

Project Closeout: Guidance for Final Evaluation of Building America Communities

P. Norton, J. Burch, and B. Hendron

Technical Report
NREL/TP-550-42448
March 2008

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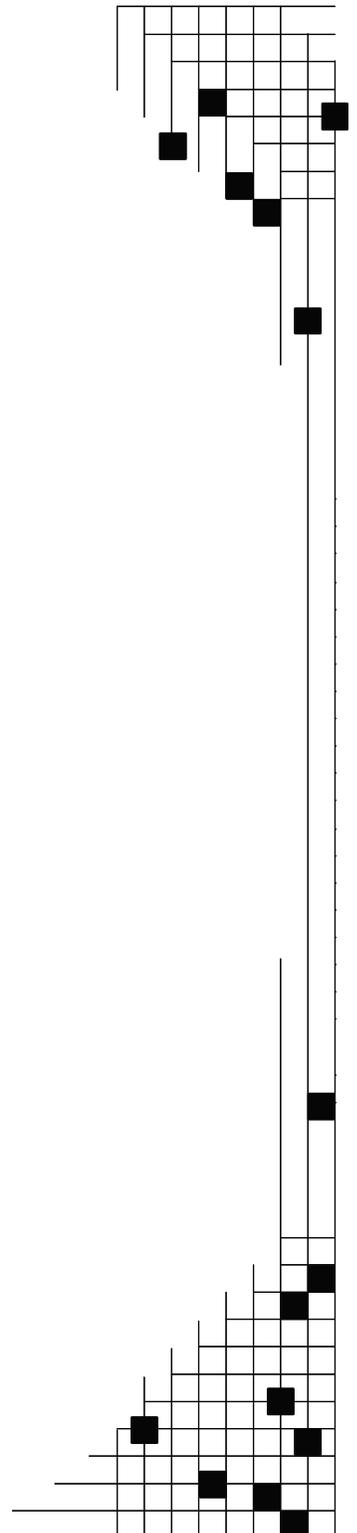
Prepared under Task No. BET88001

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303-275-3000 • www.nrel.gov

Operated for the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
by Midwest Research Institute • Battelle

Contract No. DE-AC36-99-GO10337



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Acknowledgments

This document was completed with the help of a working group that provided extensive input through weekly conference calls as the document was being developed and reviews of the completed draft document. The working group members are:

Bruce Baccei of ConSol
Srikanth Puttagunta of Steven Winter Associates
Danny Parker of the Florida Solar Energy Center
David Springer of the Davis Energy Group
Tom Taylor of Pacific Northwest National Laboratory
Kohta Ueno of Building Science Corporation

This work was supported by the U.S. Department of Energy Building Technologies Office, Edward Pollock, Office Director.

For their contributions, the authors would like to thank Kelly Kissock of the University of Dayton; Elizabeth Brown and Stefanie Woodward of NREL; Edward C. Hancock of Mountain Energy Partnership; Barbara Farhar; and Tim Coburn of Abilene Christian University.

Executive Summary

The U.S. Department of Energy researches improvements in residential energy efficiency through its Building America (BA) program. The ultimate goal of the BA program is to develop cost-neutral zero-energy homes for all climate zones by 2020. An intermediate goal of the program is to develop homes with energy savings from 30% to 90%, as measured against the BA Benchmark. The Benchmark is a well-defined building and occupant description that provides a fixed reference corresponding to approximately 1994 code and to “average” occupants. A stage-gate process is used to guide the progress toward these goals.

This report presents guidelines for Project Closeout. It is used to determine whether the BA program is successfully facilitating improved design and practices to achieve energy savings goals in production homes. Its objective is to use energy simulations, targeted utility bill analysis, and feedback from project stakeholders to evaluate the performance of occupied BA communities.

The production home evaluation begins with the testing and analysis of a sample of homes from the production community to verify the source energy savings for the package of energy efficiency measures used. These results are augmented with information collected from the BA builder, publicly available sales information, and a homeowner questionnaire to address all Project Closeout criteria. The Project Closeout criteria represent the minimum set of programmatic topics that must be addressed by the final evaluation of occupied BA homes.

Acronyms

ACH	air changes per hour
BA	Building America
CEC	California Energy Commission
CV	coefficient of variance
DOE	U.S. Department of Energy
ECM	electronic control module
ERV	energy recovery ventilator
HVAC	heating, ventilation, and air conditioning
IQR	inner quartile range
IRB	Institutional Review Board
MEL	miscellaneous electricity loads
NAC	normalized annual consumption
NCDC	National Climate Data Center
NREL	National Renewable Energy Laboratory
OMB	Office of Management and Budget
PRA	Paperwork Reduction Act
PV	photovoltaic
QA	quality assurance
QC	quality control
RH	relative humidity
SD	standard deviation
SHGC	solar heat gain coefficient
TMY	typical meteorological year
TVA	Tennessee Valley Authority
ZEH	zero-energy home

Nomenclature

N	number in sample or subset
Q	quantity of fuel energy (electrical, gas, or source), monthly or annual sum
ΔQ	difference in annual energy consumption
comm	community, BA or reference (Ref)
fuel	fuel type - electricity or natural gas
h	house
m	month
Ref	reference community to be compared to the BA community
regr	regression results
sim	simulation results

Notes on notation: Energy quantities Q are annual totals over 12 months, unless explicitly subscripted by month. To distinguish simulated and regressed quantities from actual data, simulated quantities are always superscripted ^{sim}, regressed quantities as ^{regr}.

