	X	X	X	X				
56	-212		X				X	X	X				X	X			X	X	X	X	X	X		X			
70	-497		X				X	X	X				X	X			X	X	X	X	X	X			X		
84	-781		X				X	X	X				X	X			X	X	X	X	X	X				X	
98	-1066		X				X	X	X				X	X			X	X	X	X	X	X					X

(blue)	30% Energy Savings
(green)	50% Energy Savings

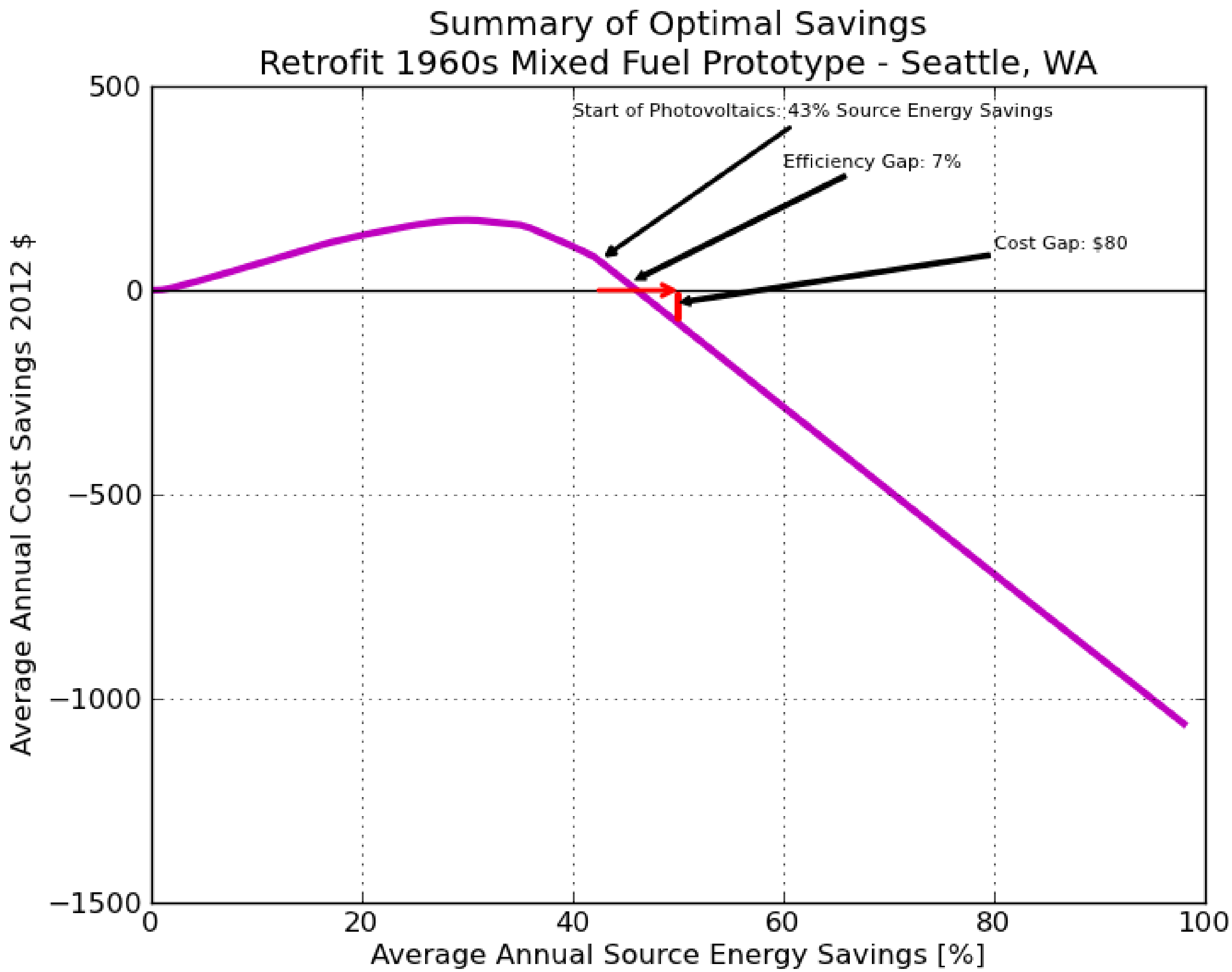

Figure 42. Summary of optimal savings retrofit 1960s mixed fuel prototype—Seattle, WA

Table 41. Summary of Measures Modeled in Retrofit 1990s All-Electric Prototype ESMPs

Category	Reference	Options Modeled							
Foundation: Basement	Chicago: Uninsulated	R-5 Rigid, 8 ft	R-10 Rigid, 8 ft	R-15 Rigid, 8 ft	R-20 Rigid, 8 ft				
Foundation: Crawlspace Wall	Atlanta: Vented|Uninsulated Seattle: Vented|Uninsulated	Vented R-13 Ceil	Vented R-19 Ceil	Vented R-30 Ceil	Vented R-38 Ceil	Closed R-5 Rigid	Closed R-10 Rigid	Closed R-15 Rigid	Closed R-20 Rigid
Foundation: Slab	Houston: Uninsulated Phoenix: Uninsulated	R-5 Rigid 2 ft	R-5 Rigid 4 ft	R-10 Rigid 2 ft	R-10 Rigid 4 ft				
Exterior Walls	R-7 Batts	Drill and Fill to R-13							
Unfinished Attic	Atlanta, Houston, Phoenix: R-11 Seattle, Chicago: R-19	R-30	R-38	R-49	R-60				
Windows	2 Pane M Frame U=0.76|SHGC=0.68	2 Pane NM Frame U=0.37|SHGC=0.53 U=0.35|SHGC=0.44 U=0.34|SHGC=0.30	2 Pane INS Frame U=0.29|SHGC=0.56 U=0.27|SHGC=0.25 U=0.26|SHGC=0.31	3 Pane NM Frame U=0.29|SHGC=0.38 U=0.27|SHGC=0.26	3 Pane INS Frame U=0.18|SHGC=0.40 U=0.17|SHGC=0.27				
Infiltration	18 ACH @ 50Pa	14 ACH @ 50Pa	10 ACH @ 50Pa	7 ACH @ 50Pa					
Heat Pump	10 SEER HSPF 6.2	13 SEER HSPF 7.7	14 SEER HSPF 8.6	15 SEER HSPF 8.8	16 SEER HSPF 8.4	17 SEER HSPF 8.6	18 SEER HSPF 9.2	19 SEER HSPF 9.5	22 SEER HSPF 10.0
Ducts	Leaky (30%) Uninsulated	Leaky (30%) R-6	Leaky (30%) R-8	Typical (15%) Uninsulated	Typical(15%) R-6	Typical(15%) R-8	Tight(7.5%) Uninsulated	Tight(7.5%) R-6	Tight(7.5%) R-8
Water Heater	EF = 0.92	EF = 0.95	HPWH, 50 gal	HPWH, 80 gal					
Lighting	20% CFL	40% CFL	60% CFL	80% CFL	100% CFL				
Refrigerator	Standard 480 kWh	EnergyStar 374 kWh							
Dishwasher	Standard 318 kWh	EnergyStar 290 kWh							
Clothes Washer	Standard 1.41 MEF	EnergyStar 2.47 MEF							
Hot Water Pipe Insulation	Uninsulated	R-2							
Solar Hot Water	None	32 ft2 ICS	40 ft2 Closed Loop	64 ft2 Closed Loop					
PV	None	1 kW 1.5 kW	2 kW 2.5 kW	3 kW 3.5 kW	4 kW 4.5 kW	5 kW 5.5 kW	6 kW 6.5 kW	7 kW 7.5 kW	8 kW

Table 42. 30% ESMPs—Retrofit 1990s All-Electric Prototype

30% Energy Savings Measure Packages - Retrofit 1990s Prototype All Electric	Atlanta, GA	Chicago, IL	Houston, TX	Phoenix, AZ	Seattle, WA
MHWL: Low-Flow Showers & Sinks	X	X	X	X	X
Lighting: 100% CFL	X	X	X	X	X
Clothes Washer: EnergyStar - Cold Only	X	X	X	X	X
Ceiling Fan: Whole-house coverage, 20W	X		X	X	
DHW Piping: R-5, Copper, Timer	X	X	X		
Attic: Ceiling R-49, Vented	X	X			
Air Sealing: 10 ACH@50Pa	X	X			
Attic: Ceiling R-38, Vented			X	X	
Ducts: Typical, R6 Insulation			X	X	
DHW Piping: R-2, Copper				X	X
Water Heater: Electric Premium	X				
Crawlspace: Wall R5 Rigid	X				
Ducts: Leaky, R6 Insulation		X			
Unfinished Basement: Wall 4ft R10 Rigid		X			
Walls: Drill and Fill to R-13		X			
Heat Pump: SEER 15, HSPF 8.5		X			
PV System: 0.5 kW			X		
Windows: 2 Pane (U=0.368, SHGC=0.300)				X	
Attic: Ceiling R-30, Vented					X
Air Sealing: 14 ACH@50Pa					X
Crawlspace: Wall R10 Rigid					X

Table 43. 50% ESMPs—Retrofit 1990s All-Electric Prototype

50% Energy Savings Measure Packages - Retrofit 1990s Prototype All Electric	Atlanta, GA	Chicago, IL	Houston, TX	Phoenix, AZ	Seattle, WA
MHWL: Low-Flow Showers & Sinks	X	X	X	X	X
Lighting: 100% CFL	X	X	X	X	X
Clothes Washer: EnergyStar - Cold Only	X	X	X	X	X
DHW Piping: R-5, Copper, Timer	X	X	X		X
Water Heater: Electric Premium	X	X			X
Ceiling Fan: Whole-house coverage, 20W	X		X	X	
Attic: Ceiling R-49, Vented	X			X	X
Air Sealing: 10 ACH@50Pa	X	X			
PV System: 4.0 kW	X		X		
Heat Pump: SEER 22, HSPF 10.		X			X
Ducts: Typical, R6 Insulation			X	X	
PV System: 0.5 kW			X		X
Crawlspace: Wall R5 Rigid	X				
Unfinished Basement: Wall 4ft R10 Rigid		X			
Walls: Drill and Fill to R-13		X			
Ducts: Leaky, R8 Insulation		X			
Windows: 2 Pane (U=0.389, SHGC=0.528)		X			
Attic: Ceiling R-60, Vented		X			
PV System: 1.5 kW		X			
Attic: Ceiling R-38, Vented			X		
DHW Piping: R-2, Copper				X	
Windows: 2 Pane (U=0.368, SHGC=0.300)				X	
PV System: 2.0 kW				X	
Air Sealing: 14 ACH@50Pa					X
Crawlspace: Wall R15 Rigid					X
Ducts: Leaky, R6 Insulation					X

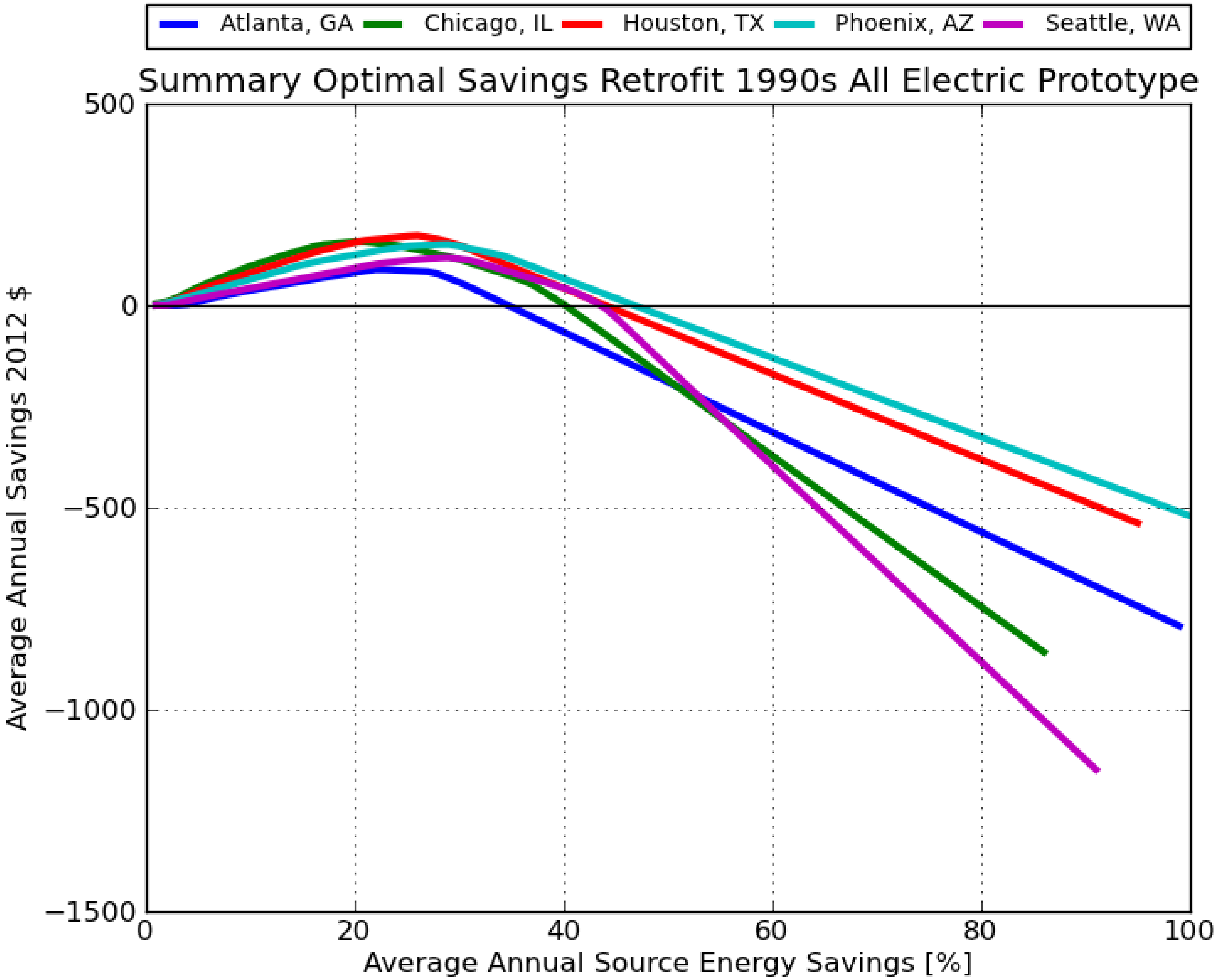

Figure 43. Summary of optimal savings—retrofit 1990s all-electric prototype

Table 44. ESMPs for Retrofit 1990s All-Electric Prototype—Atlanta

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Showers	MHWL: Low-Flow Showers & Sinks	Lighting: 100% CFL	Water Heater: Electric Premium	Attic: Ceiling R-30, Vented	Attic: Ceiling R-19, Vented	Crawlspace: Wall R5 Rigid	Clothes Washer: EnergyStar - Cold Only	DHW Piping: R-2, Copper	Ceiling Fan: Whole-house coverage, 20W	Attic: Ceiling R-38, Vented	Attic: Ceiling R-49, Vented	DHW Piping: R-5, Copper, Timer	Air Sealing: 10 ACH@50Pa	PV System: 4.0 kW	PV System: 5.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	1	X																	
4	1		X																
6	18		X	X															
7	23		X	X	X														
10	35		X	X	X	X													
17	69		X	X	X		X	X											
19	77		X	X	X	X		X											
22	89		X	X	X	X		X	X										
23	90		X	X	X	X		X	X	X									
27	85		X	X	X	X		X	X	X	X								
27	83		X	X	X			X	X	X	X	X							
28	78		X	X	X			X	X	X	X		X						
29	64		X	X	X			X	X		X		X	X					
30	53		X	X	X			X	X		X		X	X	X				
50	-190		X	X	X			X	X		X		X	X	X	X			
65	-372		X	X	X			X	X		X		X	X	X		X		
82	-584		X	X	X			X	X		X		X	X	X			X	
99	-796		X	X	X			X	X		X		X	X	X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

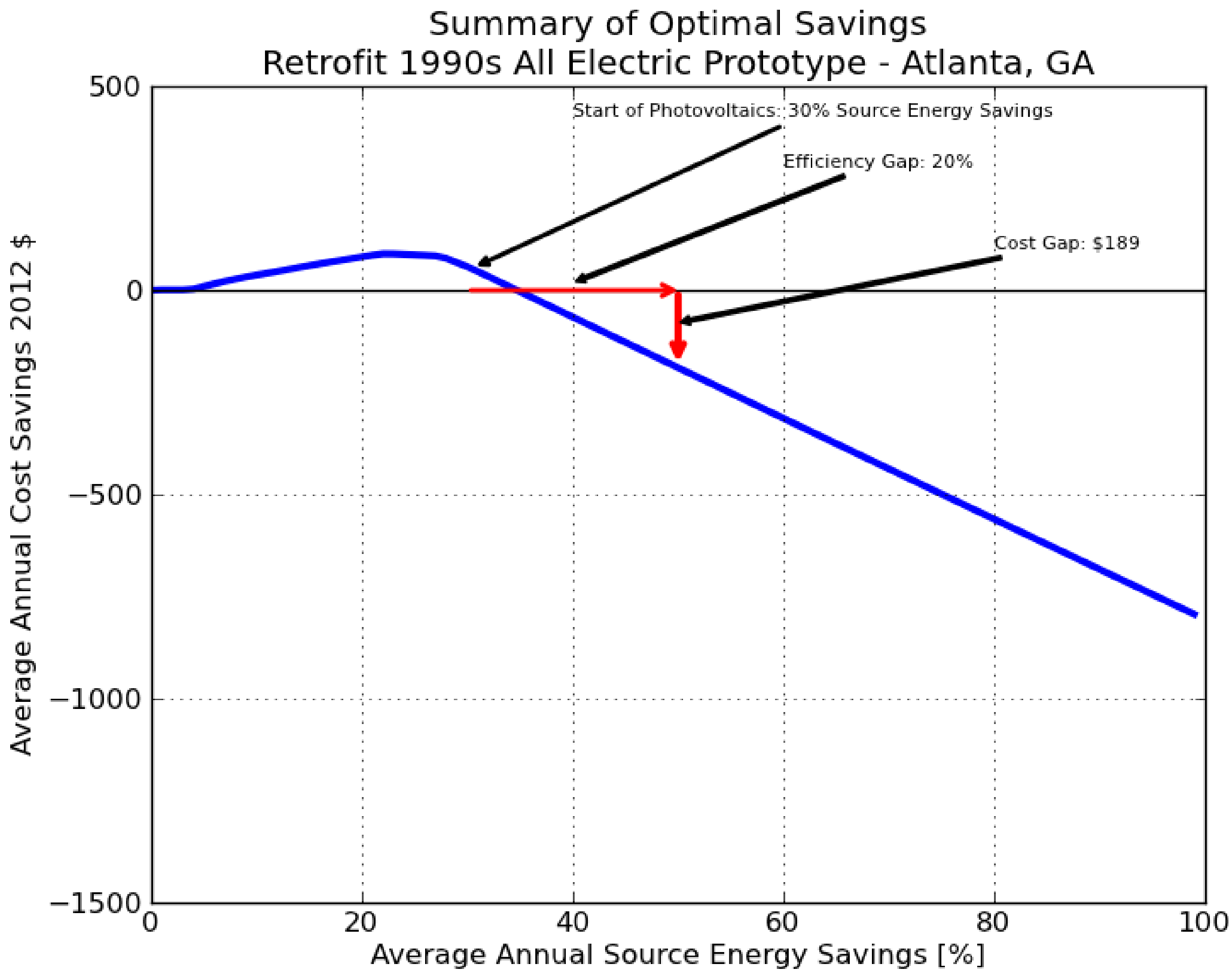

Figure 44. Summary of optimal savings retrofit 1990s all-electric prototype—Atlanta