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Introduction

The U.S. Department of Energy (DOE) researches improvements in residential energy efficiency through its Building America (BA) program. The ultimate goal of the BA program is to develop cost-neutral zero-energy homes (ZEHs) for all climate zones by 2020. An intermediate goal of the program is to develop homes with energy savings from 30% to 90%, as measured against the BA Benchmark [1]. The Benchmark is a well-defined building and occupant description that provides a fixed reference corresponding to approximately 1994 code and to “average” occupants. A stage-gate process is used to guide the progress toward these goals. Details about the stage-gate process are presented in Appendix A. The stages for each energy savings level are given below:

Stage 1	System Evaluations
Stage 2	Prototype House Evaluations
Stage 3	Initial Community Evaluations
Project Closeout	Final Evaluations of Occupied Homes

This report presents guidelines for Project Closeout. It is used to determine whether the BA program is successfully facilitating improved design and practices to achieve energy savings goals in production homes.

Project Closeout Criteria

Objective

Use energy simulations, targeted utility bill analysis, and feedback from project stakeholders to evaluate the performance of occupied BA communities.

Must-Meet Criteria

Source Energy Savings

1. Final production homes must provide targeted whole house source energy savings based on BA performance analysis procedures and energy performance measurements in unoccupied homes.

Neutral Cost Target

2. The final incremental annual cost of energy improvements, when financed as part of a 30-year mortgage, should be less than or equal to the annual reduction in utility bill costs relative to the BA Benchmark house.

Quality Control Integration

3. Health-, safety-, durability-, comfort-, and energy-related quality assurance (QA) and quality control (QC) training and commissioning requirements must be integrated within construction documents, contracts, and subcontractor scopes of work and builder quality procedures.

Should-Meet Criteria

Marketability

1. Based on sales data, should be marketable relative to the value-added benefit (which includes utility peak demand reduction benefits) seen by consumers at increased or neutral cost.

Builder Commitment

2. Should demonstrate strong builder commitment to continued construction at current or future BA performance targets.

Homeowner Satisfaction

3. Should demonstrate high levels of homeowner satisfaction

Gaps Analysis

4. Should include a summary of builder technical support requirements, gap analysis, lessons learned, optimal builder business practices, what not to do, documentation of failures, recommendations for policy improvements, and major technical and market barriers to achieving the next performance levels.

Evaluation Summary

The production home evaluation begins with the testing and analysis of a sample of one or more homes from the production community. The testing and analysis are used to verify the source energy savings for the package of energy efficiency measures used. These results are augmented with information collected from the BA builder, publicly available sales information, and a homeowner questionnaire to address all Project Closeout criteria.

The Project Closeout criteria do not exhaust the possible research topics that can be addressed for production homes. Although the Project Closeout criteria represent the minimum set of programmatic topics that must be addressed by the final evaluation of occupied BA homes, specific projects may provide opportunities to pursue other important research objectives. When the specifics of the project and sufficient cost sharing present the opportunity, a detailed evaluation of the community average energy savings compared to a reference community can be performed with a utility bill analysis. Detailed information about building performance and interactions with occupant behavior can be gathered through long-term end-use monitoring. Guidelines for community utility bill analysis and end-use monitoring, as well as a case study about end-use monitoring, are included in appendices.

Short-Term Testing and Performance Analysis

Short-term tests provide insight into the performance of the home and identify construction and installation issues. The results of the tests are used as input information for tuning simulations to approve their accuracy in areas that are difficult to know without measurements. The *Building America Performance Analysis Procedures* [2] are then applied to evaluate the source energy savings in relation to the BA Benchmark.

The testing and analysis address Must-Meet Gate Criterion 1 – *Source Energy Saving*, and Should-Meet Gate Criterion 4 – *Gaps Analysis*.

Information Provided by the Building America Builder

The BA builder of the production homes can provide important information about the characteristics of the homes in each community, the incremental cost of energy efficiency features, construction documentation, implementation experiences, QA procedures, training and commissioning practices, home sales, callbacks, and commitment to continuing BA practices in future communities.

This information addresses Must-Meet Gate Criteria 2 and 3 – *Neutral Cost Index* and *Quality Control Integration*, and Should-Meet Gate Criteria 1, 2, and 4 – *Marketability*, *Builder Commitment*, and *Gaps Analysis*.

Sales and Home Value Data Analysis

In addition to any sales information obtained directly from the community builders, public records are available for home sales information. These records can be used to determine sale prices, rate of home sales, and resale values.

The sales data addresses Should-Meet Gate Criterion 1 – *Marketability*.

Homeowner Questionnaires

There is much information about the homes and their operation that can be gathered only from the homeowners. Information about equipment in the home, temperature set points, homeowner demographics, purchase decision making, homeowner satisfaction, and homeowner attitudes toward energy efficiency can be included in a questionnaire.

The homeowner questionnaire addresses Should-Meet Gate Criteria 3 and 4 – *Homeowner Satisfaction* and *Gaps Analysis*.