Table 45. ESMPs for Retrofit 1990s All-Electric Prototype—Chicago

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Sinks	MHWL: Low-Flow Showers & Sinks	Lighting: 100% CFL	Unfinished Basement: Wall 4ft R5 Rigid	Air Sealing: 10 ACH@50Pa	Clothes Washer. EnergyStar - Cold Only	Attic: Ceiling R-38, Vented	Ducts: Leaky, R6 Insulation	DHW Piping: R-2, Copper	Attic: Ceiling R-49, Vented	Unfinished Basement: Wall 4ft R10 Rigid	Walls: Drill and Fill to R-13	Walls: R-7 Batts, 2x4, 16"o.c.	Heat Pump: SEER 15, HSPF 8.5 (68.59 kBtu/hr) (3.31 tons)	DHW Piping: R-5, Copper, Timer	Heat Pump: SEER 22, HSPF 10.0 (68.59 kBtu/hr) (3.31 tons)	Ducts: Leaky, R8 Insulation	Windows: 2 Pane (U=0.389, SHGC=0.528)	Water Heater: Electric Premium	Attic: Ceiling R-60, Vented	PV System: 1.5 kW	PV System: 4.0 kW	PV System: 8.0 kW
2	12	X																						
5	41		X																					
6	61		X	X																				
10	95		X	X	X																			
13	125		X	X	X	X																		
16	144		X	X	X	X	X																	
17	151		X	X	X	X	X	X																
19	157		X	X	X	X	X	X	X															
20	158		X	X	X	X	X	X	X	X														
21	159		X	X	X	X	X		X	X	X													
21	157		X	X		X	X		X	X	X	X												
24	149		X	X		X	X		X	X	X	X	X											
27	130		X	X		X	X		X	X	X	X		X	X									
30	117		X	X		X	X		X	X	X	X	X		X									
31	106		X	X		X	X		X		X	X	X		X	X								
35	74		X	X		X	X		X		X	X		X		X	X							
37	56		X	X		X	X		X		X	X	X			X	X							
37	54		X	X		X	X				X	X	X			X	X	X						
39	14		X	X		X	X		X		X	X	X			X	X		X					
40	3		X	X		X	X		X		X	X	X			X	X		X	X				
40	0		X	X		X	X				X	X	X			X	X	X	X	X				
41	-6		X	X		X	X					X	X			X	X	X	X	X	X			
50	-185		X	X		X	X					X	X			X	X	X	X	X	X	X		
64	-443		X	X		X	X					X	X			X	X	X	X	X	X		X	
87	-873		X	X		X	X				X	X	X			X	X	X	X	X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

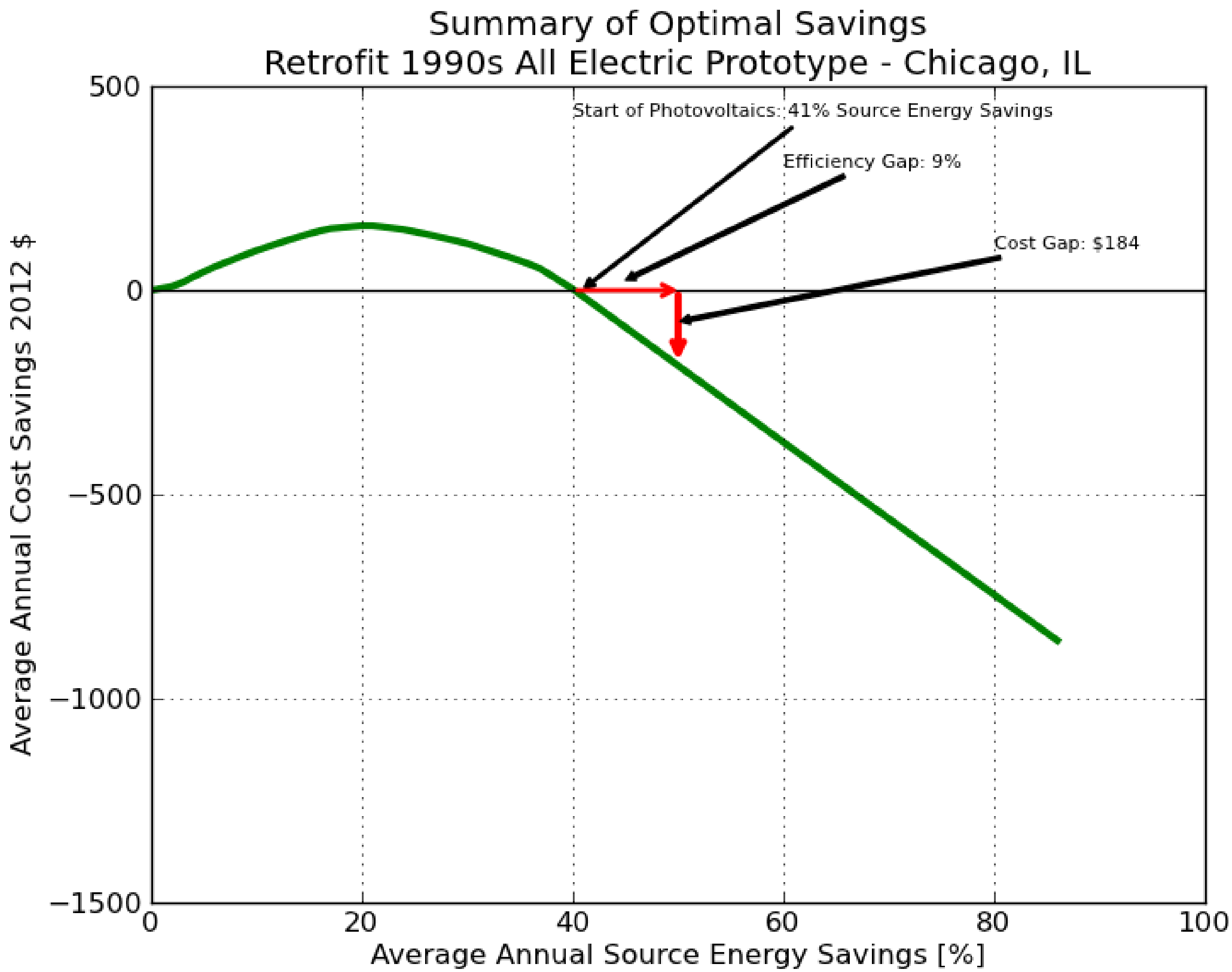

Figure 45. Summary of optimal savings retrofit 1990s all-electric prototype—Chicago

Table 46. ESMPs for Retrofit 1990s All-Electric Prototype—Houston

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Showers	MHWL: Low-Flow Showers & Sinks	Lighting: 100% CFL	Ceiling Fan: Whole-house coverage, 20W	Clothes Washer: EnergyStar - Cold Only	Attic: Ceiling R-30, Vented	DHW Piping: R-2, Copper	Ducts: Typical, Uninsulated	Attic: Ceiling R-38, Vented	Ducts: Typical, R6 Insulation	DHW Piping: R-5, Copper, Timer	PV System: 0.5 kW	PV System: 4.0 kW	PV System: 5.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	1	X															
3	9		X														
6	45		X	X													
16	133		X	X	X												
19	150		X	X	X	X											
20	159		X	X	X	X	X										
21	162		X	X	X	X	X	X									
26	173		X	X	X	X	X	X	X								
26	172		X	X	X	X		X	X	X							
28	165		X	X	X	X		X		X	X						
29	154		X	X	X	X				X	X	X					
30	150		X	X	X	X				X	X	X	X				
50	-63		X	X	X	X				X	X	X	X	X			
62	-194		X	X	X	X				X	X	X			X		
79	-368		X	X	X	X				X	X	X				X	
95	-541		X	X	X	X				X	X	X					X

(blue)	30% Energy Savings
(green)	50% Energy Savings

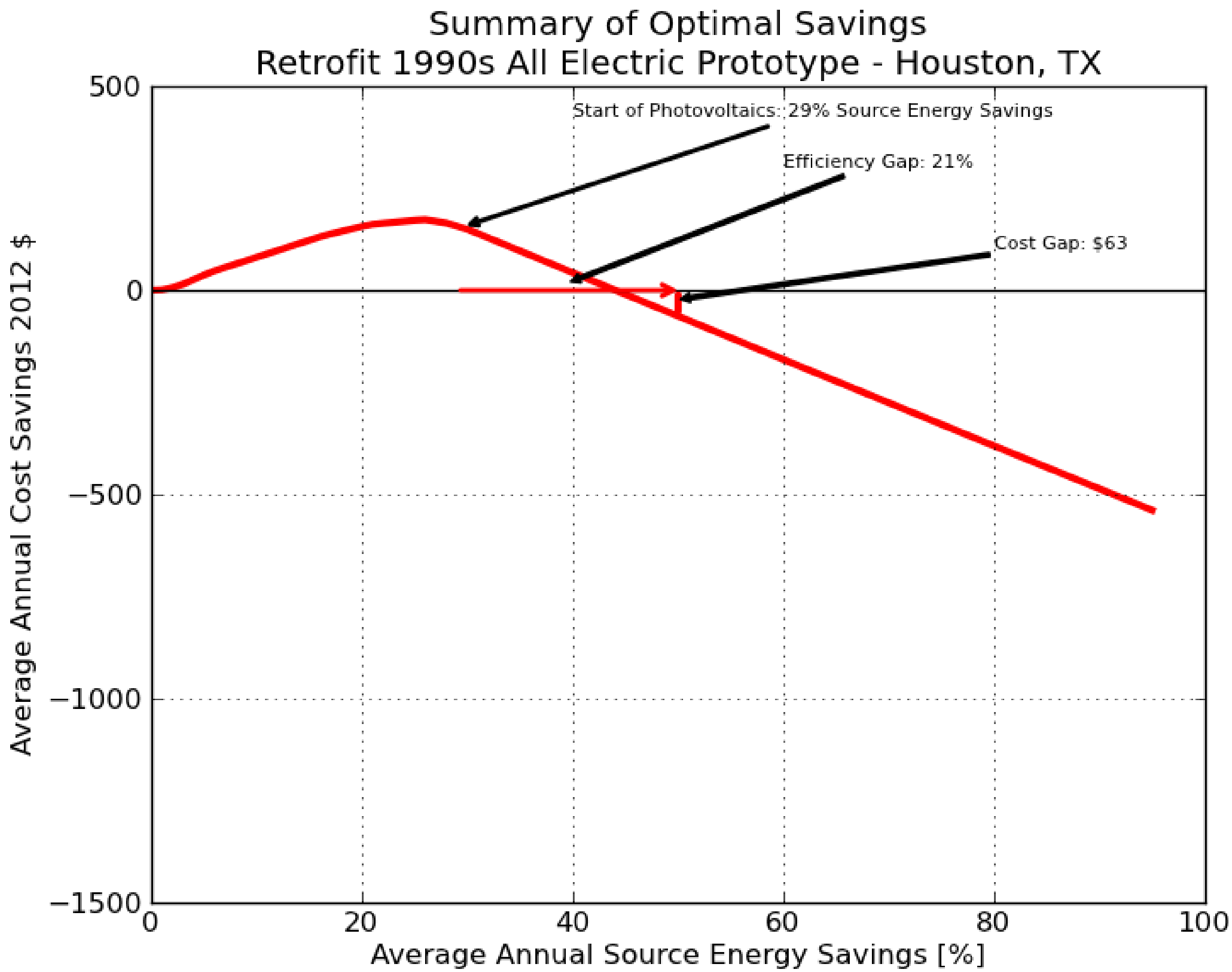

Figure 46. Summary of optimal savings retrofit all-electric 1990s prototype—Houston

Table 47. ESMPs for Retrofit 1990s All-Electric Prototype—Phoenix

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Showers	MHWL: Low-Flow Showers & Sinks	Lighting: 100% CFL	Ceiling Fan: Whole-house coverage, 20W	Attic: Ceiling R-30, Vented	Ducts: Typical, Uninsulated	Clothes Washer: EnergyStar - Cold Only	DHW Piping: R-2, Copper	Ducts: Typical, R6 Insulation	Attic: Ceiling R-38, Vented	Windows: 2 Pane (U=0.368, SHGC=0.300)	Attic: Ceiling R-49, Vented	PV System: 2.0 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	1	X															
1	1		X														
4	22		X	X													
15	99		X	X	X												
17	110		X	X	X	X											
23	140		X	X	X	X	X										
25	147		X	X	X	X	X	X									
26	148		X	X	X	X	X	X	X								
29	152		X	X	X	X		X	X	X							
29	151		X	X	X			X	X	X	X						
34	124		X	X	X			X	X	X	X	X					
35	120		X	X	X			X	X	X		X	X				
50	-31		X	X	X			X	X	X		X	X	X			
70	-231		X	X	X			X	X	X		X	X		X		
88	-406		X	X	X			X	X	X		X	X			X	
106	-580		X	X	X			X	X	X		X	X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

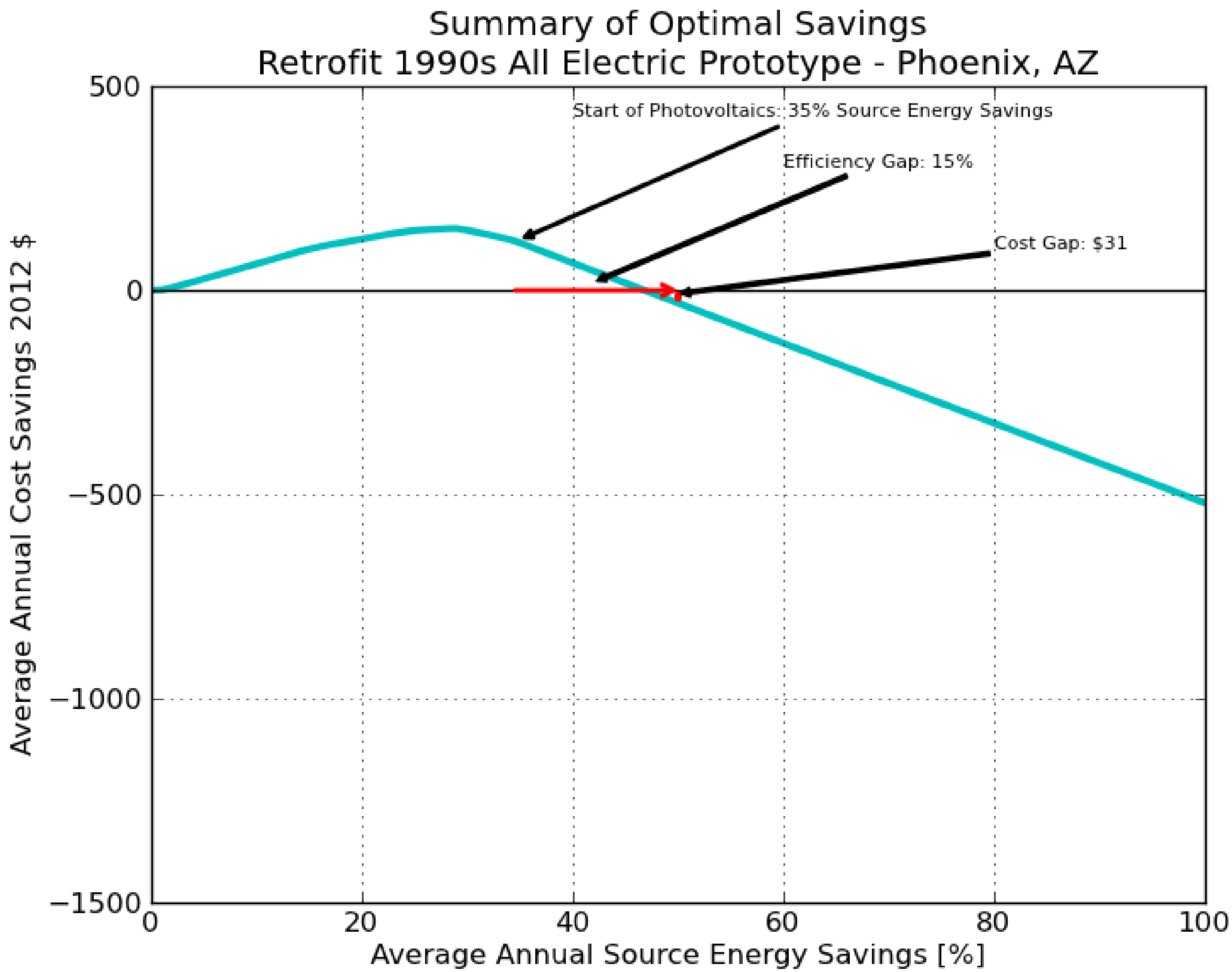

Figure 47. Summary of optimal savings retrofit 1990s all-electric prototype—Phoenix

Table 48. ESMPs for Retrofit 1990s All-Electric Prototype—Seattle

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Sinks	MHWL: Low-Flow Showers & Sinks	Lighting: 100% CFL	Crawlspace: Wall R5 Rigid	Attic: Ceiling R-30, Vented	Clothes Washer: EnergyStar - Cold Only	Air Sealing: 14 ACH@50Pa	Crawlspace: Wall R10 Rigid	DHW Piping: R-2, Copper	Attic: Ceiling R-38, Vented	Crawlspace: Wall R15 Rigid	Heat Pump: SEER 22, HSPF 10.0 (48.41 kBtu/hr) (1.65 tons)	Ducts: Leaky, R6 Insulation	DHW Piping: R-5, Copper, Timer	Water Heater: Electric Premium	Attic: Ceiling R-49, Vented	PV System: 0.5 kW	PV System: 2.0 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
2	1	X																				
5	15		X																			
6	25		X	X																		
22	104		X	X	X																	
24	110		X	X	X	X																
27	117		X	X	X	X	X															
29	119		X	X	X	X	X	X														
30	117		X	X		X	X	X	X													
30	115		X	X		X	X	X	X	X												
31	112		X	X			X	X	X	X	X											
31	110		X	X			X	X		X	X	X										
41	38		X	X	X	X	X	X		X			X	X								
41	33		X	X	X		X	X		X	X		X	X								
43	16		X	X	X		X	X			X		X	X	X							
43	10		X	X			X	X	X		X		X	X	X							
44	-3		X	X			X	X	X		X		X	X	X	X						
44	-7		X	X			X	X			X	X	X	X	X	X						
44	-15		X	X			X	X				X	X	X	X	X	X					
50	-153		X	X			X	X				X	X	X	X	X	X	X				
56	-300		X	X			X	X				X	X	X	X	X	X		X			
68	-585		X	X			X	X				X	X	X	X	X	X			X		
80	-870		X	X			X	X				X	X	X	X	X	X				X	
91	-1154		X	X			X	X				X	X	X	X	X	X					X

30% Energy Savings
50% Energy Savings

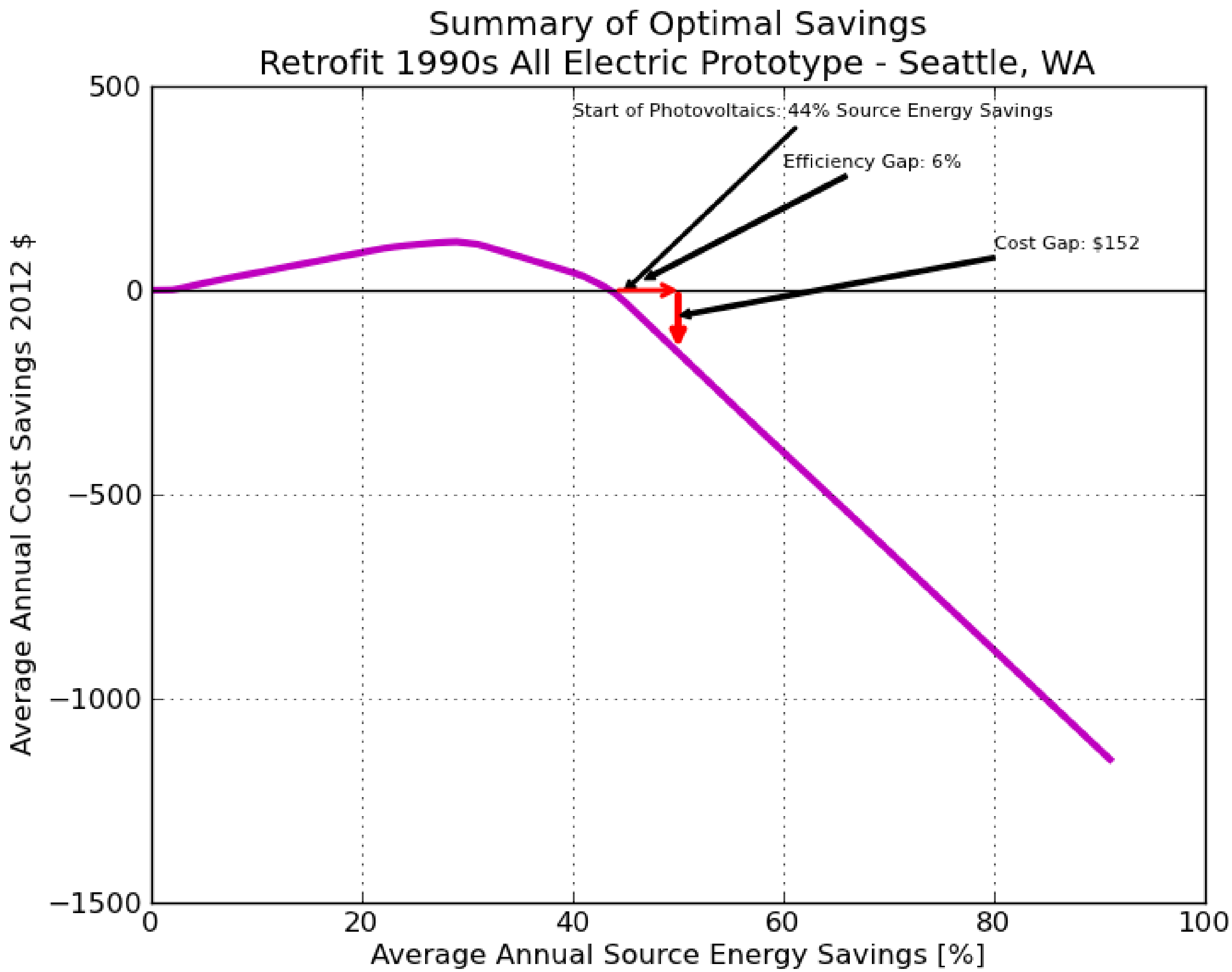

Figure 48. Summary of optimal savings retrofit 1990s all-electric prototype—Seattle

Table 49. Summary of Measures Modeled in Retrofit 1990s Mixed Fuel Prototype ESMPs

Category	Reference	Options Modeled								
Foundation: Basement	Chicago: Uninsulated	R-5 Rigid, 8 ft	R-10 Rigid, 8 ft	R-15 Rigid, 8 ft	R-20 Rigid, 8 ft					
Foundation: Crawlspace Wall	Atlanta: Vented|Uninsulated Seattle: Vented|Uninsulated	Vented R-13 Ceil	Vented R-19 Ceil	Vented R-30 Ceil	Vented R-38 Ceil	Closed R-5 Rigid	Closed R-10 Rigid	Closed R-15 Rigid	Closed R-20 Rigid	
Foundation: Slab	Houston: Uninsulated Phoenix: Uninsulated	R-5 Rigid 2 ft	R-5 Rigid 4 ft	R-10 Rigid 2 ft	R-10 Rigid 4 ft					
Exterior Walls	R-7 Batts	Drill and Fill to R-13								
Unfinished Attic	Atlanta, Houston, Phoenix: R-11 Seattle, Chicago: R-19	R-30	R-38	R-49	R-60					
Windows	2 Pane M Frame U=0.76|SHGC=0.68	2 Pane NM Frame U=0.37|SHGC=0.53 U=0.35|SHGC=0.44 U=0.34|SHGC=0.30	2 Pane INS Frame U=0.29|SHGC=0.56 U=0.27|SHGC=0.25 U=0.26|SHGC=0.31	3 Pane NM Frame U=0.29|SHGC=0.38 U=0.27|SHGC=0.26	3 Pane INS Frame U=0.18|SHGC=0.40 U=0.17|SHGC=0.27					
Infiltration	18 ACH @ 50Pa	14 ACH @ 50Pa	10 ACH @ 50Pa	7 ACH @ 50Pa						
Furnace	Gas, AFUE 78%	Gas, AFUE 92.5%								
Air Conditioner	SEER 10	SEER 13	SEER 14	SEER 15	SEER 16	SEER 16 (2-Stage)	SEER 17	SEER 18	SEER 21	SEER 24
Ducts	Leaky (30%) Uninsulated	Leaky (30%) R-6	Leaky (30%) R-8	Typical (15%) Uninsulated	Typical(15%) R-6	Typical(15%) R-8	Tight(7.5%) Uninsulated	Tight(7.5%) R-6	Tight(7.5%) R-8	
Water Heater	Gas, Standard EF = 0.59	Gas, Premium EF = 0.67	Gas, Tankless EF = 0.82	Gas, Tankless Condensing EF = 0.96						
Lighting	20% CFL	40% CFL	60% CFL	80% CFL	100% CFL					
Refrigerator	Standard 480 kWh	EnergyStar 374 kWh								
Dishwasher	Standard 318 kWh	EnergyStar 290 kWh								
Clothes Washer	Standard 1.41 MEF	EnergyStar 2.47 MEF								
Hot Water Pipe Insulation	Uninsulated	R-2								
Solar Hot Water	None	40 sq ft Closed Loop	64 sq ft Closed Loop							
PV	None	1 kW 1.5 kW	2 kW 2.5 kW	3 kW 3.5 kW	4 kW 4.5 kW	5 kW 5.5 kW	6 kW 6.5 kW	7 kW 7.5 kW	8 kW	

Table 50. 30% ESMPs—Retrofit 1990s Mixed Fuel Prototype

30% Energy Savings Measure Packages - Retrofit 1990s Prototype Mixed Fuel	Atlanta, GA	Chicago, IL	Houston, TX	Phoenix, AZ	Seattle, WA
MHWL: Low-Flow Showers & Sinks	X	X	X	X	X
Water Heater: Gas Tankless	X	X	X	X	X
Lighting: 100% CFL	X	X	X	X	X
Attic: Ceiling R-38, Vented	X		X	X	X
Clothes Washer: EnergyStar - Cold Only	X	X	X		X
Ceiling Fan: Whole-house coverage, 20W	X	X	X	X	
Air Sealing: 10 ACH@50Pa	X	X			
Furnace: Gas, AFUE 92		X			X
Ducts: Typical, R6 Insulation			X	X	
Crawlspace: Wall R5 Rigid	X				
Attic: Ceiling R-49, Vented		X			
Ducts: Leaky, R6 Insulation		X			
Walls: Drill and Fill to R-13		X			
Unfinished Basement: Wall 4ft R10 Rigid		X			
DHW Piping: R-2, Copper			X		
Crawlspace: Wall R15 Rigid					X

Table 51. 50% ESMPs—Retrofit 1990s Mixed Fuel Prototype

50% Energy Savings Measure Packages - Retrofit 1990s Prototype Mixed Fuel	Atlanta, GA	Chicago, IL	Houston, TX	Phoenix, AZ	Seattle, WA
MHWL: Low-Flow Showers & Sinks	X	X	X	X	X
Water Heater: Gas Tankless	X	X	X	X	X
Lighting: 100% CFL	X	X	X	X	X
Clothes Washer: EnergyStar - Cold Only	X	X	X	X	X
Ceiling Fan: Whole-house coverage, 20W	X	X	X	X	
DHW Piping: R-2, Copper	X		X	X	X
Air Sealing: 10 ACH@50Pa	X	X			X
Furnace: Gas, AFUE 92	X	X			X
PV System: 2.0 kW	X			X	X
Attic: Ceiling R-49, Vented	X			X	
Ducts: Leaky, R6 Insulation		X			X
Walls: Drill and Fill to R-13		X			X
Attic: Ceiling R-60, Vented		X			X
PV System: 4.0 kW		X	X		
Ducts: Typical, R6 Insulation			X	X	
Crawlspace: Wall R5 Rigid	X				
Unfinished Basement: Wall 4ft R10 Rigid		X			
Windows: 2 Pane (U=0.389, SHGC=0.528)		X			
Attic: Ceiling R-38, Vented			X		
Windows: 2 Pane (U=0.368, SHGC=0.300)				X	
Crawlspace: Wall R20 Rigid					X

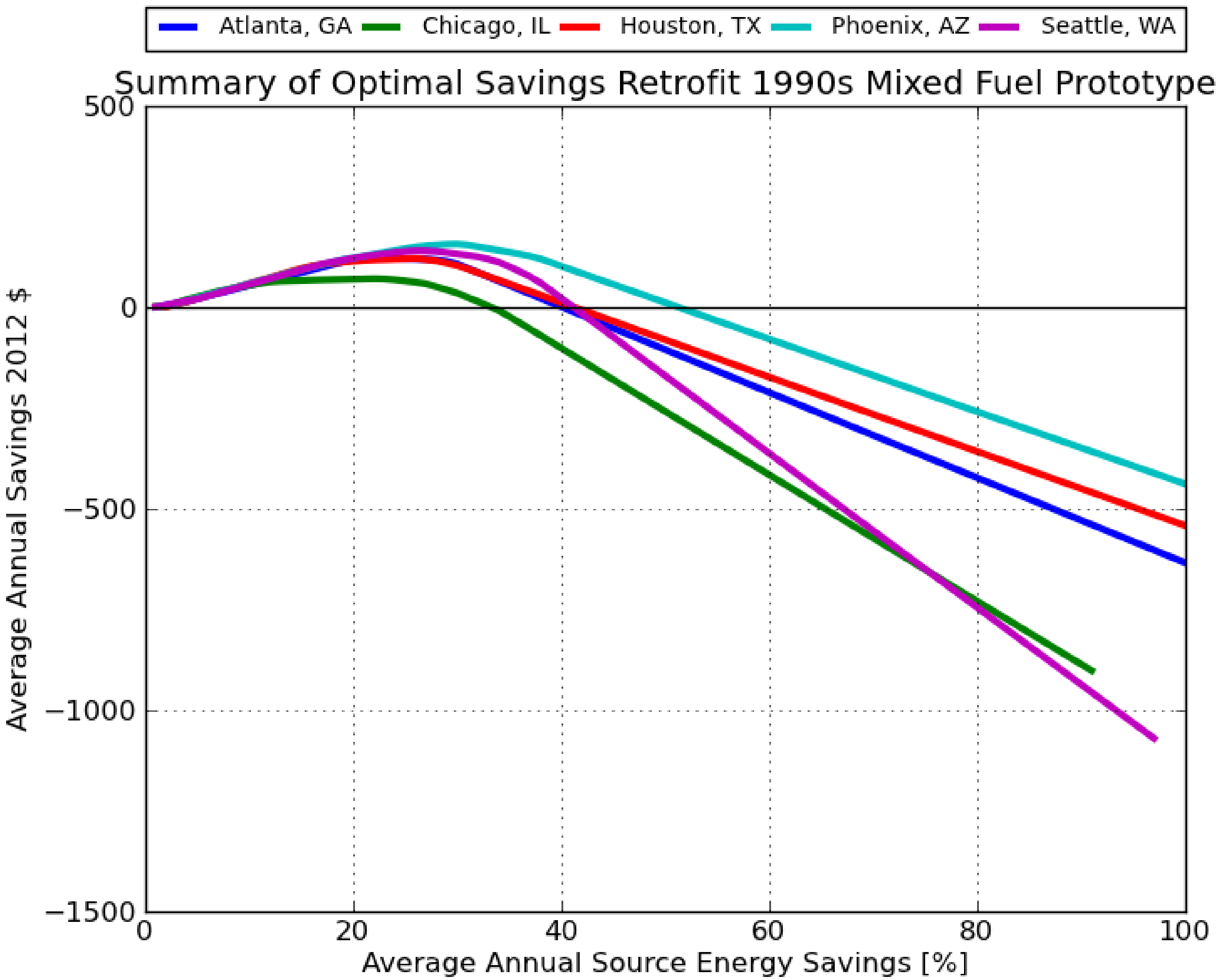

Figure 49. Summary of optimal savings—retrofit 1990s mixed fuel prototype

Table 52. ESMPs for Retrofit 1990s Mixed Fuel Prototype—Atlanta

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Sinks	MHWL: Low-Flow Showers & Sinks	Attic: Ceiling R-30, Vented	Attic: Ceiling R-19, Vented	Crawlspace: Wall R5 Rigid	Water Heater: Gas Tankless	Lighting: 100% CFL	Attic: Ceiling R-38, Vented	Clothes Washer: EnergyStar - Cold Only	Ceiling Fan: Whole-house coverage, 20W	Air Sealing: 10 ACH@50Pa	Attic: Ceiling R-49, Vented	DHW Piping: R-2, Copper	PV System: 4.0 kW	PV System: 5.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	1	X																
1	1		X															
3	11		X	X														
11	60		X		X	X												
15	84		X		X	X	X											
18	104		X		X	X	X	X										
20	119		X	X		X	X	X										
21	121		X			X	X	X	X									
23	122		X			X	X	X	X	X								
28	119		X			X	X	X	X	X	X							
29	115		X			X	X	X	X	X	X	X						
29	112		X			X	X	X		X	X	X	X					
30	110		X			X	X	X		X	X	X	X	X				
50	-105		X			X	X	X		X	X	X	X	X	X			
70	-316		X			X	X	X		X	X	X	X	X		X		
90	-528		X			X	X	X		X	X	X	X	X			X	
110	-740		X			X	X	X		X	X	X	X	X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

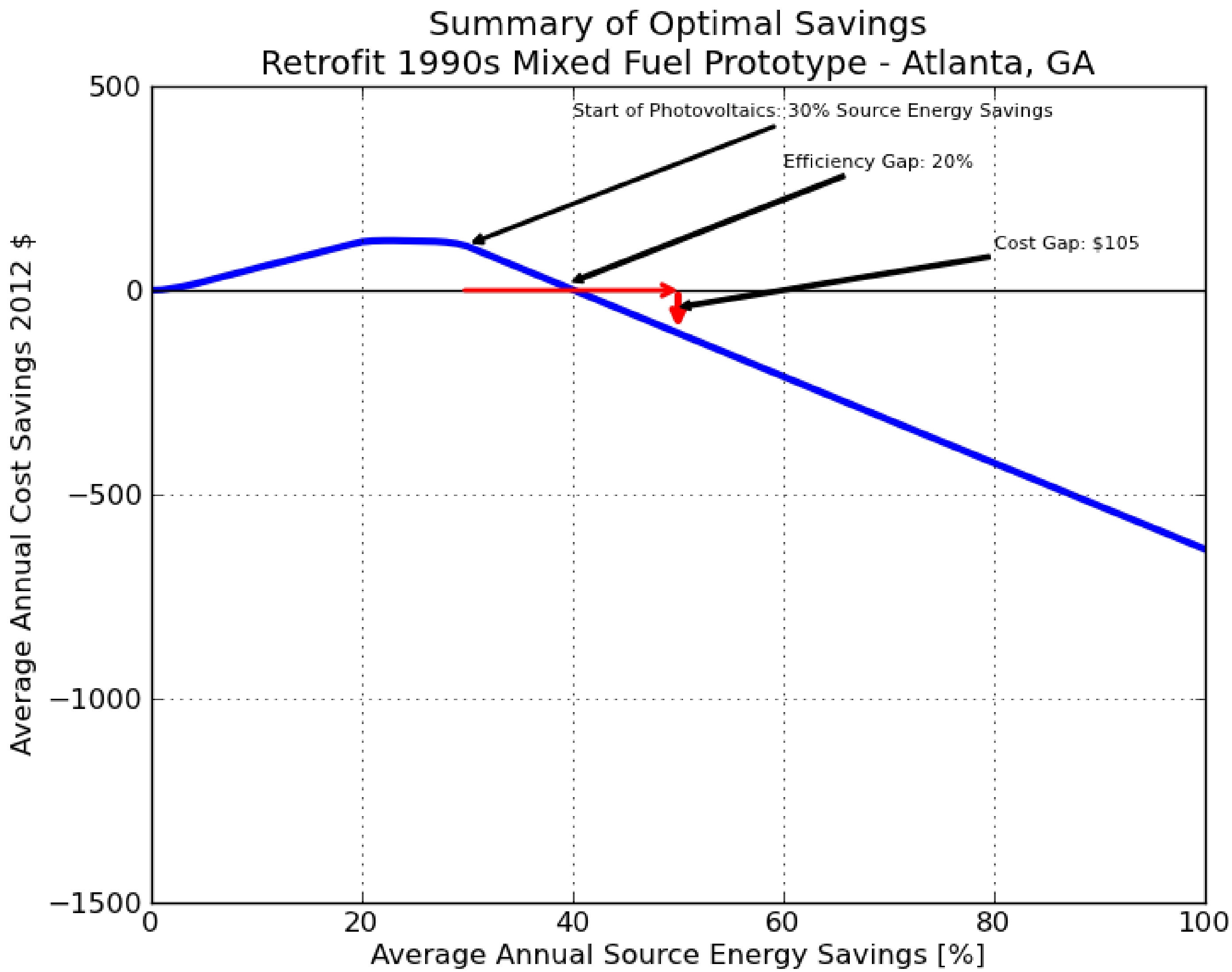

Figure 50. Summary of optimal savings retrofit mixed fuel 1990s prototype—Atlanta

Table 53. ESMPs for Retrofit 1990s Mixed Fuel Prototype—Chicago

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	Lighting: 100% CFL	MHWL: Low-Flow Showers	MHWL: Low-Flow Showers & Sinks	Unfinished Basement: Wall 4ft R5 Rigid	Air Sealing: 10 ACH@50Pa	Attic: Ceiling R-38, Vented	Furnace: Gas, AFUE 78% (68.32 kBtu/hr)	Water Heater: Gas Tankless	Furnace: Gas, AFUE 92.5% (68.32 kBtu/hr)	Clothes Washer: EnergyStar - Cold Only	Attic: Ceiling R-49, Vented	Ducts: Leaky, R6 Insulation	Walls: Drill and Fill to R-13	Unfinished Basement: Wall 4ft R10 Rigid	Ceiling Fan: Whole-house coverage, 20W	Attic: Ceiling R-60, Vented	Windows: 2 Pane (U=0.389, SHGC=0.528)	Ceiling Fan: None	PV System: 4.0 kW	PV System: 5.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	1	X																					
2	3	X	X																				
4	18	X		X																			
8	43	X		X	X																		
11	60	X		X	X	X																	
12	65	X		X	X	X	X																
17	68	X		X	X	X	X	X	X														
23	72	X		X	X	X	X		X	X													
24	69	X		X	X	X	X		X	X	X												
25	67	X		X	X	X			X	X	X	X											
26	63	X		X	X	X	X		X	X	X		X										
27	60	X		X	X	X			X	X	X	X	X										
29	41	X		X	X	X			X	X	X	X	X	X									
30	37	X		X		X			X	X	X	X	X	X	X								
32	15	X		X		X			X	X	X	X	X	X	X	X							
34	-8	X		X		X			X	X	X		X	X	X		X	X	X				
36	-34	X		X		X			X	X	X		X	X	X	X	X	X					
50	-259	X		X		X			X	X	X		X	X	X	X	X	X		X			
64	-471	X		X		X			X	X	X		X	X	X	X	X	X			X		
77	-689	X		X		X			X	X	X		X	X	X	X	X	X				X	
91	-907	X		X		X			X	X	X		X	X	X	X	X	X					X

	30% Energy Savings
	50% Energy Savings

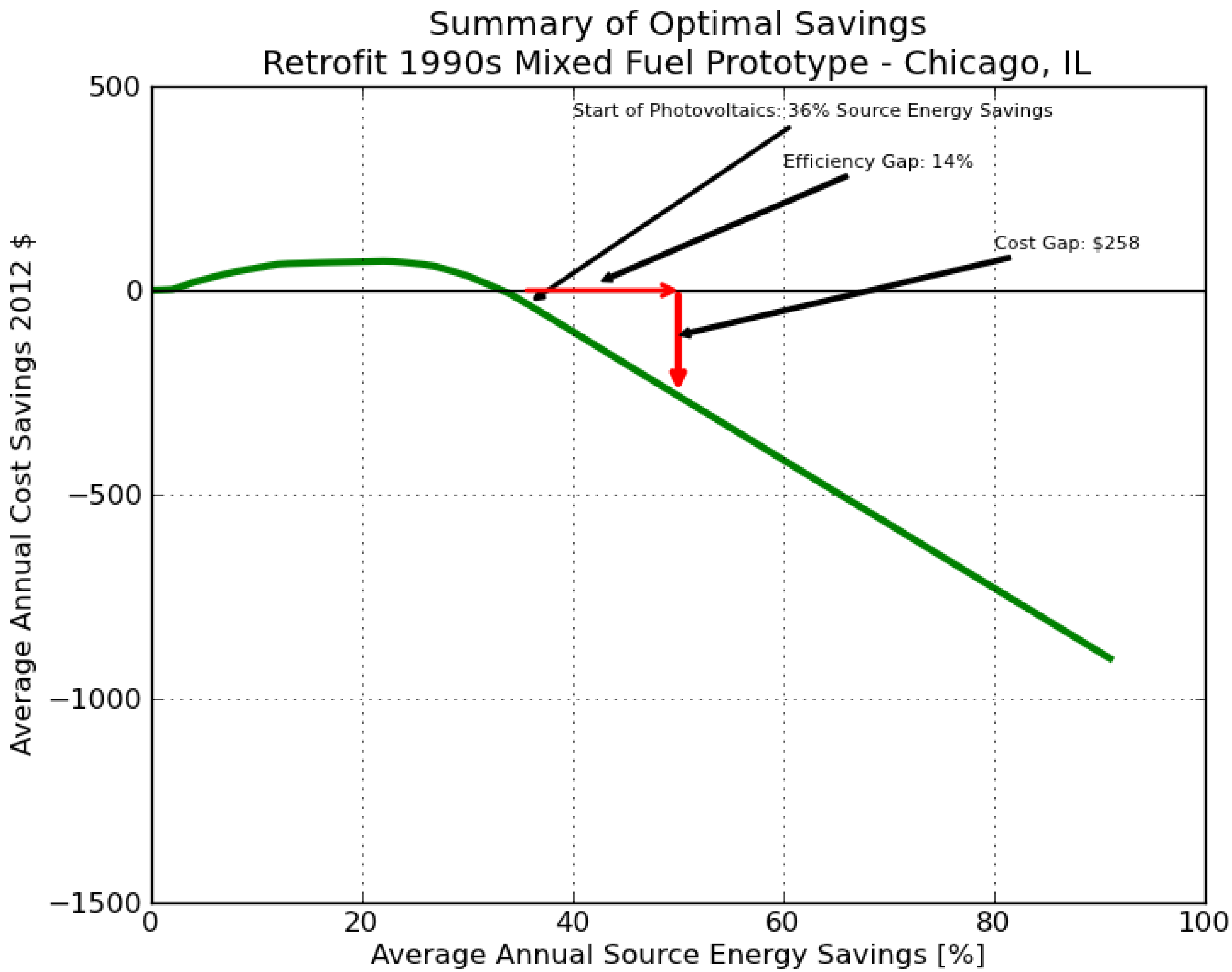

Figure 51. Summary of optimal savings retrofit 1990s mixed fuel prototype—Chicago