Optional Additional Analyses

Utility Bill Analysis (Appendix C)

Utility bill analysis provides a direct comparison between the actual energy use in a BA community and a community built using standard practices. Careful attention to sample size, potential bias, and outliers is needed to achieve statistically significant results. The analysis can be augmented with linear regression techniques. The results of the comparison are compared to expectations based on building simulations.

End-Use Monitoring (Appendix D)

End-use monitoring allows the overall energy use of the home to be disaggregated into components and sheds light on how the energy is being used in the home. This can help answer how much home energy was saved and how it was saved. If the savings are lower than expected, end-use monitoring can shed light on why. Challenges with end-use monitoring include potentially high equipment, installation, and analysis costs.

Short-Term Testing and Performance Analysis

In response to Project Closeout Must-Meet Gate Criterion 1 – *Source Energy Savings*, one or more homes from the production community will be tested and simulated to evaluate the annual whole-house source energy savings in the production home community. BA Benchmark assumptions about occupant choices and behavior are used to perform this evaluation according to the *Building America Performance Analysis Procedures*. These results are then compared to the Stage 3 and Stage 4 results for the community to ensure that the expected energy savings level has been achieved in the production homes.

A battery of short-term tests with well-established protocols is available for testing homes. These include:

- Envelope leakage (house pressurization)
- Duct leakage (duct pressurization, nulling test, Delta-Q)
- Air handler flow rate (flow plate)
- Infrared thermograph (IR camera)
- Register flows (flow hood)

Short-term testing provides quick feedback on new equipment installed in BA homes. These tests can be designed to address specific questions about the new equipment. Examples include tracer gas testing to determine ventilation rates achieved by new ventilation equipment and coefficient of performance testing of new ground-source heat pumps.

For the production home evaluation, short-term testing will be used to provide input to building simulations. These inputs, such as envelope and duct leakage, are difficult to estimate without direct measurements.

The results of the short-term test and the simulated energy savings must be compared to the Stage 3 and Stage 4 results for the community. Any differences in performance between the prototypes, early production, and production homes should be presented and discussed.

Information Provided by the Building America Builder

The type and amount of information available about the incremental cost of energy efficiency features, construction documentation, implementation experiences, QA procedures, training and commissioning practices, home sales, and callbacks vary considerably among builders. For example, some builders do not track callbacks at all; others hire outside firms to collect, track, and analyze their callback information. Because of the wide variation in the availability of this type of information, specific protocols cannot be prescribed. The BA team must work with the BA builder to ascertain what information to collect and present about each production home project. Incremental cost data and sales and marketing information will be available from most builders and should be presented.

Home and Equipment Descriptions

Details about home construction and installed equipment should be collected from the builders of the BA and reference communities. At a minimum, the information collected should include:

- Shell construction details and insulation levels
- Foundation type and insulation levels
- Attic type and insulation levels
- Roof color
- Window types, U-values, and solar heat gain coefficients (SHGCs)
- Ventilation system details
- Percentage of ductwork in conditioned spaces
- Ductwork insulation levels
- HVAC equipment type, fuel used, capacity, and efficiency ratings
- Type of thermostat (programmable or nonprogrammable)
- Water heater type, fuel used, and efficiency rating
- Appliances included as standard and the fuels they use
- Type of hard-wired lighting (incandescent, compact fluorescent, etc.)
- Installed wattage of interior lighting
- Installed wattage of exterior lighting
- Energy-related options offered to the home buyers
- Number of stories of each model
- Square footage and number of bedrooms for each model
- Number and type (wood or natural gas) of fireplaces in each model
- Number of homes of each model

Incremental Cost Data

In general, the BA builder can provide the incremental costs of energy upgrades. These are usually costs *to the builder* relative to the *builder's standard practice*. These do not represent costs to the homeowner or costs relative to the BA Benchmark home. The incremental cost information may have been collected in previous stages with the BA builder. The cost information should be combined with the expected energy savings relative to the BA Benchmark and the local utility tariffs to calculate the Building America Neutral Cost Index [3]. Incentives or rebates may be available for some equipment such as photovoltaic (PV)

systems. These incentives may be available to the builder or to the homeowners. The cost information should be presented with and without the contribution of the total incentives (both to the builder and the homeowner). The form of the table to present the cost information is given in Table 1. Where multiple measures are closely linked or dependent, combined costs for the package of measures may be provided.

Table 1. Presentation of Cost Information and the BA Cost Index

Efficiency or Renewable Energy Measure	Builder's Incremental Cost without Incentives	Builder's Incremental Cost with Incentives*
<i>Measure 1</i>	\$xxx	\$xxx
<i>Measure 2</i>	\$xxx	\$xxx
.....
Total incremental cost versus builders' standard practice		
Incremental annual cost on 30-yr mortgage @ 7%		
Annual electricity savings versus BA Benchmark	kWh	kWh
Annual natural gas savings versus BA Benchmark	therms	therms
Annual utility bill savings versus BA Benchmark	\$	\$
Building America Cost Neutrality Index		

* Incentives delivered to the builder or the homeowner are included.

Sales and Marketing Materials

The materials used to market the BA homes and their energy efficiency features should be collected and included in the community evaluation report. These materials will generally be publicly available and easy to collect.