Table 54. ESMPs for Retrofit 1990s Mixed Fuel Prototype—Houston

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	Lighting: 100% CFL	MHWL: Low-Flow Showers	MHWL: Low-Flow Showers & Sinks	Ceiling Fan: Whole-house coverage, 20W	Attic: Ceiling R-30, Vented	Water Heater: Gas Tankless	Ducts: Typical, Uninsulated	Attic: Ceiling R-38, Vented	Clothes Washer: EnergyStar - Cold Only	DHW Piping: R-2, Copper	Ducts: Typical, R6 Insulation	PV System: 4.0 kW	PV System: 5.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	1	X														
2	1	X	X													
3	10	X		X												
16	102	X		X	X											
18	109	X		X	X	X										
21	117	X		X	X	X	X									
26	122	X		X	X	X	X	X								
28	115	X		X	X		X	X	X	X						
29	113	X		X	X		X	X	X	X	X					
30	102	X		X	X		X		X	X	X	X				
50	-81	X		X	X		X		X	X	X	X	X			
68	-246	X		X	X		X		X	X	X	X		X		
87	-420	X		X	X		X		X	X	X	X			X	
106	-593	X		X	X		X		X	X	X	X				X

(blue)	30% Energy Savings
(green)	50% Energy Savings

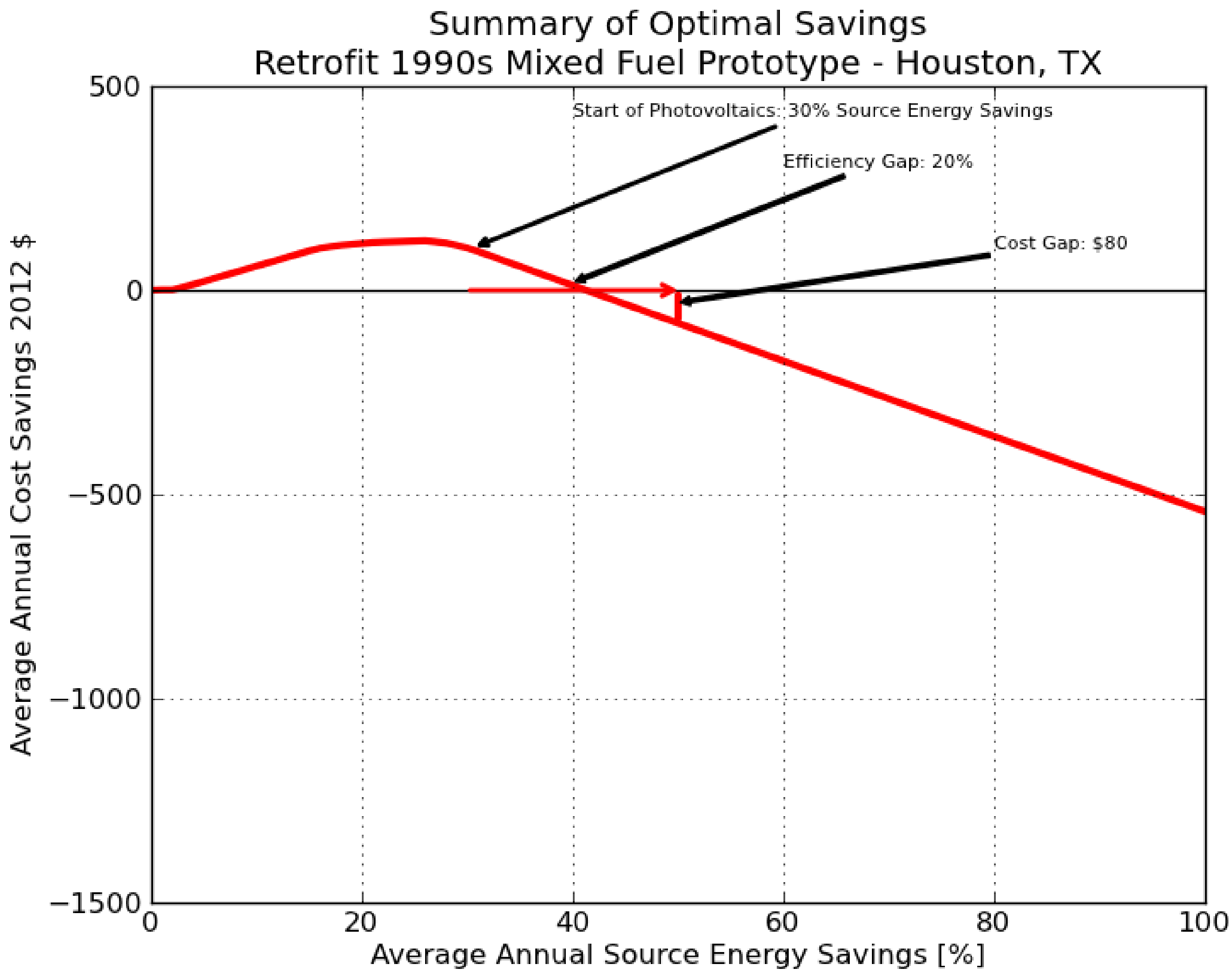

Figure 52. Summary of optimal savings retrofit mixed fuel 1990s prototype—Houston

Table 55. ESMPs for Retrofit 1990s Mixed Fuel Prototype—Phoenix

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Sinks	MHWL: Low-Flow Showers & Sinks	Lighting: 100% CFL	Ceiling Fan: Whole-house coverage, 20W	Attic: Ceiling R-30, Vented	Water Heater: Gas Tankless	Ducts: Typical, Uninsulated	Ducts: Typical, R6 Insulation	Attic: Ceiling R-38, Vented	Clothes Washer: EnergyStar - Cold Only	DHW Piping: R-2, Copper	Windows: 2 Pane (U=0.368, SHGC=0.300)	DHW Piping: Uninsulated	Attic: Ceiling R-49, Vented	PV System: 2.0 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	1	X																	
1	1		X																
2	5		X	X															
14	88		X	X	X														
16	102		X	X	X	X													
19	118		X	X	X	X	X												
26	152		X	X	X	X	X	X											
29	157		X	X	X	X	X		X										
30	157		X	X	X		X		X	X									
31	155		X	X	X		X		X	X	X								
32	153		X	X	X		X		X	X	X	X							
37	130		X	X	X		X		X	X	X		X	X					
37	128		X	X	X		X		X	X	X	X	X						
38	125		X	X	X		X		X		X	X	X		X				
50	12		X	X	X		X		X		X	X	X		X	X			
76	-226		X	X	X		X		X		X	X	X		X		X		
96	-401		X	X	X		X		X		X	X	X		X			X	
115	-575		X	X	X		X		X		X	X	X		X				X

	30% Energy Savings
	50% Energy Savings

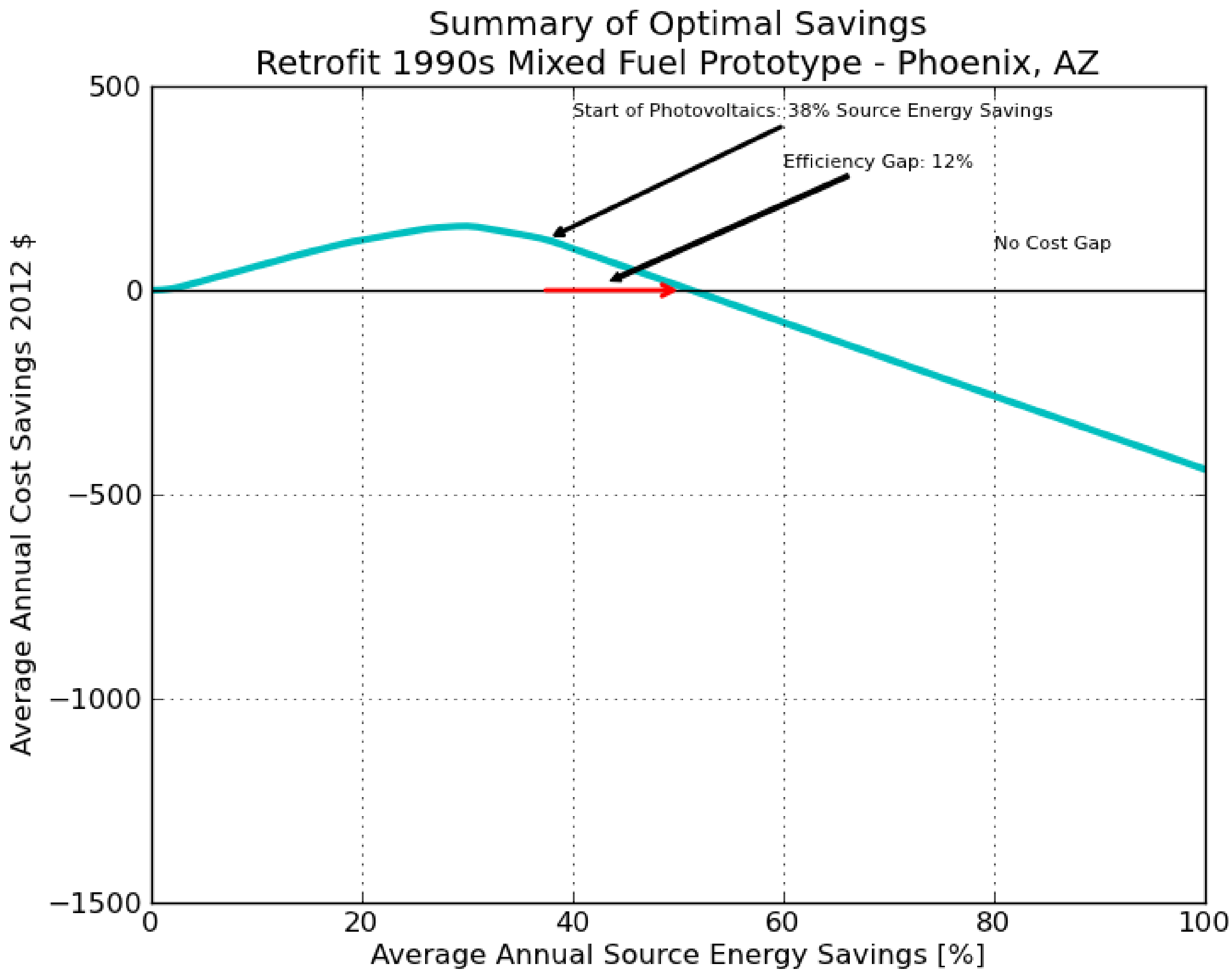

Figure 53. Summary of optimal savings retrofit mixed fuel 1990s prototype—Phoenix

Table 56. ESMPs for Retrofit 1990s Mixed Fuel Prototype—Seattle

Average Source Energy Savings (%)	Average Annual Cost Savings (2012 $)	MHWL: Low-Flow Sinks	MHWL: Low-Flow Showers & Sinks	Crawlspace: Ceiling R13, Vented	Crawlspace: Wall R5 Rigid	Water Heater: Gas Tankless	Lighting: 100% CFL	Crawlspace: Wall R10 Rigid	Attic: Ceiling R-38, Vented	Crawlspace: Wall R15 Rigid	Clothes Washer: EnergyStar - Cold Only	Furnace: Gas, AFUE 92.5% (40.94 kBtu/hr)	Attic: Ceiling R-49, Vented	Air Sealing: 10 ACH@50Pa	Ducts: Leaky, R6 Insulation	Walls: Drill and Fill to R-13	Ducts: Leaky, Uninsulated	Crawlspace: Wall R20 Rigid	Attic: Ceiling R-60, Vented	DHW Piping: R-2, Copper	PV System: 2.0 kW	PV System: 2.5 kW	PV System: 4.0 kW	PV System: 6.0 kW	PV System: 8.0 kW
1	1	X																							
1	1		X																						
5	21		X	X																					
17	109		X		X																				
21	126		X		X	X																			
23	135		X		X	X	X																		
25	138		X			X	X	X																	
26	140		X			X	X	X	X																
26	141		X			X	X		X	X															
28	140		X			X	X		X	X	X														
32	127		X			X	X		X	X	X	X													
33	123		X			X	X			X	X	X	X												
34	115		X			X	X			X	X	X	X	X											
35	100		X			X	X			X	X	X	X	X	X										
36	92		X			X	X			X	X	X	X	X		X	X								
36	88		X			X	X				X	X	X	X		X	X	X							
37	75		X			X	X			X	X	X	X	X	X	X									
38	68		X			X	X			X	X	X		X	X	X			X						
38	64		X			X	X			X	X	X		X	X	X			X	X					
38	59		X			X	X				X	X		X	X	X		X	X	X					
50	-170		X			X	X				X	X		X	X	X		X	X	X	X				
53	-226		X			X	X				X	X		X	X	X		X	X	X		X			
68	-510		X			X	X				X	X		X	X	X		X	X	X			X		
83	-795		X			X	X				X	X		X	X	X		X	X	X				X	
98	-1080		X			X	X				X	X		X	X	X		X	X	X					X

(blue)	30% Energy Savings
(green)	50% Energy Savings

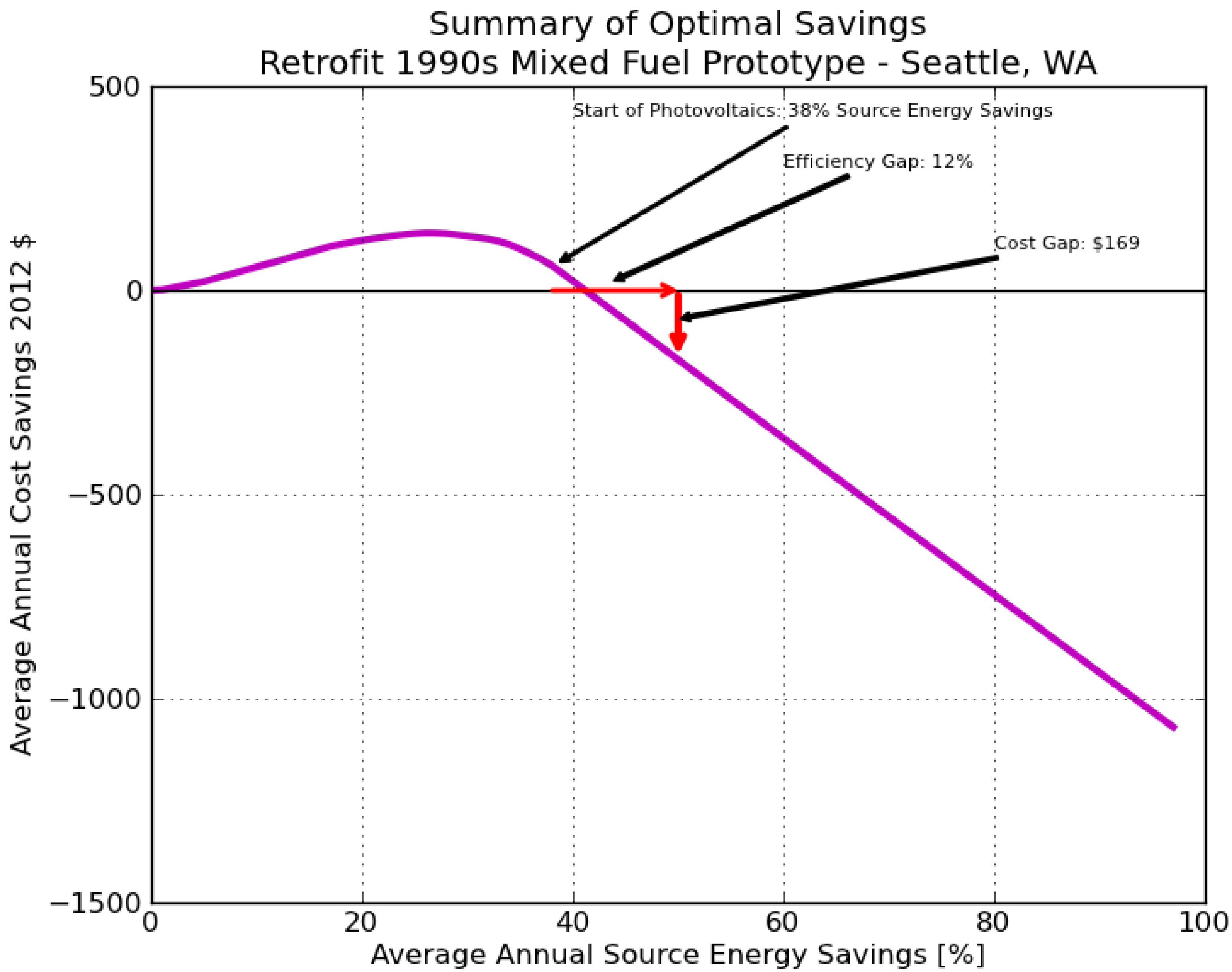

Figure 54. Summary of optimal savings retrofit mixed fuel 1990s prototype—Seattle

Appendix C: Detailed Activities

Key Highlights From Building America Team Research Projects

Table 57 summarizes select highlights from ongoing BA projects. This list is not intended to be comprehensive.

Table 57. Highlights From BA Team Activities

Team	Project Highlight
ARBI	Cottle House: This is the first home in California to be officially certified net-zero energy (HERS index lower than zero) by CalCerts and the California Energy Commission. ARBI supported the design and build process and is conducting whole-building and system-level monitoring, which will continue for at least one year.
ARBI	Hot Water Distribution Modeling: ARBI developed a detailed domestic hot water TRNSYS model, with first calibration efforts focused on laboratory pipe heat loss testing. The results provided a very good match to laboratory data. The model will also be calibrated against high-quality field data collected by NREL. Results will improve our understanding of water heating system performance based on load variations, ultimately informing the development of a comprehensive hot water design guide.
ARBI	Retrofit Delivery: ARBI has focused on developing a performance guarantee as an approach for encouraging homeowner participation in home energy upgrades. Davis Energy Group has been working with Green Home Solutions to offer this as a component of home energy upgrades in Stockton. A calculation method was developed for the energy modeler to complete to determine the heating and cooling savings that can be guaranteed for a specific project. This method uses a spreadsheet that takes BEopt outputs and actual weather and Typical Meteorological Year 3 weather data to make determinations about savings estimations. The pre-retrofit process has been tested with actual utility data. The technique must be validated with available post-retrofit data.
ARBI	Air-to-Water Heat Pumps: Data analysis of winter heating data and 2011 summer cooling data for the air-to-water heat pump at the S.E.E.D. house (Super Energy Efficient Design) and Cana house resulted in development of operational performance curves versus outdoor dry bulb temperature and entering water temperature. The data indicate that power is most sensitive to entering water temperature with little effect from varying outdoor air temperatures. The reverse was observed with capacity; outdoor air temperature had a significant effect on capacity output. The performance curves from S.E.E.D. have been imported into the TRNSYS model and calibration of the heat pump in heating operation is underway.
ARIES	Optimizing Air Distribution Retrofit Strategies in Affordable Housing: After working for nearly a year to identify the best partner, ARIES joined with RHA to evaluate duct sealing strategies in 40 of RHA's affordable attached housing units. The project moved forward rapidly: specifications were developed, contractors were selected, and other preparations were concluded.

Team	Project Highlight
	By the end of March, retrofits and testing were nearly completed in all 40 units. Based on the preliminary findings, RHA plans to seal ducts in 90 additional housing units and is considering a more extensive research project with ARIES in the near future.
ARIES	Fuel Oil Flow Field Measurement Protocol: This project, initiated at the suggestion of the Better Buildings Program, developed and verified an inexpensive and simple method for measuring fuel oil consumption to evaluate the effectiveness of retrofits in existing properties with oil heat. ARIES researchers developed a testing protocol to use burner runtime as a surrogate for oil use. Results showed very good correlation between estimating oil use based on burner runtime and direct measurements of oil volume based on delivery and height in the tank.
ARIES	Hydronic Heating Retrofits for Low-Rise Multifamily Buildings: ARIES is testing multiple control strategies to reduce operational energy use of hydronic heating systems in existing multifamily buildings. Data collection was completed for the first winter and results show that the new control system resulted in space heating energy savings of 12.7%–18%. Total cost saved to date for three buildings is approximately $3,600. For the 2011–2012 heating season, the new control system was implemented in stages, becoming fully functional in all three buildings as of April 2012. Therefore, greater weather-normalized savings are expected in the next heating season.
ARIES	Enclosure Redesign for Manufactured Housing: The advanced enclosure research for factory built housing research effort, started in 2011, continued into Phase 3 with the goals of completing a wall design and developing and testing a salient manufacturing process strategy. The ARIES research team focused on developing an insulative sheathing with batt insulation solution for wall construction by resolving key issues related to design, manufacture, code compliance, and component performance.
BA-PIRC	Hot Water Test Facility: FSEC began the evaluation of ultra high efficiency, hybrid water heating systems during the first quarter of 2012. These systems integrate solar thermal, heat pumps, and natural gas tankless condensate components. Auxiliary heating components of three solar systems were replaced by either heat pump or tankless condensate natural gas to fulfill energy demand; solar renewable energy handles most of the water heating load. These high efficiency systems have been submitted to family realistic hot water draws (NREL/BA schedule). Results indicate that these systems can yield the highest efficiencies ever measured at the side-by-side hot water facility in Cocoa (Central Florida) for the period ending in mid-April 2012. For electric hybrid systems, energy reductions of 72%–81.7% over the baseline reference system have been measured. Natural gas/solar hybrid systems have achieved energy reductions of 71.1%–90.5%.
BA-PIRC	Large Scale Retrofit: Since the fall of 2009 researchers have been working with affordable housing initiatives to identify technical pathways for achieving whole-house energy improvements in existing homes in the hot-humid climate, primarily in Florida. The study involved 100 homes, 70 of

Team	Project Highlight
	which completed the research/retrofit process. The partnering organizations renovated vacant foreclosed homes, most of which needed comprehensive renovations of nonenergy-related improvements such as new bathroom and kitchen fixtures, flooring, and rewiring. Researchers identified and presented a customized set of improvements for each home that were projected to achieve 30% savings; however, partners incorporated the recommendations to differing degrees.
BA-PIRC	Multifamily Retrofit: BA-PIRC's Multifamily deep energy retrofit project at Bay Ridge Gardens in Annapolis is evaluating the cost and performance of a 50% energy savings package. Interim findings indicate that measured space heating energy savings are easily achieving the aggressive savings the team expected with the use of high efficiency hybrid heat pump systems (heat pump with gas furnace backup) and an improved building envelope. The hybrid heat pump systems offer greater system efficiency at milder outdoor temperatures compared to the existing furnace system, and has helped boost energy savings.
BA-PIRC	Pre-Code Retrofit Analysis: The evaluation of cost effectiveness of home energy retrofits in pre-code vintage U.S. homes includes an analytical study examining the opportunities for cost-effective improvements in residential archetypes constructed before 1980 in 14 U.S. cities. These cities are representative of each IECC CZ in the contiguous United States. The principal objectives are to determine the opportunities for cost-effective source energy reductions in a large cohort of existing residential buildings as a function of local climate and energy costs. With favorable economics, older homes can reach performance levels close to zero energy when evaluated on an annual source energy basis. Findings indicate that retrofit financing alternatives and whether equipment requires replacement have a large impact on the achievable energy reductions in these archetypes.
BA-PIRC	SEER 21 AC Units: BA-PIRC completed tabulation and analysis of results for a research task that compares performance of a variable capacity, centrally ducted, SEER 21 heat pump to a standard SEER 13 unit. The study focused on the impact of duct leakage on system performance. Calibrated return leaks and supply leaks were imposed on the FSEC Manufactured Housing Laboratory's attic duct system.
BA-PIRC	Combined Systems: Major water heater manufacturers are now developing or currently marketing pre-engineered forced air combined space and water heating equipment. Modeling shows at least 12% whole-house energy savings from implementing new generation combos, but controlled system comparisons have been lacking and are needed to provide guidance for best practices. Standardized testing for combo systems requires the air handler to be tested against space heating loads and the water heater to be tested separately against water heating loads. The laboratory tests subjected the combined air handler and water heater (combo system) to realistic and coincidental space and domestic hot water loads. The results highlight the attributes of combo technologies that use traditional storage water heaters and

Team	Project Highlight
	tankless water heaters as their thermal engines.
BARA	Clark County Neighborhood Stabilization Program: A successful media event focused on BARA's Las Vegas Retrofit Project (This Old House media partnership). As such, Las Vegas Mayor Carolyn Goodman declared February 22, 2012 Building America Retrofit Alliance Day. Mayor Goodman made the proclamation at a ribbon cutting ceremony unveiling two BA test homes that were renovated through the city's NSP. The project resulted in a city-wide effort to increase energy efficiency through the adoption of BA measures.
BARA	Enhanced Publication Outreach: This project facilitated the establishment of a core partnership between Hanley Wood and the DOE Residential Buildings Program with a core focus on promotion and communications of BA innovations to key audiences through publications, events, and education.
BARA	Cool Energy House: A deep energy remodel was completed as part of the Cool Energy House Project. The house was showcased at the 2012 International Builders Show and included tours and other events. The project attracted significant media coverage by the Scripps Networks, *Qualified Remodeler Magazine*, and *Energy Design Update*.
BARA	Researchers wrote an article for *Home Energy Magazine* that focused on transitioning HVAC contractors to home performance contractors, to be included in the issue of *Home Energy Magazine* featured at the Energy and Environmental Building Alliance 2012 Conference.
BSC	Wyandotte NSP2 Existing Building Retrofit: Results from the first complete houses suggest that the technology package employed (which includes spray foam insulation and insulating sheathing) does meet the specific whole-house water, air, and thermal control performance specification established for this project and the project's affordability goals. The technology specification for the existing NSP2 houses has achieved an estimated 42% reduction in whole-house energy use relative to the BAB.
BSC	Winn Development Retrofit Community: This examines a large-scale renovation project in a 500-unit, 1960s era subsidized urban housing community. The development comprises low-rise structures that have exposed concrete frames with uninsulated masonry infill walls. The project focuses particularly on indoor environmental quality and energy performance. The research focuses on the airflow control and window replacement measures implemented as part of the renovations. The window replacement reduced the nominal conductive loss of the apartment enclosure by approximately 15%; air sealing measures reduced measured air leakage by approximately 40% on average. The full scope of renovation work, which also includes mechanical system upgrades, is expected to achieve energy savings of approximately 30% relative to existing conditions.
BSC	External Insulation of Masonry and Framed Walls: Exterior insulation effectively increases the overall thermal resistance of wall assemblies, improves water management, and often increases airtightness. However, the engineering basis and support for this work had not been conducted, resulting in obstacles for building official and building code acceptance. Additionally,

Team	Project Highlight
	the water management and integration of window systems, door systems, decks, balconies, and roof-wall intersections had not been adequately developed. This gap stands in the way of wider deployment. This research project developed baseline engineering analysis to support the installation of thick layers of exterior insulation (2–8 in.) on existing masonry and wood-framed walls through the use of wood furring strips (fastened through the insulation back to the structure) as a cladding attachment location. Water management details necessary to connect the exterior insulated wall assemblies to roofs, balconies, decks, and windows were created to provide guidance on the integration of exterior insulation strategies with other enclosure elements.
BSC	Masonry Over-Clad: Work began on the two masonry over-clad projects that are the subject of research collaboration between BSC and CEDA Weatherization. One involves a two-family masonry building; the other involves an 84-unit (single-room occupancy) multifamily building. Each project involves the installation of exterior insulation and new cladding on side elevations of existing masonry buildings. Implementation involves self-adhered membranes for window flashing and for airflow control transition between the roof and walls. Fiber cement cladding for the two-family structure is lapped siding. For the larger multifamily structure, the cladding consists of fiber cement panels (4 × 8 sheets).
BSC	Mini-Split Heat Pump and Thermal Distribution: Beginning in 2012, Transformations, Inc. decided to experiment with placing only one 1-ton mini-split heat pump in its smaller, two-bedroom houses, rather than the two 1-ton units, which has been its standard practice. BSC selected two of these houses for monitoring. During the first summer of occupancy, the builder received comfort complaints, which convinced him to add a 1-ton mini-split on the second floor of each house. In May of 2012, data loggers were installed in two two-bedroom homes in the Easthampton development. One is occupied. In each home, the energy drawn by the mini-split is logged on a 5-minute interval. Temperature/RH data loggers were placed in each bedroom and in common areas. The temperature and RH in each room are logged on a 30-minute interval. Because these homes are occupied or soon to be occupied, data loggers were also placed on the bedroom doors to record when they are closed.
BSC	Moisture Monitoring: Data were collected from the double stud wall moisture content monitoring project for roughly seven months (December 2011 through June 2012); this captures data from the building's first winter (albeit unoccupied conditions) through spring and early summer. The wall assemblies being compared are pairs of north- and south-facing walls. The wintertime data for the open cell foam walls and the cellulose show the expected increase in wintertime sheathing moisture contents; the open cell foam wall (N1) showed a peak wintertime sheathing moisture content near 12%–15%; the 12-in. cellulose wall (N2) showed considerably higher moisture contents, in the 25%–28% range. The moisture contents for all walls

Team	Project Highlight
	fell during the spring and summer as outdoor temperatures rose; all three walls dried to roughly the same range (8%–10%).
BSC	UT-Tyler: The 1,450-ft^2 twin lab houses at UT-Tyler offer a unique opportunity to directly compare nearly identical homes (except one has a vented attic and the other has an unvented attic assembly, also known as sealed cathedralized attic). Different ventilation strategies will be investigated and the airflow regimes of both houses will be carefully characterized.
CARB	Air Leakage in Attached Dwellings: CARB held an expert meeting on Determining Air Leakage Rates and Envelope Leakage in Attached Dwellings at the 2012 Affordable Comfort, Inc. National Home Performance Conference. This meeting was well attended and CARB is coordinating with interested parties to obtain field testing data. CARB plans to compare unguarded to whole-building or guarded test results and determine the relative magnitude of leakage from interior and exterior sources. From these data, the goal is to identify, if viable, an algorithm to inform a meaningful standard for the total leakage test.
CARB	Heat Pump Water Heaters: Field monitoring is complete and all monitoring equipment has been removed from the 14 test homes in the Northeast. CARB is also actively participating in the Northeast HPWH Advisory Committee to help guide proper adoption of this technology in cold climates. Steven Winter Associates has worked with several utility companies in the Northeast to develop a quality installation guide and an informational trifold for consumers. One key gap in current research is the space conditioning impact of these units. CARB has begun monitoring an HPWH in Orlando. This unit has more extensive monitoring (additional temperature/RH sensors and condensate measurement) to enhance our understanding of the space conditioning impacts of this technology. CARB has been using this research to work on an HPWH performance model for various HPWH units. CARB has also been working with NREL to better understand how HPWHs are being modeled in BEopt.
CARB	Cool Energy House: A report described the moderate retrofit of an all-electric 1990s spec home in the hot-humid climate of Orlando that was showcased at the NAHB International Builder Show in February. This retrofit achieved 48% whole-house energy savings and was minimally intrusive to the home's envelope. The retrofit included additional blown-in insulation to exterior walls, insulating the roof deck to bring ducts and equipment into conditioned space, addition of a whole-house dehumidification system (which also provides fresh air ventilation), and energy efficient replacements of air source heat pumps, windows, lighting, and water heaters. Even though this was not an intrusive retrofit (minimal impact to interior finishes), the overall building infiltration was reduced by 20% to 4.8 ACH50. In addition to applying mastic to ductwork where accessible, the attic was converted to an unvented attic. This resulted in duct leakage to outside being reduced to only 2.5%. Initial results from field monitoring of the whole-house dehumidifier show roughly 50 pints/day being extracted by the unit, along with the supplemental

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	dehumidification of the two central air conditioning systems, to maintain interior RH levels at 55%.
CARB	WUFI Modeling: CARB is actively involved in a research effort to validate modeling results from WUFI for wall construction types that are becoming increasingly popular: code minimum walls using hybrid insulation strategies; high R-value walls at least 12 in. thick; brick walls with interior insulation. Extensive review of existing research resulted in a focused research effort and led to collaboration between known moisture experts from Oak Ridge National Laboratory, BSC, Owens Corning, the Spray Foam Alliance, and the ASHRAE Standard 160 committee.
IBACOS	Mixed-Dry Climate Unoccupied Test House: Construction was completed for the Fresno, California New Construction Unoccupied Test House. Brief specifications include R-60 attic, R-29 wall, R-10 slab edge insulation, and U-0.16 windows. The test HVAC system was installed and commissioned. The system consists of a central ducted air hander unit installed in the living/kitchen area with ductwork routed in conditioned space to each individual room but incorporating remote-controlled dampers that allow the ductwork to be disabled so different sections of the house can be nonactively conditioned. The ductwork is disabled so the effectiveness of high and low through-the-wall transfer grilles and through-the-wall transfer fans can be studied. After completion, discussions with NREL and the project partners resulted in substantial revisions to the originally envisioned instrumentation and testing strategy.
IBACOS	Multi-Climate Military Housing: Lend Lease has been sharing its current data structures for managing its approximate 40,000-unit military housing portfolio. These include a property management database that captures some characteristics of the housing and occupants, a geographic information system database that captures physical attributes of the houses, and a utility usage database that captures information on actual utility consumption. Utility data are primarily electricity consumption; some meters collect data at 15-minute intervals. IBACOS worked with NREL to understand how this information could be aggregated to perform predictive modeling on housing units, which could help support broad BA community-scale retrofit goals. Long-term analysis of actual energy savings based on utility bills for one neighborhood where Lend Lease will be undertaking retrofits will help validate the model.
IBACOS	Cold Climate Space Conditioning Implications for Advanced Enclosure Upgrades: IBACOS hosted a strategic planning meeting with manufacturers, contractors, and New York State Energy Research and Development Authority representatives in April. During that meeting, details for construction of both the rigid foam and spray foam retrofits were discussed. It was decided that mockups of new construction details will be done at the facility of project partner GreenHomes America in Syracuse, New York. IBACOS and GreenHomes America have worked together to finalize the details, pricing, material information, and overall energy modeling for each retrofit solution.

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IBACOS	Simplified Space Conditioning Strategies in Unoccupied Test Houses (Both NC and EX): Review of wintertime results from the Pittsburgh, Pennsylvania, new construction unoccupied test house has revealed that all systems—the two experimental systems and the conventional system—allow substantial (10°–15°F) solar heat gain-related temperature drift in the south- and west-facing bedrooms when the interior partition doors are closed. This occurs because the interior partition door in all cases prevents communication from the bedrooms receiving solar heat gain to the thermostat. This finding will influence the summertime operation of the house and raises the larger question of how door position (open or closed) in occupied houses influences occupant comfort.
IBACOS	Hot-Humid Climate Occupied Test House (NC): IBACOS has employed an alternative space conditioning design strategy for the HVAC system in this Task 3 occupied test house using distributed air handlers (mini-split heat pumps). The basic design consists of a single outdoor compressor unit and four indoor units. Three indoor units are located on the first floor, and one unit is centrally located on the second floor. To help distribute conditioned air to all thermal zones, passive and fan-assisted through-wall transfer grilles are included in the design and are located between all bedrooms, the office, and the adjacent hallways. To further distribute conditioned air and to provide fresh air to the living space, an energy recovery ventilator was included in the design and will exhaust air from all bathrooms and the kitchen while supplying fresh air to a central diffuser on the second floor. During the initial calculations of space conditioning loads, IBACOS identified the need for supplemental heating above the capacity of the mini-split heat pumps. By performing additional load calculations, IBACOS determined that supplemental heating would be unnecessary if a minimum of R-5 insulation were installed on the exposed edge of the monolithic slab foundation. Discussions with the builder, who wanted to avoid the additional installation of space heaters, led to the exploration of several options for insulating the slab, including insulating concrete block, insulating concrete forms (ICFs), and rigid foam fastened to the exterior or interior of the stem walls. Of special consideration in determining the final solution for this detail was the large amount of exposed slab edge that was necessary because of the topography. With approximately 2,000 ft^2 of exposed slab edge, cost was a major factor in the decision to move forward with 1 in. (R-5) of extruded polystyrene installed on the exterior of the stem wall.
NAHB-RC	Expert Meeting—Key Innovations for Adding Energy Efficiency to Maintenance Projects: Key outcomes from the expert meeting included general agreement that adding energy efficiency to maintenance projects (e.g., in conjunction with roof replacement) is a real and timely opportunity for companies that specialize in common larger maintenance activities. This is technically achievable for the contractor and more affordable for the homeowner. The energy efficiency value added can result in additional profit centers for the companies and cost savings and better long-term performance

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	for the homeowner. These additional homeowner benefits are often overlooked in many re-roofing projects. This approach can easily be extended to other major maintenance and remodeling projects to address the needs within the energy retrofit industry.
NAHB-RC	High-R Wall Systems: The efforts focus on developing approaches for high-R walls for existing homes. Specifically, the research includes wall moisture field testing. In response to an emerging performance issue in some more efficient homes, NAHB-RC continues to investigate the moisture characteristics at the structural wood sheathing in new home construction in the Midwest. As part of the NCTH project in CZ 4, higher R-value walls (2 × 6 construction with at least R-23 fiberglass and a house infiltration rate less than 3 ACH50) have been instrumented with moisture sensors at the sheathing location. The sensor data stream has been initiated and will be added to the database of higher R-value wall moisture performance.
NAHB-RC	Nexus EnergyHomes: An affordable infill project in the mixed-humid climate, the attached single-family home goals are to achieve energy use reductions of more than 50%, and ultimately net-zero electricity use of builder-provided features when renewables are included (excluding miscellaneous electrical loads).
NAHB-RC	Greenbelt Homes: The 28 pilot homes in this existing home cooperative are currently being monitored for baseline energy use and BEopt models were developed to estimate energy savings for various levels of investment to select the most cost-effective solutions to upgrade the building envelopes.
NAHB-RC	Winchester/Camberley Homes New Construction Test House: The primary goal of the NCTH is to develop and standardize a high performance home that meets the BA program energy performance metrics using approaches that provide the builder with design flexibility, affordable technological solutions, and consistent and reliable results. Features include advanced framing and structural approaches to significantly improve the thermal performance of the wall systems; an integrated approach to wall insulation and air sealing to achieve U-values that are improved by at least one third over the 2009 IECC; a comprehensive air sealing approach seeks to achieve infiltration rates that are less than half that of typical homes, but much more reliable and consistent for the trades contractors and builder; ducts located in conditioned space, minimized duct runs, and duct sealing; and a robust HVAC system to supply conditioned air to all three above-grade stories.
NAHB-RC	Lancaster County Career & Technology Center: This single-story house with a full basement is an ICF design. Unlike the previous two projects that used a ground source heat pump, this house will be heated using a high efficiency heat pump. During 2011, the Research Center performed a Manual J load calculation and provided a preliminary HVAC duct system layout. In January 2012, the Research Center prepared estimated annual equipment operating cost comparison to finalize the HVAC equipment selection. Foundation footers and ICF walls were installed in November 2011. Floor and roof framing were installed during February and March 2012. Windows and