Sales Data

An effort should be made to collect sales data, including the advertised sale price of each home model and cost of available upgrades, from the BA builder. Other information that may be available from the builder includes:

- The rate of home sales (i.e. homes sold per month)
- The turnover rate (time between home completion and sale)
- Change in sale prices over time

Information about actual sales dates and prices is public and available through the Internet, as discussed in the next section; however, any specific sales information from the builders should be collected and reported and may be more cost effective than collecting the information through the Internet.

Quality Control Integration

The BA builder's approach to ensuring QC should be reported. Examples of this include quality testing such as building and duct leakage testing, and integrating air leakage instructions into plan sets. Difficulties encountered and lessons learned should be gleaned

through conversations with key builder staff and documented in the production home evaluation. Any available information about commissioning should be included.

Callback Information

A callback occurs when a new homeowner is not happy with some aspect of his or her new home and a builder needs to perform some after-sale repair. Callbacks directly affect a builder's profitability.

Builders vary widely in their tracking of callbacks. Some hire outside firms to track and analyze callbacks; others do not track them at all. The approach used by the BA builder to track callbacks should be documented in the production home evaluation. All specific information available about the number and type of callbacks should be reported.

Sales and Home Value Data Analysis

In addition to any sales information obtained directly from the community builders, public records are available for home sales information. These records can be used to determine sale prices, rate of home sales, and resale values.

When a house is sold, the date of sale and price become public record. Many Web sites such as RealEstateABC.com and Zillow.com provide this information for any given address. This information should be collected and presented for all addresses in the BA and reference community samples.

This information can be used to verify and augment the sales data collected from the builders. In addition, if any homes in the communities were resold, data about the resale value and appreciation rate should be presented.

Homeowner Questionnaires

A questionnaire will be used to gauge homeowner satisfaction in response to the Project Closeout Should-Meet Gate Criterion 3. Although a succinct questionnaire is likely to illicit the greatest number of responses, this must be balanced against the wealth of information that could be gleaned from the homeowners in the BA community. A great deal of information about the homes can be gathered only from the homeowners. In addition to homeowner satisfaction, information about equipment, temperature set points, homeowner behavior and demographics, purchase decision making, and attitudes toward energy efficiency can be included in a questionnaire. However, persuading a high percentage of homeowners to complete the questionnaire is a major challenge. If a utility bill analysis is part of the evaluation, the questionnaire can identify homes with unusually high or low temperature set points and high energy use equipment such as pools, spas, second refrigerators, and stand-alone freezers.

Clearly defining objectives is the first step in designing a questionnaire that delivers useful information. Objectives of a homeowner questionnaire may include understanding what energy equipment is in the home (pool, spa, second refrigerator, etc.), occupant behavior (set points), occupant demographics (age, income, level of education, etc.) and homeowner perceptions (satisfaction, purchase decision making processes, perceptions of the builder, marketing materials, efficiency features, etc.). The objectives for a given project will be determined by the needs of all project partners.

Questionnaire Design and Methods

The questionnaire should be kept as short and simple as possible. Such a questionnaire is more likely to be completed and will therefore provide the most information. When deciding what questions to include, ask yourself what you will do with the answers to those questions. Try to avoid questions that simply provide interesting information but do not substantively aid in the community evaluation.

Include a “Don’t know” option in questions where the homeowner may reasonably not know the answer. It may be helpful to review Web sites with tips for good questionnaire design. Examples include Creative Systems Research (<http://www.surveysystem.com/sdesign.htm>) and Statpac (<http://www.statpac.com/surveys>). Once the design is completed, it is a good idea to pretest the questionnaire with a set of homeowners outside the communities being studied. A pretest can provide valuable feedback about your questionnaire design before you apply it to the community evaluation. If the utility company is a partner in the evaluation, it may conduct questionnaires of its own; the BA team may be able to piggyback energy-related questions onto these.

There are various methods for delivering the questionnaire, including personal interviews, telephone interviews, mail, and e-mail. Personal interviews can be scheduled with a phone call to the homeowner and can be done in the home. This approach is expensive, but provides the advantage of potentially longer questionnaires and the possibility of examining home energy equipment directly. Telephone interviews may be done by BA team members or by a professional telephone marketing firm. This approach may be fastest way to collect the

information, but many people are put off by telephone marketers. Delivering a questionnaire by mail is a less expensive approach, but it takes more time and the response rate can be low—20% to 50% response rates are typical. Response rates can be improved by mailing a card or letter before the survey telling the homeowners that the survey is coming then mailing a card after the survey to remind them to fill out the survey and return it. Another way to increase the response rate is to include an incentive. In the SheaHomes study [4] a \$10 bill was enclosed with the survey. Other possibilities to increase the response rate include entering the people who return completed surveys in a drawing for a prize or offering a copy of the completed study to those who respond to the survey. E-mailing questionnaires has the advantage of speed, but you must have the homeowners' e-mail addresses and you run the risk of having the questionnaire spam filtered or lost.

Questions to Include

Homeowner satisfaction must be addressed in the questionnaire to fulfill the gate criteria. The questionnaire can also aid in a gaps analysis by identifying areas of homeowner dissatisfaction and high energy use equipment that is not included in current BA savings strategies.

Appendix B contains a sample questionnaire that can be used directly or modified to meet the needs of a specific production home evaluation. The questions focus on high energy use equipment, occupant behavior, homeowner satisfaction, and some basic information such as the number of people living in the home. Some of these questions are most useful when used in conjunction with a utility bill analysis, and may not be needed on all projects. Additional questions may be added for specific projects with objectives that go beyond the Project Closeout Criteria.

Approval for Questionnaires

Two potential legal issues are associated with homeowner questionnaires:

- Protection of Human Subjects (Federal regulation Title 45, Part 46) (available at <http://www.hhs.gov/ohrp/humansubjects/guidance/45cfr46.htm>)
- The Paperwork Reduction Act (PRA) (Public Law 104-13) (available at <https://acc.dau.mil/communitybrowser.aspx?id=33632>)

Once the questionnaire is in its final form, the Protection of Human Subjects regulation requires the questionnaire be reviewed by an Institutional Review Board (IRB) before being distributed to the homeowners. The role of an IRB is to ensure that human subjects are adequately protected from risk of harm and that their rights are protected. If you do not have an IRB in-house, you may be able to use the IRB of a local university. The IRB will provide guidance about the information and forms that must be provided for the review process.

The National Renewable Energy Laboratory (NREL), as a government-owned contractor-operated (GOCO) laboratory is exempt from the PRA and the requirement to obtain Office of Management and Budget (OMB) collection of information clearance. However, DOE and teams that have cooperative agreements with DOE will require OMB approval for the

questionnaire. A summary of the requirements of the PRA with examples is available at http://www.usa.gov/webcontent/reqs_bestpractices/laws_regs/paperwork_reduction.shtml. A form with instructions for obtaining the approval is available at <http://www.whitehouse.gov/omb/inforeg/83i-fill.pdf>.

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Appendix A The Building America Stage-Gate Process

The BA systems research is applied in five stages for each climate zone, and a stage-gate planning process [5] is used to review the project status after each stage is completed. BA acts as a national residential energy systems test bed where homes with different system options are evaluated, designed, built, and tested during the five stages. To accelerate progress toward multiyear goals, research is conducted in parallel at different performance levels, facilitating rapid use of new system solutions at all performance levels. Research houses, production prototype houses, and evaluations of community-scale housing validate the reliability, cost effectiveness, and marketability of the energy systems that are integrated into production housing.

The first stage focuses on evaluating the expected savings and benefits of technology packages, including advanced systems and the evaluation of system performance specifications relative to BA performance goals. From these results, the optimal efficiency targets can be identified and technologies developed that will meet the energy savings needs cost effectively in all climate regions.

Stages 2 and 3 implement successful energy-saving strategies from Stage 1 into the day-to-day business practices of production home builders. After the initial community evaluations in Stage 3 are complete, a low level of technical support may be provided as needed to ensure the system research results are implemented. A summary of the three stages of the system research process is captured in Figure A1.

Building Technologies Corporate Stage-Gate Criteria

The Building Technologies (BT) corporate stage-gate criteria are applied across all projects and throughout all stages with slight modifications as stages progress. Stage-gate criteria are separated into must-meet and should-meet criteria. The corporate criteria are generally what a particular activity must or should meet to proceed. The answer to these criteria has to be “yes” or the activity is sent back for more information. The should-meet criteria are less stringent and can be passed at a less than fully satisfactory level if the next stage is likely to satisfy these criteria.

Must-Meet Criteria

- Does the technology or system address a priority or an identified need for achieving ZEB?
 - Is the proposed work compatible with the BT program rationale and priorities, as identified in the Multi-Year Plan, technology roadmaps, and other approved materials?
 - Does the proposed project have a clear potential role in the residential integration initiatives?
- Is the technology or system technically feasible?
 - Have horizon scanning and literature reviews been conducted for feasibility insight?

- What are the technical barriers or showstoppers from the literature review?
- How superior (quantitatively) is the technology potentially in performance to current and future alternatives?
- Is the DOE role clear and compelling?
- If DOE does not conduct this work, will anyone else, including other nations, take over?
- If DOE opts out, what opportunity does the nation lose? (How large is the lost opportunity?)