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	roofing were installed in May. The Research Center conducted an on-site final air sealing and mechanical design review in May, and provided an updated Manual D and final heat pump and ventilation specifications.
NorthernSTAR	Energy Audit Assessment & Data Set: Data sets aggregated for approximately 186 homes where a Home Energy Rating and Energy Advocate review were completed in the WPS Community Pilot Home Retrofit Program in Allouez, Wisconsin. Data sets include REM/Rate building file, ancillary data including refrigerator and freezer consumption data (where available), building diagram, and at least 12 months historical energy use. The initial data set of 150 homes was exceeded to allow for exclusion where obvious inconsistencies or gaps in data are noted.
NorthernSTAR	Model Retrofit Deliver System: Nine program designs offered in Wisconsin for single-family home energy efficiency improvements will be compared. The programs vary in the following critical aspects of delivery: homeowner recruitment, auditor approach, contractor approach, use of energy advocates, and incentive strategy. Background information for each program design is nearing completion. Staff are gathering data about number of completed measures and budget allocations for each Retrofit Delivery System. This will allow for a quantitative evaluation of each program design with respect to MMBtu savings per home, program costs, and identifying the most cost-effective home retrofit delivery mechanisms.
NorthernSTAR	Foundation Wall Insulation Hygrothermal Testing: NorthernSTAR plans to add two more foundation test systems to the two systems currently being installed (referred to as the “base” systems) as part of the overall experimental program. The first will be the same as the existing test system, except that the adhered water separation plane (WSP) will be replaced with a nonadhered WSP. Bulk water will be introduced into the cavity between the wall and the WSP to assess the hygrothermal impacts of water leakage. The wall will be instrumented to the same level as that of the base systems to measure the differences in structural wall system moisture phenomenology and compliance with the hygrothermal performance criteria (Minnesota Statutes 2012 Energy Code, in preparation) between retrofit foundation wall insulation systems with adhered and nonadhered WSPs. However, the first test system wall will be in contact with the naturally wetted native soils and no soil wetting system will be installed. The second test system will evaluate partial wall exterior insulation compatible with the “excavationless” foundation insulation strategy being studied in another project. A 4-ft wide sheet of 3-in. thick extruded polystyrene (in compliance with the 2012 IECC) will be installed from the top of the wall to 38 in. below grade. An interior adhered WSP will be installed as in the base systems. This insulation system will be less intensely instrumented, with a focus on measuring the thermal impacts of the partial exterior wall insulation system relative to the interior full-wall insulation systems installed on the other test bays. Moisture measurements will focus on structural wall system exterior to the WSP and will be at the same level as those of the base systems. Again, this test system will be in

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	contact with the naturally wetted native soil and no soil wetting system will be installed. Thus the final composite TO-3 experiment will embrace three foundation retrofit wall insulation strategies and will capture the bulk water conditions that can be expected in retrofitting basement walls with insulation in CZs 6 and 7.
PARR	CNT Energy: PARR, through CNT Energy, oversaw the installation of steam balancing measures in the 10 test buildings, including construction oversight to ensure quality work and installations. PARR is conducting the project to identify best practices, typical costs, and energy savings associated with steam system balancing, an important (yet not currently well-defined or widespread) efficiency opportunity for centrally steam-heated buildings. Post-measure follow-up visits were conducted to collect temperature data and boiler runtime data. A tenant survey was also administered during these visits. Calculations thus far show that the steam balancing measures will save approximately 14% of the natural gas used for heating annually (and can improve tenant comfort) in the test buildings.
PARR	Chicagoland Single Family Housing Characterization: This project evaluated 432,605 houses representing approximately 30% of the single family detached buildings in the region using assessor data for house description and utility data for actual energy consumption. The report documents a replicable methodology for characterizing single-family housing stock and identifies three housing characteristics (structural, vintage, and size) that have the greatest impact on energy use in the region's single family homes. It also sorts the buildings into 15 separate groups with similar characteristics and proposes measure packages that have the greatest potential for energy savings. Based on the results of a BEopt analysis, the project identifies the three groups that provide the maximum energy savings potential as defined by annual source energy savings multiplied by the total number of houses in the sample population. The savings range for the three groups is 20%–28% of source energy. 1. Wood-frame pre-1942 construction 1 to 1½ stories 2. Brick (double-brick) pre-1942 construction 1 to 1½ stories 3. Wood-frame 1942–1978 construction 1 to 1½ stories These groups will be used in the next step to evaluate the measure packages.
PARR	Combustion Safety Expert Meeting: Larry Brand conducted this expert meeting with participation from NREL, Lawrence Berkeley National Laboratory, ASHRAE Committee members, PARR members, codes and standards participants, and researchers. Combustion safety is a critical issue for retrofitting buildings for energy efficiency. The codes must be carefully followed and factors contributing to depressurization must be carefully considered before retrofit measures are implemented. The key research questions discussed at the meeting will help inform future research.

Summary of Key Building America Team Publications in FY 2012

Table 58. Summary of BA Team Publications in FY 2012

Publication	Author	URL	Published
Measure Guideline: Evaporative Condensers ***Summary:*** This measure guideline provides information on properly designing, installing, and maintaining evaporative condenser systems, as well as understanding the benefits, costs, and tradeoffs.	ARBI	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_evap_condensers.pdf	4/2012
Measure Guideline: Ventilation Cooling ***Summary:*** This measure guideline provides information on a cost-effective solution for reducing cooling system energy and demand in homes located in hot-dry and cold-dry climates.	ARBI	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_vent_cooling.pdf	4/2012
A Feasibility Study: Ductless Hydronic Distribution Systems with Fan Coil Delivery ***Summary***: The primary goals of this study are to estimate potential energy savings relative to conventional ducted air distribution, and to identify equipment requirements, costs, and barriers with a focus on ductless hydronic delivery systems that use water-to-air terminal units in each zone. Results indicate that annual heating and cooling energy use can be reduced by up to 27%, assuming replacement of the conventional 13 SEER heat pump and coil with a similarly rated air-to-water heat pump.	ARBI	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ductless_hydronic_dist.pdf	8/2012
Strategy Guideline: Proper Water Heater Selection ***Summary***: This strategy guideline provides step-by-step procedures for evaluating preferred cost-effective options for energy-efficient water heater alternatives based on local utility rates, climate, and anticipated loads.	ARBI	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/strategy_guide_water_heater.pdf	8/2012
Expert Meeting Report: Hydronic Heating in Multifamily Buildings ***Summary:*** This expert meeting was presented by the ARIES Collaborative, and discussed cost-effective controls and distribution retrofit options for hot water and steam space heating systems in multifamily buildings. The goals were to reduce energy waste and improve occupant comfort.	ARIES	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/expt_mtg_hydronic.pdf	10/2011
Expert Meeting Report: Advanced Envelope Research for Factory Built Housing ***Summary:*** This report provides information about the BA expert meeting on advanced envelope research for factory built housing, hosted by the ARIES Collaborative on October 11, 2011, in Phoenix, Arizona. The goals were to provide a comprehensive solution to the use of three previously selected advanced alternatives for factory built wall construction, assess each option focusing on major issues relating to viability and commercial potential, and determine additional steps that are required to reach this potential.	ARIES	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/expt_mtg_adv_envelope.pdf	4/2012
Hydronic Heating Retrofits for Low-Rise Multifamily Buildings ***Summary:*** The ARIES Collaborative partnered with NeighborWorks America affiliate Homeowners' Rehab Inc. of Cambridge, Massachusetts, to implement and study improvements to the heating system in one of the nonprofit's housing developments. The heating control systems in the 42-unit Columbia CAST housing development were upgraded in an effort projected to reduce heating costs by 15%–25%.	ARIES	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/hydronic_heating_multifamily.pdf	5/2012

Publication	Author	URL	Published
Energy Savings and Peak Demand Reduction of a SEER 21 Heat Pump vs. a SEER 13 Heat Pump with Attic and Indoor Duct Systems ***Summary***: This report describes results of experiments that were conducted in an unoccupied 1,600-ft^2 house—the Manufactured Housing at FSEC—to evaluate the delivered and relative performance of a SEER 21 variable capacity heat pump versus a SEER 13 heat pump. The performance was evaluated with a standard attic duct system and an indoor duct system located in a dropped-ceiling space.	BA-PIRC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/energy_savings_heat_pumps.pdf	12/2011
Achieving Very High Efficiency and Net Zero Energy in an Existing Home in a Hot-Humid Climate: Long-Term Utility and Preliminary Monitoring Data ***Summary:*** This study summarizes the first six months of detailed data collected on a single-family home that experienced a series of retrofits targeting reductions in energy use. The project was designed to develop data on how envelope modifications and renewable measures can result in considerable energy reductions and potentially net-zero energy for an existing home. Using utility billing records and recent detailed monitoring data, this study was also able to chronicle the progress of energy reduction over a 22-year period.	BA-PIRC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/net_zero_hot_humid_data.pdf	2/2012
Measure Guideline: Managing the Drivers of Air Flow and Water Vapor Transport in Existing Single-Family Homes ***Summary:*** This guideline focuses on managing the driving forces that move air and moisture across the building envelope (and in the home), as well as ways to control air infiltration, keep RH within acceptable limits, avoid combustion safety problems, improve occupant comfort, and reduce house energy use.	BA-PIRC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_airflow_water_vapor.pdf	2/2012
Measure Guideline: Summary of Interior Ducts in New Construction, Including an Efficient, Affordable Method to Install Fur-Down Interior Ducts ***Summary:*** This guideline illustrates guidelines for the efficient installation of interior duct systems in new housing, including the fur-up chase method, the fur-down chase method, and interior ducts positioned in sealed attics or sealed crawlspaces.	BA-PIRC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_ducts_new_con.pdf	4/2012
Residential Energy Efficiency Research Planning Meeting Summary Report—Washington, D.C.: October 28–29, 2001 ***Summary:*** This report summarizes key findings and outcomes from the BA Residential Energy Efficiency Research Planning meeting, held on October 28–29, 2011, in Washington, D.C.	BARA	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ee_research_planning_mtg.pdf	2/2012
Building America Spring 2012 Stakeholder Meeting Report—Austin, Texas: February 29–March 2, 2012 ***Summary:*** The BA Spring 2012 Stakeholder Meeting was held on February 29–March 2, 2012, in Austin, Texas, and outlined stakeholder needs, collaboration opportunities, and research results as they relate to DOE's Residential Buildings Program. Presenters represented key industry stakeholders, as well as the 10 DOE BA teams. Attendees represented a variety of industries, including manufacturing, government, nonprofit, and private sector programs.	BARA	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/spring2012_stakeholder_mtg.pdf	5/2012
Expert Meeting Report: Transforming Existing Buildings	BARA	http://apps1.eere.energy.go	5/2012

Publication	Author	URL	Published
through New Media - An Idea Exchange ***Summary:*** This report describes results of a BA expert meeting on September 13, 2011, in Las Vegas, Nevada, hosted by BARA. This meeting provided a forum for presentations and discussions on the use of new media to work with remodelers and retrofit projects to improve energy efficiency and deliver research results from the BA program to remodelers.		v/buildings/publications/pdfs/building_america/expt_mtg_idea_exchange.pdf	
Measure Guideline: Replacing Single-Speed Pool Pumps with Variable Speed Pumps for Energy Savings ***Summary:*** This measure guideline evaluates potential energy savings by replacing traditional single-speed pool pumps with variable speed pool pumps, and provides a basic cost comparison between continued uses of traditional pumps verses new pumps. A simple step-by-step process for inspecting the pool area and installing a new pool pump follows.	BARA	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_pool_pump.pdf	5/2012
Laboratory Testing of Aerosol for Enclosure Air Sealing ***Summary:*** This report presents a process for improving the airtightness of a building envelope by sealing shell leaks with an aerosol sealing technology. Retrofit and new construction applications are possible by applying this process in either attics and crawlspaces or during the rough-in stage.	BIRA	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/test_aerosol_airsealing.pdf	6/2012
The Role of Appraisals in Energy Efficiency Financing ***Summary:*** This report identifies barriers and challenges and current industry status, including several key appraisal industry developments for identifying and valuing energy efficiency. The report covers critical obstacles to documenting and assessing the potential added value from energy efficiency improvements, current opportunities to support and standardize reporting on energy efficiency and to ensure proper valuation, and next steps toward enabling energy efficiency financing market transformation.	BIRA	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/appraisals_ee_financing.pdf	6/2012
Reaching for High Performance in Existing Homes – A Cold Climate Study With Synergy Construction ***Summary:*** Two test homes located in Millbury and Somerville, Massachusetts, are examined with the goal of providing case studies that could be applied to other similar New England homes. The retrofit process for the enclosure and mechanical systems are examined in detail and the decision-making process is discussed.	BSC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/cold_climate_synergy.pdf	12/2011
Strategy Guideline: Advanced Construction Documentation Recommendations for High Performance Homes ***Summary:*** As whole-house energy efficiency increases, new materials and new systems require greater coordination and communication between industry stakeholders. This report presents four changes that are recommended to achieve improvements in energy efficiency, durability and health in BA houses: create coordination drawings, improve specifications, improve detail drawings, and review drawings and prepare a quality control plan.	BSC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/strat_guide_constr_doc.pdf	12/2011
Expert Meeting Report: Interior Insulation Retrofit of Mass Masonry Wall Assemblies ***Summary:*** BSC held an expert meeting on Interior Insulation	BSC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/expt_	3/2012

Publication	Author	URL	Published
Retrofit of Mass Masonry Wall Assemblies on July 30, 2011, in Westford, Massachusetts. This report outlines the extensive information that was presented on assessing risk factors for premature building deterioration caused by interior insulation retrofits, and methods to reduce such risks.		mtg_mass_masonry.pdf	
National Grid Deep Energy Retrofit Pilot ***Summary:*** Through discussion of five case studies (test homes), this project evaluates strategies to elevate the performance of existing homes to a level commensurate with best-in-class implementation of high performance new construction homes. The test homes featured in this research activity participated in the Deep Energy Retrofit Pilot Program sponsored by the electric and gas utility National Grid in Massachusetts and Rhode Island. Building enclosure retrofit strategies are evaluated for impact on durability and indoor air quality in addition to energy performance.	BSC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/national_grid_retrofit.pdf	3/2012
Leveraging Limited Scope for Maximum Benefit in Occupied Renovation of Uninsulated Cold Multifamily Housing ***Summary:*** This project examines a large-scale renovation project in a 500-unit, 1960s era subsidized urban housing community. The research focuses on the airflow control and window replacement measures implemented as part of the renovations to the low-rise apartment buildings. The window replacement reduced the nominal conductive loss of the apartment enclosure by approximately 15%; air sealing measures reduced measured air leakage by approximately 40% on average.	BSC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/renovation_uninsul_multifamily.pdf	4/2012
Water Management of Noninsulating and Insulating Sheathings ***Summary:*** There is an increasing market in liquid (or fluid) applied water management barriers for residential applications that could be used in place of tapes and other self-adhering membranes if applied correctly, especially around penetrations in the enclosure. This report discusses current best practices, recommends ways in which the best practices can be improved, and looks at some current laboratory testing and testing standards.	BSC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/water_mgmt_sheathings.pdf	5/2012
Measure Guideline: Hybrid Foundation Insulation Retrofits ***Summary:*** This measure guideline provides recommendations for designs and variations for retrofit hybrid assemblies in improving interior foundation insulation and water management of basements. Variations include closed cell spray foam with membrane waterproofing or air gap membrane drainage layers, rigid board foam insulation at flat walls (cast concrete or concrete masonry unit block), a "partial drainage" detail making use of the bulk water drainage that occurs through the field of a rubble stone wall, and nondrained spray foam assemblies (including slab insulation).	BSC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_hybrid_found.pdf	5/2012
Attic or Roof? An Evaluation of Two Advanced Weatherization Packages ***Summary***: This project examines implementation of advanced retrofit measures in the context of a large-scale weatherization program and the archetypal Chicago brick bungalow. By	BSC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/adv_weather_packages.pdf	7/2012

Publication	Author	URL	Published
implementing the retrofit strategies in eight test homes, researchers found that the two strategies achieve similar reductions in air leakage measurement and predicted energy performance relative to the pre-retrofit conditions.			
Measure Guideline: Internal Insulation of Masonry Walls ***Summary***: This measure guideline provides recommendations for interior insulation assemblies that control interstitial condensation and durability risks; recommendations for acceptable thermal performance are also provided. An illustrated guide of high-risk exterior details (which concentrate bulk water), and recommended remediation details are provided, followed by a recommended methodology for assessing the risks associated with a masonry interior insulation project.	BSC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_masonry.pdf	7/1/2012
Expert Meeting Report: Recommendations for Applying Water Heaters in Combination Space and Domestic Water Heating Systems ***Summary***: This expert meeting centered on the design, performance, and maintenance of these combination water heating systems. The goal was to develop a BA measure guideline.	BSC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/expt_mtg_combi_systems.pdf	8/2012
Measure Guideline: Combination Forced-Air Space and Tankless Domestic Hot Water Heating Systems ***Summary:*** This document describes design and application guidance for combination space and tankless domestic hot water heating systems (combination systems) used in residential buildings, based on field evaluation, testing, and industry meetings conducted by BSC. As residential building enclosure improvements continue to drive heating loads down, using the same water heating equipment for both space heating and domestic water heating becomes attractive from an initial cost and space-saving perspective. This topic is applicable to new and retrofitte single—and multi-family residential buildings.	BSC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_combi_systems.pdf	8/2012
Proven Performance of Seven Cold Climate Deep Retrofit Homes ***Summary***: Seven test homes in Massachusetts are examined in this report. The retrofit strategies of each are presented along with a comparison of the pre- and post-retrofit airtightness achieved by the group.	BSC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/seven_cold_climate_homes.pdf	8/2012
Measure Guideline: Sealing and Insulating Ducts in Existing Homes ***Summary:*** This guideline begins with a discussion of the potential cost and performance benefits of duct sealing and insulating, and reviews typical duct materials and components and the overall procedures for assessing and improving the duct system.	CARB	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/meas_guide_seal_ducts.pdf	12/2011
Chamberlain Heights Redevelopment: A Large Scale, Cold Climate Study of Affordable Housing Retrofits ***Summary:*** The City of Meriden Housing Authority in Connecticut collaborated with affordable housing developer Jonathon Rose Companies to complete a gut renovation of 124 residential units in the Chamberlain Heights retrofit project. The affordable housing community is composed of 36 buildings in duplex and quad configurations on 22 acres	CARB	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/chamberlain_hghts_redev.pdf	3/2012

Publication	Author	URL	Published
within two miles of downtown Meriden. The final post-retrofit analysis showed 40%–45% source energy savings over the pre-retrofit conditions.			
Measure Guideline: Heat Pump Water Heaters in New and Existing Homes ***Summary:*** This measure guideline is intended for builders, contractors, homeowners, and policy makers. It is intended to explore the issues surrounding HPWHs to ensure that homeowners and contractors have the tools needed to appropriately and efficiently install these units.	CARB	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_hpwh.pdf	3/2012
An In-Depth Look at Ground Source Heat Pumps and Other Electric Loads in Two GreenMax Homes ***Summary:*** CARB partnered with WPPI Energy to answer key research questions about in-field performance of ground source heat pumps and lighting, appliance, and miscellaneous loads through extensive field monitoring at two WPPI GreenMax demonstration homes in Wisconsin.	CARB	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ground_sourcehp_greenmax.pdf	4/2012
Evaluation of Boulder, CO, SmartRegs Ordinance and Better Buildings Program ***Summary:*** Under the SmartRegs ordinance in the City of Boulder, Colorado, all rental properties must achieve an energy efficiency level comparable to a HERS Index of approximately 120 points or lower by 2019. The City of Boulder received a $12 million grant from DOE's Better Buildings initiative to create and incentivize its EnergySmart Program. In this report, CARB describes its work with the program, including energy audits of rental properties, developing training programs for insulators and inspectors, and conducting interviews with property owners.	CARB	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/boulder_smartregs.pdf	4/2012
Expert Meeting Report: Retrofit Implementation – A Neighborhood at a Time ***Summary:*** This report provides information about a BA expert meeting hosted by CARB on October 25, 2011, in New York City. The meeting discussed several community residential retrofit projects underway across the United States, and included representatives from utilities, energy program implementation firms, affordable housing agencies, and the financing industry.	CARB	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/expt_mtg_one_neighbd.pdf	4/2012
Measure Guideline: Air Sealing Attics in Multifamily Buildings ***Summary:*** This measure guideline is intended for owners, builders, contractors, homeowners, and other stakeholders in the multifamily building industry, and focuses on challenges for a variety of housing types. It explains why air sealing is desirable, explores related health and safety issues, and identifies common air leakage points in multifamily building attics. It gives an overview of materials and techniques typically used to perform air sealing work.	CARB	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_air_sealing_attics.pdf	6/2012
Measure Guideline: Installing Rigid Foam Insulation on the Interior of Existing Brick Walls ***Summary:*** This measure guideline provides information on an effective method to insulate the interior of existing brick masonry walls with extruded polystyrene insulation board. The guide outlines step-by-step design and installation procedures and explains the benefits and tradeoffs where	CARB	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_rigid_foam.pdf	7/2012