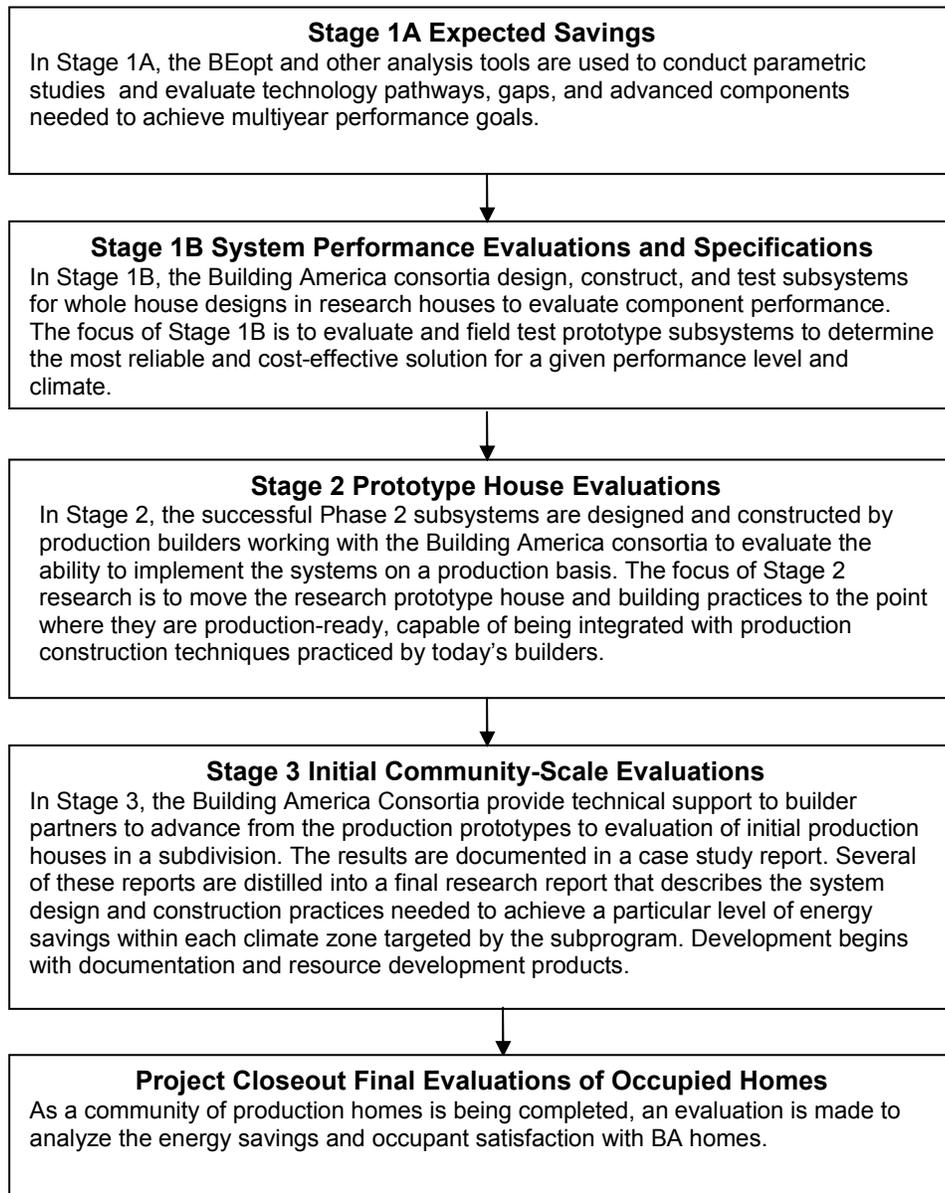


Figure A1. Residential integration systems approach

- Does the proposed technology or system provide significant energy savings potential?
- Do you have a detailed plan for the next stage? (Milestones, required budgets to realize a probability of success within the timeline stated, and a list of success factors and showstoppers.)

Should-Meet Criteria

- Can the technology or system compete economically against current and future alternatives? (Advantages over baseline.)
 - Determine a realistic target market segment.
 - Determine potential customers (based on their economics, wants, and needs)
 - Determine likely competing best available technologies or systems.
 - Estimate national energy savings potential.
- Do any legal or regulatory issues need to be addressed?
 - Perform a quick patent search.
 - Conduct a quick building code consultation with BT codes staff to determine potential hurdles.

Building America Project-Specific Stage-Gate Criteria

In addition to the BT corporate stage-gate criteria, several must-meet and should-meet criteria are specific to BA projects.

Gate 1 – System Evaluations

Gate 1A – Expected Whole House Energy Saving and Cost Targets

Gate 1A – Research Objective

Within a whole building context and technology package, use energy simulations and currently available performance data to estimate the system’s contribution to BA energy performance and neutral cost targets.

Gate 1A – Must-Meet Criteria

1. Source Energy Savings Target Expected source energy savings of a technology package, including the advanced system must meet BA program performance goal.

Neutral Cost Target

2. The incremental mature market cost of all energy improvements, when financed as part of a 30-year mortgage, should be less than or equal to the annual reduction in utility bill costs relative to the BA Benchmark house.

Gate 1A – Should-Meet Criteria

Least Cost

1. The mature market incremental cost of technology package, including advanced system should be less than or equal to currently available least cost alternatives based on the sum of utility bills and energy-related increases in mortgage costs.

Marketability

2. The system should contribute market value and performance benefits, including utility peak demand reduction benefits, relative to climate region best practices.

Gaps Analysis

3. Should include initial evaluation of major technical and market barriers to achieving the targeted system performance levels.

Gate 1B – System Evaluations and Specifications

Gate 1B – Research Objective

Use bench-top tests, laboratory tests, tests in laboratories and research homes, and energy simulations to evaluate performance benefits and develop performance specifications for advanced systems.

Must-Meet Gate Criteria

Source Energy Savings and Whole Building Benefits

1. New whole house system solutions must provide demonstrated source energy and whole building performance benefits relative to current system solutions based on BA test and analysis results.

Performance-Based Code Approval

2. Must meet performance-based safety, health, and building code requirements for use in new homes.

Gate 1B – Systems Should-Meet Criteria

Prescriptive-Based Code Approval

1. Should meet prescriptive safety, health, and building code requirements for use in new homes.

Cost Advantage

2. Should provide strong potential for cost benefits relative to current systems within a whole building context.

Reliability Advantage

3. Should meet reliability, durability, ease of operation, and net added value requirements for use in new homes.

Manufacturer/Supplier/Builder Commitment

4. Should have sufficient logistical support (warranty, supply, installation, and maintenance support) to be used in prototype homes.

Gaps Analysis

5. Should include the system's gaps analysis, lessons learned, and evaluation of major technical and market barriers to achieving the targeted performance level.

Gate 2 – Prototype House Evaluations

Gate 2 – Objective

Use results from field tests and energy simulations to evaluate the ability to integrate advanced systems with production building practices in prototype homes.

Must-Meet Gate Criteria

Source Energy Savings

1. Prototype homes must provide targeted whole house source energy savings based on BA performance analysis procedures and energy performance measurements.

Prescriptive-Based Code Approval

2. Must meet prescriptive or performance safety, health, and building code requirements for new homes.

Quality Control Requirements

3. Must define critical design details, construction practices, training, QA, and QC practices required to successfully implement new systems with production builders and contractors.

Should-Meet Criteria

Neutral Cost Target

1. The incremental annual cost of energy improvements, when financed as part of a 30-year mortgage, should be less than or equal to the annual reduction in utility bill costs relative to the BA Benchmark. The estimated mature market cost is used to evaluate incremental first cost relative to a builder's standard practice.

Quality Control Integration

1. Health, safety, durability, comfort, and energy-related QA, QC, training, and commissioning requirements should be integrated within construction documents, contracts, and subcontractor scopes of work.

Gaps Analysis

2. Should include prototype house gaps analysis, lessons learned, and evaluation of major technical and market barriers to achieving the targeted performance level.

Gate 3 – Initial Community-Scale Evaluations

Gate 3 – Objective

Use energy simulations and targeted field tests, if needed, to evaluate the performance of final production building designs.

Must-Meet Gate Criteria

Source Energy Savings

1. Final production home designs must provide targeted whole house source energy efficiency savings based on BA performance analysis procedures and previous stage energy performance measurements.

Market Coverage (including project from all teams)

2. Must have at least 5 builders with at least 10 homes per project and at least 5 homes completed by March or April.

Neutral Cost Target

3. The incremental annual cost of energy improvements, when financed as part of a 30-year mortgage, must not exceed the annual reduction in utility bill costs relative to the BA benchmark house. The mature market incremental first cost is evaluated relative to a builder's standard practice.

Should-Meet Criteria

Marketability

1. Based on initial response from model homes, should be marketable relative to the value-added benefit seen by consumers at increased or neutral cost.

Market Coverage

2. Project case studies should cover a representative range of weather conditions and construction practices in major metropolitan areas in the targeted climate region.

Builder Commitment

3. Should demonstrate strong builder commitment to continued construction at current or future BA performance targets.

Gaps Analysis

4. Should include a summary of builder technical support requirements, gaps analysis, lessons learned, optimal builder business practices, what not to do, documentation of failures, recommendations for policy improvements, and remaining technical and market barriers to achieving current and future performance levels.

Quality Assurance

5. Should provide documentation of builder's energy-related QA and QC processes.

Final Project Closeout Evaluations

Closeout Objective

Use energy simulations, targeted utility bill analysis, and feedback from project stakeholders to evaluate the performance of occupied BA communities.

Must-Meet Criteria

Source Energy Savings

1. Final production homes must provide targeted whole house source energy savings based on BA performance analysis procedures and energy performance measurements in unoccupied homes

Neutral Cost Target

2. The final incremental annual cost of energy improvements, when financed as part of a 30-year mortgage, should be less than or equal to the annual reduction in utility bill costs relative to the BA Benchmark house.

Quality Control Integration

3. Health, safety, durability, comfort, and energy-related QA, QC, training, and commissioning requirements must be integrated within construction documents, contracts, and subcontractor scopes of work and builder quality procedures.

Should-Meet Criteria

Marketability

1. Based on sales data, should be marketable relative to the value-added benefit, including utility peak demand reduction benefits, seen by consumers at increased or neutral cost.

Builder Commitment

2. Should demonstrate strong builder commitment to continued construction at current or future BA performance targets.

Homeowner Satisfaction

3. Should demonstrate high levels of homeowner satisfaction.

Gaps Analysis

4. Should include a summary of builder technical support requirements, gaps analysis, lessons learned, optimal builder business practices, what not to do, documentation of failures, recommendations for policy improvements, and major technical and market barriers to achieving the next performance levels.

Appendix B Basic Homeowner Questionnaire

Questionnaire on the Energy Use and Comfort of Your Home

PLEASE COMPLETE AND RETURN THIS QUESTIONNAIRE WITHIN 10 DAYS

This short questionnaire is designed to help us understand the energy use within your home as part of a home energy study sponsored by the U.S. Department of Energy. It will be used in conjunction with an analysis of your utility bills. Your name and address will be kept confidential and will not appear in publications of the results of this study.