Publication	Author	URL	Published
applicable. The authors intend that this report be useful to a varied audience that includes builders, remodelers, contractors, and homeowners.			
Retrofitting Air Conditioning and Duct Systems in Hot, Dry Climates ***Summary***: This report describes CARB's work with Clark County Community Resources Division in Las Vegas, Nevada, to optimize procedures for upgrading cooling systems on existing homes to implement health, safety, and energy improvements. Detailed monitoring of five air conditioning systems showed that three of the five systems met or exceeded airflow rate goals.	CARB	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/retrofit_ac_duct_systems.pdf	7/2012
Wisdom Way Solar Village: Design, Construction, and Analysis of a Low-Energy Community ***Summary:*** This report describes work conducted at the Wisdom Way Solar Village, a community of 10 high performance duplexes (20 homes) in Greenfield, Massachusetts, constructed by Rural Development, Inc. CARB monitored temperatures and comfort in several homes during the winter of 2009–2010, and tracked utility bill information from 13 occupied homes. Because of efficient lights, appliances, and conscientious home occupants, the energy generated by the solar electric systems exceeded the electric energy used in most homes	CARB	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/wisdom_way_community.pdf	8/2012
Expert Meeting Report: Transitioning Traditional HVAC Contractors to Whole House Performance Contractors ***Summary***: This expert meeting was hosted by IBACOS to determine how HVAC companies can transition from a traditional contractor status to a service provider for whole-house energy upgrade contracting.	IBACOS	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/expt_mtg_hvac_contr.pdf	10/2011
Measure Guideline: Water Management at Tub and Shower Assemblies ***Summary:*** Because of the high concentrations of water and the consequential risk of water damage to the home's structure, a comprehensive water management system is imperative to protect the building assemblies underlying the finish surround of tub and shower areas. This guideline shows how to install fundamental waterproofing strategies to prevent water-related issues in these areas.	IBACOS	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/meas_guide_tub_shower.pdf	12/2011
Strategy Guideline: Air Distribution Basics and Duct Design ***Summary:*** This guideline discusses considerations for designing an air distribution system for an energy-efficient house that requires less air volume to condition the space. Considering the HVAC system early in the design process will allow adequate space for equipment and ductwork and can result in cost savings	IBACOS	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/strategy_guide_air_distr.pdf	12/2011
Measure Guideline: Air Sealing Mechanical Closets in Slab-On-Grade Homes ***Summary:*** This measure guideline describes two fundamental retrofit strategies for air sealing around air handling systems that are located in the living space in an enclosed closet: one in which all the equipment is removed and being replaced, and a closet where the equipment is to remain and existing conditions are sealed. It includes the design and installation	IBACOS	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_mech_closets.pdf	2/2012

Publication	Author	URL	Published
details necessary to effectively seal the air handler closet and central return system to maximize the efficiency and safety of the space conditioning system.			
Strategy Guideline: High Performance Residential Lighting ***Summary:*** This report provides a tool for the understanding and application of high performance lighting in the home, with strategies drawn from recent advances in commercial lighting, to application to typical spaces found in homes. This guide offers strategies to greatly reduce lighting energy use with high quality fluorescent and light emitting diode technologies. These strategies save energy and satisfy the homeowner's expectations for high performance lighting.	IBACOS	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/strategy_guideline_high_perf_lighting.pdf	2/2012
Strategy Guideline: HVAC Equipment Sizing ***Summary:*** This guide describes the equipment selection of a split system air conditioner and furnace for an example house in Chicago, as well as a heat pump system for an example house in Orlando. The required heating and cooling load information for the two example houses was developed in *Strategy Guideline: Accurate Heating and Cooling Load Calculations*.	IBACOS	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/strategy_guide_hvac_sizing.pdf	2/2012
Strategy Guideline: Transitioning HVAC Companies to Whole House Performance Contractors ***Summary:*** This report describes the findings from research IBACOS conducted related to HVAC companies that have decided to transition to whole-house performance contracting.	IBACOS	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/strategy_guide_hvac_contractors.pdf	4/2012
Measure Guideline: Transitioning From Three-Coat Stucco to One-Coat Stucco With EPS ***Summary:*** This measure guideline was developed to help builders transition from using a traditional three-coat stucco wall-cladding system to a one-coat stucco wall-cladding system with expanded polystyrene insulated sheathing.	IBACOS	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_3coat_stucco.pdf	5/2012
Performance Evaluation and Opportunity Assessment for St. Bernard Project ***Summary:*** This report describes efforts by IBACOS in the St. Bernard Project, a nonprofit, community-based organization whose mission is to assist Hurricane Katrina survivors to return to their homes in the New Orleans area. The report focuses on energy modeling results of two plans that the St. Bernard Project put forth as "typical" building types, on quality issues that were observed during the field walk, and on best practice recommendations that could improve the energy efficiency and durability of the renovated homes.	IBACOS	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/st_bernard_evaluation.pdf	6/2012
Strategy Guideline: Accurate Heating and Cooling Load Calculations ***Summary:*** This guide presents the key criteria for accurately calculating heating and cooling loads and offers examples of the implications when inaccurate adjustments are applied to the HVAC design process. The guide shows, through realistic examples, how various defaults and arbitrary safety factors can lead to significant increases in the load estimate. It emphasizes the risks incurred from inaccurate adjustments or ignoring critical inputs of the load calculation.	IBACOS	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/hvac_load_calc.pdf	6/2012
Expert Meeting Report: Simplified Space Conditioning Strategies for Energy Efficient Houses	IBACOS	http://apps1.eere.energy.gov/buildings/publications/pd	7/2012

Publication	Author	URL	Published
Summary: The purpose of this expert meeting was to recap the current state of knowledge in the area of simplified space conditioning systems in new and retrofitted house, and to provide a peer review of IBACOS's research plan for new and existing unoccupied test houses with minimized space conditioning systems.		fs/building_america/expt_mtg_space_cond.pdf	
Results From Development of Model Specifications for Multifamily Energy Retrofits ***Summary***: In this report, IBACOS and Mercy Housing developed sample model specifications based on a common building construction type that Mercy Housing encounters.	IBACOS	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/modelspecs_mutlifamily.pdf	8/2012
Strategy Guideline: Quality Management Strategies in Existing Homes Cantilever Floor Example ***Summary:*** This guideline is designed to highlight the quality assurance process that can be applied to any residential building retrofit activity. The cantilevered floor retrofit process is included only to provide an actual retrofit example to better illustrate the quality assurance activities being presented.	NAHB-RC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/strategy_guide_quality_mgmt.pdf	12/2011
National Green Building Standard Analysis ***Summary:*** In compliance with ANSI standard reviews, a consensus group has been formed and the National Green Building Standard is currently being reviewed to comply with the periodic maintenance requirement.	NAHB-RC	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ngbs_analysis.pdf	7/2012
Expert Meeting Report: Achieving the Best Installed Performance from High-Efficiency Residential Gas Furnaces ***Summary:*** This report describes a BA expert meeting hosted on July 28, 2011, by PARR. The purpose was to identify installation practices that provide the best installed efficiency for residential gas furnaces, explain how alternative fuel utilization efficiency and field efficiency can differ, and investigate the impact of installation practices on the efficiency and long-term durability of the furnace.	PARR	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/expt_mtg_resid_gas_furnaces.pdf	3/2012
Chicagoland Single-Family Housing Characterization ***Summary:*** In this report, the PARR team identifies housing characteristics and energy use for 15 housing types in the Chicagoland (Cook County, Illinois) region and specifies measure packages that provide an optimum level of energy savings based on a BEopt analysis. The analysis is based on assessor data and actual energy consumption data on 432,605 houses representing approximately 30% of the population.	PARR	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/chicagoland_housing_charac.pdf	6/2012
Steam System Balancing and Tuning for Multifamily Residential Buildings in Chicagoland ***Summary***: Older heating systems often suffer from mis-investment—multiple contractors upgrading parts of systems in inadequate or inappropriate ways that reduce system functionality and efficiency—or from a lack of proper maintenance. This report addresses barriers to information, contractor resources, and cost savings, and reports on a study conducted by CNT Energy to identify best practices for the methodology, typical costs, and energy savings associated with steam system balancing.	PARR	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/steamsys_balance.pdf	8/2012

Summary of National Renewable Energy Laboratory Publications in FY 2012

Table 59. Summary of NREL Publications During FY 2012

Publication	Author	URL	Published
Technical Barriers, Gaps, and Opportunities Related to Home Energy Upgrade Market Delivery ***Summary:*** This report outlines the technical barriers, gaps, and opportunities that arise in executing home energy upgrade market delivery approaches, as identified through research conducted by DOE's BA program.	NREL—Bianchi, M.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/tech_barriers.pdf	11/2011
Condensing Hybrid Water Heater Monitoring Field Evaluation ***Summary:*** This report summarizes the Mascot home, an abandoned property that was extensively renovated with efficiency upgrades, including a unique water heater (a Navien CR240-A–one of the most efficient gas water heaters on the market). Field monitoring was performed to determine the in-use efficiency of the hybrid condensing water heater, and results were compared to the unit's rated efficiency.	NREL—Maguire, J.; Earle, L.; Booten, C.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/cond_hybrid_water_heater.pdf	11/2011
Energy Savings Measure Packages–Existing Homes ***Summary:*** This document presents the most cost effective ESMPs for existing mixed-fuel and all-electric homes to achieve 15% and 30% savings for each BetterBuildings grantee location across the United States. These packages are optimized for minimum cost to homeowners for source energy savings given the local climate and prevalent building characteristics such as foundation types. Maximum energy cost savings are typically 30%–50% over the reference home; this typically amounts to $300–$700/year.	NREL—Casey, S.; Booten, C.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/energy_savings_measures.pdf	11/2011
Three-Dimensional Numerical Evaluation of Thermal Performance of Uninsulated Wall Assemblies ***Summary***: This study describes a detailed 3D computational fluid dynamics model that evaluates the thermal performance of uninsulated wall assemblies. It accounts for conduction through framing, convection, and radiation and allows for material property variations with temperature. This research was presented at the ASME 2011 International Mechanical Engineering Congress and Exhibition; Denver, Colorado; November 11–17, 2011	NREL—Ridouane, E.H.; Bianchi, M.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/3d_eval_thermal_perf.pdf	11/2011
Building America 2011 Residential Energy Efficiency Technical Update Meeting Summary ***Summary:*** This report provides an overview of the BA program's Summer 2011 Residential Energy Efficiency Technical Update Meeting on August	NREL/ Confluence	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/resid_mtg_report_august2011.pdf	11/2011

Publication	Author	URL	Published
9–11, 2011, in Denver, Colorado. This meeting brought together more than 290 professionals representing organizations with a vested interest in energy efficiency improvements in residential buildings.			
Technical Highlight: NREL Develops New Diagnostic Test Cases To Improve Building Energy Simulation Programs ***Summary:*** This fact sheet describes NREL research to develop a set of diagnostic test cases for building energy simulations to predict energy use and savings more accurately.	NREL—Tabares-Velasco, P.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/tech_highlight_diag_test.pdf	12/2011
Technical Highlight: Evaluation of Humidity Control Options in Hot-Humid Climate Homes ***Summary:*** This fact sheet describes NREL research to analyze the indoor RH in three home types in the hot-humid climate zone, and examine the impacts of various dehumidification equipment and controls.	NREL—Fang, X.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/tech_highlight_humidity_control.pdf	12/2011
Laboratory Test Report for Six ENERGY STAR® Dehumidifiers ***Summary:*** This report documents the measured performance of six residential ENERGY STAR vapor compression dehumidifiers. The performance of each was measured over a wide range of inlet air conditions and fit to a numerical model for capacity and efficiency. This work can be used by energy modelers and equipment manufacturers to understand how current products will operate in a wide range of environments, and to develop advanced space conditioning systems for efficient, safe, durable, and healthy homes.	NREL—Winkler, J.; Christensen, D.; Tomerlin, J.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/six_es_dehumidifiers.pdf	12/2011
Technical Highlight: NREL Improves Building Energy Simulation Programs Through Diagnostic Testing ***Summary:*** This fact sheet describes NREL research to develop BESTEST-EX to increase the quality and accuracy of energy analysis tools for the building retrofit market.	NREL—Polly, B.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/tech_highlight_bestest-ex.pdf	1/2012
Technical Highlight: NREL Provides Guidance to Improve Thermal Comfort in High-Performance Homes ***Summary:*** This fact sheet describes NREL research to develop recommendations on HVAC system design and operating conditions to achieve optimal thermal comfort in high performance homes.	NREL—Ridouane, E.H.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/tech_highlight_thermal_comf.pdf	1/2012
Technical Highlight: NREL Delivers In-Home HVAC Efficiency Testing Solutions ***Summary:*** This fact sheet discusses two simple in-home efficiency test methods that can be used by technicians, researchers, and interested homeowners to verify the correct operation and energy efficiency of a home's air conditioning	NREL—Christensen, D.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/tech_highlight_efficiency_testing.pdf	1/2012

Publication	Author	URL	Published
equipment.			
Technical Highlight: NREL Evaluates the Thermal Performance of Uninsulated Walls to Improve Accuracy of Building Energy Simulation Tools ***Summary:*** This fact sheet describes NREL research to develop models of uninsulated wall assemblies that help to improve the accuracy of building energy simulation tools when modeling potential energy savings in older homes.	NREL—Ridouane, E.H.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/tech_highlight_uninsul_walls.pdf	1/2012
Technical Highlight: NREL Tests Integrated Heat Pump Water Heater Performance in Different Climates ***Summary:*** This fact sheet describes NREL tests to capture information about heat pump performance across a wide range of ambient conditions for five HPWHs.	NREL—Sparn, B.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/tech_highlight_heat_pump.pdf	1/2012
Technical Highlight: National Residential Efficiency Measures Database Aimed at Reducing Risk for Residential Retrofit Industry ***Summary:*** This fact sheet describes NREL research to develop a publicly available database of energy retrofit measures containing performance characteristics and cost estimates for nearly 3,000 measures.	NREL—Roberts, D.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/tech_highlight_measures_db.pdf	1/2012
Building Energy Simulation Text for Existing Homes (BESTEST-EX) ***Summary:*** This presentation discusses the goals of NREL Analysis Accuracy R&D; BESTEST-EX goals and how it works; "building physics" cases and reference results; "utility bill calibration" cases; limitations and potential future work.	NREL—Polly, B.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/bestest-ex.pdf	1/2012
Technical Highlight: NREL's Field Data Repository Supports Accurate Home Energy Analysis ***Summary:*** This fact sheet discusses NREL's work to develop a repository of research-level residential building characteristics and historical energy use data to support ongoing efforts to improve the accuracy of residential energy analysis tools and the efficiency of energy assessment processes.	NREL—Roberts, D.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/tech_highlight_field_data.pdf	2/2012
Laboratory Performance Testing of Residential Dehumidifiers ***Summary:*** This presentation describes research on six residential vapor compression cycle dehumidifiers spanning the available range of capacities and efficiencies were tested in NREL's HVAC Systems Laboratory. Each was tested under a wide range of indoor air conditions to facilitate the development of performance curves for use in whole-building simulation tools.	NREL—Winkler, J.; Christensen, D.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/resid_dehumifier_testing.pdf	3/2012
Improving Air-Conditioner and Heat Pump Modeling ***Summary:*** This presentation outlines a new	NREL—Winkler, J.; Cutler, D.;	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/air_cond_heat_pu	3/2012

Publication	Author	URL	Published
approach to modeling residential air conditioners and heat pumps that allows users to model systems by specifying only the more readily available SEER/energy efficiency ratio/heating seasonal performance factor-type metrics. Manufacturer data were used to generate full sets of model inputs for more than 450 heat pumps and air conditioners. A sensitivity analysis identified which inputs can be safely defaulted "behind-the-scenes" without negatively impacting the reliability of energy simulations.	Kruis, N.	mp_model.pdf	
Heat Pump Water Heater Modeling in EnergyPlus ***Summary:*** This presentation summarizes NREL's development of an HPWH model for use in hourly building energy simulation programs such as BEopt; this presentation was given at the BA Stakeholder meeting on March 1, 2012, in Austin, Texas.	NREL—Wilson, E.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/lab_testing_resid_dehumidifiers.pdf	3/2012
Highlight: NREL Tests Dehumidifiers, Defines Simplified Simulation Model ***Summary:*** Study of residential dehumidifiers results in practical performance curves for use in whole-building simulation tools.	NREL	http://www.nrel.gov/docs/FY2012osti/54845.pdf	4/2012
Highlight: NREL Evaluates Performance of Heat Pump Water Heaters ***Summary:*** NREL evaluates energy savings potential of HPWHs in homes throughout all U.S. CZs.	NREL	http://www.nrel.gov/docs/FY2012osti/54096.pdf	4/2012
Highlight: NREL Documents Efficiency of Mini-Split Heat Pumps ***Summary:*** A new report delivers mini-split heat pump performance data for use in whole-building simulation tools.	NREL	http://www.nrel.gov/docs/FY2012osti/54846.pdf	5/2012
Highlight: NREL Develops Heat Pump Water Heater Simulation Model ***Summary:*** A new simulation model helps researchers evaluate real-world impacts of HPWHs in U.S. homes.	NREL	http://www.nrel.gov/docs/FY2012osti/54848.pdf	6/2012
Highlight: Improving Building Energy Simulation Programs Through Diagnostic Testing ***Summary:*** New test procedure evaluates quality and accuracy of energy analysis tools for the residential building retrofit market.	NREL	http://www.nrel.gov/docs/fy12osti/54093.pdf	6/2012
A Realistic Hot Water Draw Specification for Rating Solar Water Heaters ***Summary***: In the United States, annual performance ratings for solar water heaters are simulated, using Typical Meteorological Year weather and specified water draw. This paper proposes a more realistic ratings draw that eliminates most bias by improving mains inlet temperature and by specifying realistic hot water	NREL—Burch, J.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/rating_solar_water_heater.pdf	7/2012

Publication	Author	URL	Published
use. Presented at the 2012 World Renewable Energy Forum; Denver, Colorado; May 13–17, 2012.			
Verification and Validation of EnergyPlus Conduction Finite Difference and Phase Change Material Models for Opaque Wall Assemblies ***Summary***: Phase change materials represent a potential technology to reduce peak loads and HVAC energy consumption in buildings. A few building energy simulation programs can simulate phase change materials, but their accuracy has not been completely tested. This report summarizes NREL efforts to develop diagnostic tests cases to obtain accurate energy simulations when phase change materials are modeled in residential buildings.	NREL—Tabares-Velasco, P., Christensen, C., Bianchi, M., Booten, C.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/energyplus_cond_pcmm.pdf	8/2012
Assessment of the U.S. Department of Energy's Home Energy Scoring Tool ***Summary***: NREL conducted a series of assessments of DOE's proposed Home Energy Scoring Tool. This report is an assessment of the April 27, 2012 release of the tool. Predictions of electric and natural gas consumption were compared with weather-normalized utility billing data for a mixture of newer and older homes located in Oregon, Wisconsin, Minnesota, North Carolina, and Texas.	NREL—Roberts, D., Merket, N., Polly, B., Heaney, M., Casey, S., Robertson, J.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/home_energy_score_assess.pdf	8/2012
Low-Cost Solar Water Heating Research and Development Roadmap ***Summary***: This roadmap presents analysis of cost and performance tradeoffs between high performance water heating systems; annual energy simulations were run using TRNSYS, and analysis was performed to compare the energy savings associated with HPWHs and solar water heating technologies to conventional water heating methods.	NREL—Hudon, K., Merrigan, T., Burch, J., Maguire, J.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/solar_waterhtg_roadmap.pdf	8/2012
Results of Laboratory Testing of Advanced Power Strips ***Summary:*** Presented at the ACEEE Summer Study on Energy Efficiency in Buildings on August 12–17, 2012, this presentation reports on laboratory tests of 20 currently available advanced power strip products, which reduce wasteful electricity use of miscellaneous electric loads in buildings.	NREL—Sparn, B., Earle, L.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/advanced_power_strips.pdf	9/2012
Energy Impacts of Nonlinear Behavior of PCM When Applied into Building Envelope ***Summary:*** Presented at the ASME 2012 6th International Conference on Energy Sustainability & 10th Fuel Cell Science, Engineering and Technology Conference on July 23-26, 2012, this study analyzes the effects a nonlinear enthalpy profile has on thermal performance and expected energy benefits for phase change material-enhanced insulation.	NREL—Tabares-Velasco, P.	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/pcm_building_envelope.pdf	9/2012

Appendix D: Summary of Building America Critical Path Milestones

Table 60. Summary of BA Critical Path Milestones

Technical Owner	Milestone	2012	2013	2014	2015
Implementation	**Comm. Strategies w/Validated Channels—Better Practice, Practiced.**				
Implementation	Identify Key Stakeholders, Comm. Needs & Channels				
Implementation	Dev. Audience Specific Comm, Define KPIs				
Implementation	Implement Audience Specific Comm, Measure KPIs				
Implementation	Comm. Strategies w/ Validated Channels—Better Practice, Practiced.				
Space Cond.	**BA Best Practice: Mechanical Ventilation**				
Space Cond.	White Paper, Protocol for Collecting T&RH				
Space Cond.	Data Analysis, Expert Meeting on T&RH Ranges				
Space Cond.	Expert Meeting on Application of Mech. Vent.				
Space Cond.	BA Best Practice Guidance Issued on Mech. Vent.				
Space Cond.	**Market Ready Space Cond. @ 30% Savings Relative to SEER 16**				
Space Cond.	Guideline on HPWH Integration to Space Cond.				
Space Cond.	BA Best Practice Guidance on RH Control				
Space Cond.	Expert Meeting, Remaining Equipment Needs				
Space Cond.	Demonstrated Systems and Strategies				
Space Cond.	**Distribution System Solutions with Negligible Heat Losses**				
Space Cond.	Demonstrate Comm. Scale Interior Duct				
Space Cond.	Document Alternative Solutions				
Space Cond.	Update Existing Guidance				
Space Cond.	Adoption of Distribution System Solutions in All CZs and House Types				
Space Cond.	**10-20% Htg Savings in Low-Load Homes**				
Space Cond.	Optimize Cold Climate HP Sizing				
Space Cond.	Demonstrate Combi Savings w/ ES Water Heaters				
Space Cond.	Optimize HP Transition Temp as f(climate, aux fuel, load, capacity)				
Space Cond.	Demonstrate Systems and Strategies				

Table 60 (continued): Summary of BA Critical Path Milestones

Technical Owner	Milestone	2012	2013	2014	2015
Space Cond.	**10-15% Savings for Existing Equipment**				
Space Cond.	ECM, Tune-Up Results				
Space Cond.	Evaluate Supplemental HVAC Retrofits				
Space Cond.	Community Scale Evaluations				
Space Cond.	Demonstrated Systems and Strategies				
Hot Water	**Optimized HPWH Design and Operation & Best Practice Guidelines**				
Hot Water	Indoor Location Assessments for All Climates				
Hot Water	Data Feedback to Stakeholders/Manufacturers				
Hot Water	HPWH Best Practice Guidelines				
Hot Water	**High Efficiency Gas Solutions for Existing System Infrasturcture**				
Hot Water	Specification for Closed-Combustion High-Efficiency Gas Products				
Hot Water	> 0.82 EF (or > 90% thermal efficiency) Solution with <100 kBtu/hr Capacity				
Hot Water	**New Construction System Solutions (35%+ for Gas and to 50%+ for Electric)**				
Hot Water	Multiple Field Demonstrations of System Solutions				
Hot Water	Validated Modeling Study of Solutions				
Hot Water	System Solutions Guidelines				
Hot Water	**Best Practice Design and Implementation Guidelines for Combined Systems**				
Hot Water	Multi-Climate Field Trials, Assessment of Alternative Distribution Options				
Hot Water	Design Guidelines for Variety of New and Existing Conditions				
Hot Water	Best Practice Guidelines for Design and Implementation				
Hot Water	**Optimized Multifamily Recirculation Systems Solutions**				
Hot Water	Complete Comparative Field Testing of Control Strategies				
Hot Water	Demonstrated 15% Savings Compared to Continuous Recirculation				

Table 60 (continued): Summary of BA Critical Path Milestones

Technical Owner	Milestone	2012	2013	2014	2015
Hot Water	**System Integration Evaluations for Solar Water Heating**				
Hot Water	Cost Reduction and System Simplification Opportunity Identification				
Hot Water	Re-evaluate in Anticipation of Low-Cost Polymer Component Developments				
Hot Water	Demonstrate System Solution(s)				
Enclosures	**Code Language for Attaching Cladding of Insulating Sheathing**				
Enclosures	Submit Code Language				
Enclosures	Define Design Parameters Addressing Creep				
Enclosures	Accepted Code Language for Cladding Attachment				
Enclosures	**Code Language for Insulating Sheathing for Underside of Wood Floors**				
Enclosures	Submit Code Language				
Enclosures	Accepted Code Language for Cladding Attachment				
Enclosures	**Approved Fire Tested Assemblies Including Insulating Sheathing Over Wood Frame**				
Enclosures	Complete Testing of Assemblies				
Enclosures	Approved Testing for Code Review				
Enclosures	**Address Weatherization Program Practices that Violate Code**				
Enclosures	Identify and Address Code Conflicts With Wx Practices				
Enclosures	Improved Wx Practices				
Enclosures	**Retrofit Method for Monolithic Slab**				
Enclosures	Development of Method				
Enclosures	Accepted Retrofit Method for Monolithic Slab				
Enclosures	**High-R Enclosure System Selection Guidelines**				
Enclosures	Define Risk Metric				
Enclosures	Complete Characterization of Enclosure Assemblies				
Enclosures	Publish Selection Guideline				

Table 60 (continued): Summary of BA Critical Path Milestones

Technical Owner	Milestone	2012	2013	2014	2015
AHEM	**Determination of Effective Control Strategies that Maximize Comfort and Savings**				
AHEM	Evaluation of Commercially Available Sensors				
AHEM	Identification of Control Saving Opportunities				
AHEM	Test Sensor/Control Suite Solutions				
AHEM	Recommended Sensor/Control Suite Solutions				
AHEM	**Support Development of AHEM Taxonomy**				
AHEM	Survey of Existing Market Products and Key Functionality				
AHEM	AHEM Technical Update, Engage Manufacturers to Reinforce Consistent Taxonomy				
AHEM	Support Consistent AHEM Taxonomy				
AHEM	**Opportunities to Curb Inadvertent Energy Use**				
AHEM	Determine HVAC Energy Saving Potential				
AHEM	Determine Lighting Energy Saving Potential				
AHEM	Determine MELs Energy Saving Potential				
AHEM	Define Theoretical AHEM Saving Potential (Excluding Demand Response)				
AHEM	**Energy Impact of Control Strategies For Demand Response (DR)**				
AHEM	Test Existing DR Controls in GE Appliances, Precooling Testing In High-Performance Homes				
AHEM	Expanded DR Testing, Precooling Studies in Typical Homes				
AHEM	Advanced Precooling Analysis				
AHEM	High-Confidence Analysis of Energy Impacts of DR				

Table 60 (continued): Summary of BA Critical Path Milestones

Technical Owner	Milestone	2012	2013	2014	2015
Analysis	**Empirical Test Suites**				
Analysis	Identify Pre- Post-Data Sources, Develop Plan for Interior Temp Modeling				
Analysis	Initial Test Suite from BAFDR, Lab and Field Data for Interior Temp Modeling Tests				
Analysis	Add Pre- Post-Retrofit Data Sources, Complete Test Suites for Temp Modeling				
Analysis	Publicly Accessible Empirical Test Suites of Large Audit Data and Lab Data				
Analysis	**Defined Uncertainty Due to Characteristic Data and Occupancy Effects**				
Analysis	Define Initial List of Most Influential Model Inputs				
Analysis	Quantify Component Uncertainties, BEopt Uncertainty Analysis				
Analysis	Publish Uncertainty Analysis Results				
Analysis	Magnitude of Potential Errors Defined				
Analysis	**Automated, Math-Based Calibration Method(s)**				
Analysis	Initial Development, Implementation and Testing of Synthetic Data				
Analysis	Refinement of Method With Empirical Data				
Analysis	Published Method Compliant with Industry Standards				
Analysis	Implement Automated Calibration Method				
Analysis	**Community Scale BEopt**				
Analysis	Mockup User Interface, Preliminary Analysis				
Analysis	Finalize Approach for Archetype Development & Calibration				
Analysis	Beta-Version of Community Scale BEopt				
Analysis	Functional Community Scale BEopt Tool				
Analysis	**Multi-Family BEopt and HSP**				
Analysis	BEopt Analysis and HSP for Single-Family Attached				
Analysis	BEopt Analysis and HSP for Larger Multi-Family Bldgs.				

Table 60 (continued): Summary of BA Critical Path Milestones

Technical Owner	Milestone	2012	2013	2014	2015
Analysis	**Extended HPXML Platform**				
Analysis	Support Developer Requests to Mod/Improve/Extend HPXML				
Analysis	Define in HPXML Data for Empirical Test Suite, Integrate with BEopt/BAFDR				
Analysis	HPXML Integration Across Tools and DBs				
Test Methods	**Minimally-Intrusive Characterization of Whole House Consumption**				
Test Methods	Identify Technical Requirements and Develop Roadmap				
Test Methods	Demonstrate Wireless Data Logger Systems, NILM prototypes and Proxy Techniques				
Test Methods	Savings Analysis Using Expanded End-Use Types, Refine NILM and Proxy Techniques				
Test Methods	Integration of Analysis and Test Methods				
Test Methods	**Method to Characterize Low-Risk Retrofit Opportunities for Ground Elements**				
Test Methods	Develop Research Plan, Identify Sensor Gaps				
Test Methods	Develop Initial Models, Instrument Test House for Validation				
Test Methods	Transition Model to EnergyPlus, Validate Against Field Data				
Test Methods	Robust Analsysis Tools for At and Below Grade Retrofit				

Appendix E: Value of Building America System Research Process

Jake Luhn, CEO of Lifestyle Homes and son of the late founding partner John Luhn, says the BA program at FSEC may be the best possible example of what research universities and businesses can do together to help consumers and grow the economy. BA research conducted at FSEC led to a series of Lifestyle Home designs that provide homebuyers a 40% savings in electricity costs annually (emphasis added to all quotations). *"We experienced instant consumer acceptance of these revolutionary energy efficient homes,"* Luhn said. ***"At a time when home builders where going out of business because of the great recession we were not only surviving, we were prospering all thanks to FSEC."*** But that was only the beginning. The company and FSEC continued to work together, to develop a net zero energy home design. These homes use roof-mounted PV panels to produce as much energy as they consume in a year, resulting in a net $0 bill from the electric company. *"The day is not far off when we will be able to build truly affordable Net Zero Energy homes that have enough generating capacity not only to meet our own power needs but to recharge two electric powered automobiles overnight. When that happens and people figure out that they don't have to pay for electricity or gas, that's really going to revitalize the construction industry from coast to coast generating more jobs and changing the way American's live,"* Luhn said. ***"That's what I call the perfect marriage between science and business."***

> Building America researchers improve the energy efficiency of today's and tomorrow's homes by developing and test driving new technologies and systems solutions. **Proven performance in research home studies and communities constructed by early adopters has enabled the raising of the market's expectations and the minimum performance bar set by energy code standards**. For example, research and the broad dissemination of results by CARB, and other Building America teams, drew attention to the importance of good HVAC system design and installation for energy efficiency, comfort, health, and durability. As a result, significant improvements have been made in energy code and efficiency program requirements and performance testing protocols.
> *– Steven Winters, President, Steven Winter Associates*

> Building America support for the Cottle Net Zero Energy Home assured that we were able to accomplish each successive stage of a complex, leading edge, integrated design/build project with confidence that we would meet our energy goals. The process started with valuable conceptual design inputs, continued with practical applied engineering advice in areas like mechanical systems design and continues with valuable performance data and analysis to validate what measures are working best and which can be improved on our next Net Zero Energy project. **Building America participation has also assured us that we are able to fully share the results of our collective R&D efforts with the broader building industry and marketplace which lends credibility to the movement toward high performance building in the mainstream**.
> *– Alan Gilliland, One Sky Homes*

> Without support from Building America (BA), the building industry would be challenged to construct the next generation of cost competitive homes that are

energy efficient, durable, affordable, and comfortable. **While individual manufacturers provide research for the application of specific products, it is only the Building America Program that provides integrated research on houses. Without this integrated research, the successful deployment and durability of high performance homes would be much more limited**. Builders and remodelers have often expressed that they rely on this broad-based research to continually improve their homes. BA research has led to market transformation by establishing, for example, the basis for advanced framing and air sealing methods in production homes and use of optimized duct systems. These improvements have led to energy savings and reduced equipment sizes while maintaining performance and affordability of the home.
– Amber Wood, Manager of Energy Programs, NAHB Research Center

In the Upper Midwest, **we see Building America innovations, technologies, and processes built into almost every new home**. Now we must reposition ourselves in the marketplace to put that same philosophy to work on the 120 million existing homes in the U.S. that need systematic upgrades to bring them up to 21st century performance expectations for efficiency, comfort, durability, and healthy indoor air.
– Pat Huelman, Principal Investigator, NorthernSTAR

Future concerns over energy prices and availability as well as the need for clean energy sources, makes the efficiency of our residential building stock a major national priority. **The Building America program has assembled the leading experts from across the country to not only conduct research on more energy efficient homes but to provide information in forms that can truly transform the entire housing market**.
– John Carmody, Project Manager, NorthernSTAR

Our partnership with the ARIES Building America team has enabled us to take a fresh approach to reducing energy use in our older building stock (mostly low-rise masonry buildings of the type that accounts for much of the affordable housing in the Northeast) and to try out and **evaluate energy saving technologies that have provided an excellent return on our investment**.
– Jane Carbone, Senior Project Manager, Homeowners Rehab, Inc.

Thank you for what you guys are doing in support of the projects we are working on in the Buildings Program at SWEEP. We have been a promoter and benefactor of the Building America Program. As a promoter we have shared the programs such as Builders Challenge to utility companies as possible higher tier efficiency programs to assist them in meeting their energy efficiency standards. As a benefactor we have seen the building energy codes advance over the past two cycles because of programs and practices Building America has deployed over the history of the program. **We have benefited by sharing case studies, builder guides, and other materials developed by the Building America team with state energy offices, building officials, municipal leadership and others to demonstrate that energy efficient housing is not rocket science**.

– Jim Meyers, Director Buildings Efficiency Program, Southwest Energy Efficiency Project

Building America's support was instrumental in developing SMUD's SolarSmart Homes program, the first and only electric utility residential new construction program that combined high efficiency homes with mandatory solar PV on new homes built in SMUD's service territory. To date, more than 1,000 SolarSmart Homes have been built in the Sacramento area, with more than 30% new homes built SolarSmart Homes. **SMUD's SolarSmart Homes programs owes its success largely to the technical support provided by Building America, the BA teams, and NREL**.
– Mike Keese, Project Manager II, Sacramento Municipal Utility District Energy Research and Development

Working with the ARIES Building America team has enabled us together with other factory builders to explore, evaluate and soon to bring to market radically new methods of construction that will **significantly cut energy use and do so in ways that lower total homeownership costs**.
– Mark Ezzo, Vice President – Engineering, Clayton Homes

The Building America program has shown us new ways of energy conservation that are **effective, reproducible and more importantly, the measures can be implemented within the budget** constraints of public housing agencies. We would look forward to being a part of future projects.
– Gail Iris Keeter, Raleigh Housing Authority, Director of Development

Building America has helped Imagine Homes continually improve our product in terms of energy efficiency, durability and affordability. In 2011 and 2012, we have taken that research even further by exploring ways to heat and cool our houses with alternatives to central space conditioning systems in an effort to cost optimize the next level of energy efficiency for our customers. **Building America also provides a level of credibility that is essential** to our partner, Beazer Homes.
– John Friesenhahn, President, Imagine Homes

Understanding and mastering the "science of building" is paramount in our efforts to train and retain talented employees. It is also vital in designing, remodeling and building houses that are as energy efficient as possible, comfortable and safe for the occupants, sustainable and durable, and in the end "do no harm". **The information that the Building America research program provides the construction industry forms the basis for this understanding of building science and does so in a manner that is easy to understand and concise**. The diverse make-up of the BA research team assures that industry leaders, business owners, educators, scientists, and governmental specialists all collaborate for the shared benefit of sound and profitable businesses, energy efficient buildings and happy clients.
– Sam Breidenbach, President, TDS Custom Construction

Palm Harbor Homes has been building high quality energy efficient homes for over 30 years. Partnering with Building America helps us learn which items and building systems have the most value to our customers, are the most unique against our competitors products and produce a high quality product. The value you add to a home must be central to the customers wants, needs and decision making process. This is often called a products “value proposition”. **Products without strong value propositions soon have price become their default value proposition. These products are called commodities and we choose not to compete in the commodities market. Maintaining value in a competitive market requires constant research and innovation to drive uniqueness**. Uniqueness is not static. While the best value adders are those that cost the least, improve quality and are hard to copy, success begets imitators. Partnering with Building America helps us determine which products and systems help us meet those criteria. In our business, prices are determined in the market and costs are largely determined in our factory. The level of quality in producing a product determines the cost level of production and delivery to the market. If you begin with the proposition (actually the reality) that everything costs less to do right the first time rather than doing it right eventually then it is easy to see how low quality produces high costs and high quality produces low cost. With guidance from the Building America Team we learn how to do it right the first time and improve our product quality. Having high quality unique value that matters to our customer’s means that we will not be selling something everyone else has. If a customer wants something that only we offer then they have to come to us to buy it. Building high quality Builders Challenge homes gives us homes that are built to last with high value which in turn give us satisfied customers and more referrals. Referrals that won’t shop anyone else because the referring customer was so satisfied.
–Mike Draper, President, Florida Division, Palm Harbor Homes

The **value of systems integration thinking and research** is exemplified in PARR’s steam system balancing and tuning work. These central systems are often a collection of piece meal fixes by disconnected contractors. PARR’s work not only created straightforward and holistic system improvement guidelines but validated effectiveness across 10 buildings in Chicago.
– Ryan Kerr, Gas Technology Institute

PARR’s expert meeting to discuss combustion safety testing and key research needs successfully **brought together the key parties in a way that had not yet been done**. While this meeting brought both sides of the aisle together, past efforts have focused on internal debates among the same stakeholder groups.
– Ryan Kerr, Gas Technology Institute

Building America is a key contributor to the acceleration of systems integration in the marketplace. PARR’s strength is developing, reviewing and optimizing complex systems in the lab and field while applying the results to a complex world. PARR’s research is influenced by the needs of practitioners, our solutions developed in coordination with practitioners and our results

disseminated to practitioners.
– Ryan Kerr, Gas Technology Institute

K Hovnanian over the last five plus years has been committed to identifying, modeling, testing and verifying building performance improvements. We are seeking methods that can be successfully applied in a production building environment, working with today's trade base. At the core of our learning and experiences over these years has been the support of the Building America program. **In all my home building years, over 35, I have never experienced such a public-private partnership that has produced the kind of meaningful, permanent results that the Building America program has**. Just a few examples:

> Through more thoughtful design of HVAC systems, most of our mechanical systems are now inside the building envelope. The key was demonstrating to our trade base and our construction managers the actual in-the-field benefits of better design and that our systems would perform better even though they were smaller. Our HVAC contractor selected for the test tells us that his call backs for customer comfort related issues has declined by 90%.
>
> How to achieve a home with less than 3 ACH 50 economically. Again proving to both internal and external stake holders that with some thought as to how to execute, we can routinely achieve a better performing building.
>
> We have now demonstrated compact duct design and are in the process of migrating to compact design on a significant portion of our designs. The concept and execution on compact design was worked through with Building America pilot homes.
>
> As I think of what next it occurs to me that we have worked our way through the easy improvement opportunities. The next energy performance improvement goals will be more difficult to achieve, we have captured the low hanging fruit. The building science minds represented by the Building America Teams along with the commitment of builders not afraid to innovate will be the driving force. Funding is critical for the next steps and should be expanded to assure continued progress towards more efficient, proven, constructible, repeatable homes with no hidden or unintended consequences.
>
> We look forward to continuing our association with the Building America program and all it has to offer.
> *– Dean Potter, VP Quality and Home Production Processes, K. Hovanian*

The support of the NAHB Research Center's Building America team for computer modeling and testing allowed Nexus EnergyHomes to achieve Emerald Certification to the ICC 700 for all 55 of its homes in Frederick, MD at the North Pointe Homes subdivision with an average HERS index of 27.
– Paul Zanecki, Founder and CEO, Nexus EnergyHomes

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