Do you have an electric or natural gas stovetop? ***[Please check one response.]***

- Electric
- Natural gas

Do you have an electric or natural gas oven? ***[Please check one response.]***

- Electric
- Natural gas

Do you have an electric or natural clothes dryer? ***[Please check one response.]***

- Electric
- Natural gas

Have you had to replace any light bulbs? ***[Please check one response.]***

- Yes If yes, did you purchase compact fluorescent lights (CFLs)? Yes No Don't know
- No

How many people are currently living in your home? ***[Please check one response.]***

- 1
- 2
- 3
- 4
- 5
- 6
- More than 6 - Please enter the number of people living in your home: _____

How many television sets do you have in your home? ***[Please check one response.]***

- 1
- 2
- 3
- 4
- 5
- 6
- More than 6 - Please enter the number of television sets in your home: _____

How many desktop computers do you have in your home? *[Please check one response.]*

- 1
- 2
- 3
- 4
- 5
- 6
- More than 6 - Please enter the number of desktop computers in your home: _____

Is there generally someone at home all day on the weekdays? *[Please check one response.]*

- Yes
- No

At what temperature do you set your thermostat during the day *in the winter?*

[Please check one response.]

- 68°F
- 69°F
- 70°F
- 71°F
- 72°F
- 73°F
- 74°F
- Other – Please enter your thermostat setting: _____ °F

At what temperature do you set your thermostat during the day *in the summer?*

[Please check one response.]

- 73°F
- 74°F
- 75°F
- 76°F
- 77°F
- 78°F
- 79°F
- Other – Please enter your thermostat setting: _____ °F

Do you change your thermostat settings at night?

- Yes
- No

Do you use natural ventilation (opening windows at night) to avoid air conditioner use?

- Yes
- No

Please indicate if you have any of the following items in your home or yard:
[Please check all items present in your home.]

- Swimming pool
- Indoor or outdoor spa or hot tub
If checked, please indicate if your spa or hot tub is heated by electricity or natural gas
 - Electricity
 - Natural gas
 - Don't know
- Second refrigerator
If you know the approximate model year, please enter it here ____
- Independent freezer (not part of a refrigerator)
- Plasma TV
- Microwave oven
- Cable or satellite TV control box
- Dehumidifier
- Whole house fan (attic fan)
- Heated waterbed
- Window air conditioner
If checked, please indicate how many window air conditioners there are in your home: ____
- Portable electric heaters
If checked, please indicate how many portable electric heaters you use in your home:

- Aquarium
If you know the number of gallons, please enter it here: ____
- Ceiling fans
If checked, please indicate how many ceiling fans are in your home: ____
- Hot water circulation pump

PLEASE USE THE SPACE BELOW TO TELL US OF ANY POTENTIALLY HIGH ENERGY USES IN YOUR HOME. Examples include a welding or woodworking shop, a large number of grow lights for houseplants, an electric car, and a hobby that requires electricity or natural gas.

Please indicate the extent to which you agree or disagree with the following statements.
[For each statement, please circle one response.]

	Strongly Disagree	Disagree	Neutral/ Unsure	Agree	Strongly Agree
1. My home is comfortable in the winter.	1	2	3	4	5
2. My home is comfortable in the summer.	1	2	3	4	5
3. My home is comfortable all year round.	1	2	3	4	5
4. All rooms in my home are equally comfortable.	1	2	3	4	5
5. I am satisfied with the overall comfort of my home.	1	2	3	4	5
6. My home has low utility bills for its size.	1	2	3	4	5
7. My home was a good value at the price I paid for it.	1	2	3	4	5
8. I am satisfied with my home overall.	1	2	3	4	5

If there are solar aspects of your home, please respond to number 9:

9. The solar aspects of my home are important to me.	1	2	3	4	5
--	---	---	---	---	---

PLEASE USE THE SPACE BELOW FOR ANY FURTHER COMMENTS YOU HAVE ABOUT YOUR HOME.

THANK YOU FOR PARTICIPATING IN THIS STUDY!

Please complete the enclosed Utility Release Form. This will release your local utility to supply data on your home's energy use for this study. We will not identify homeowners or addresses in the results – your confidentiality will be maintained.

Please seal the completed Utility Release Form and the completed questionnaire in the postage-paid, business reply envelope and drop it in the mail.

Appendix C Utility Bill Analysis

Utility bill analysis provides a direct comparison between the actual energy use in a BA community and a community built using standard practices. Careful attention to sample size, potential bias, and outliers is needed to achieve statistically significant results. The analysis can be augmented by applying linear regression techniques. The results of the comparison are compared to expectations based on building simulations. The sample size needed for the analysis may be more realizable if the utility participates in the study.

A utility bill analysis provides the average source energy savings of the BA community compared to a reference community chosen to represent standard practice. Additional information gleaned from a utility bill analysis includes:

- Differences between the communities in electricity use, natural gas use, and utility bill cost.
- Measures of the variability in energy use in the BA and standard practice communities.
- Identification and investigation of high and unusual energy using households.

A utility bill analysis is estimated to cost \$64,000 to \$140,000 for two communities of 50 homes each. The lower end of cost estimate assumes utility partnership.

Selection of Building America and Reference Communities

Perhaps the most important step in the utility bill analysis is the choice of the communities to be compared. The choice should minimize biases that arise from systematic differences between communities, such as house size and occupant effects. The utility bill analysis focuses on determining energy use differences as a result of BA building practices, and bias is a key issue. This section presents criteria for making good community choices.

The reference community should represent a group of houses for which there is an expected energy savings compared to the BA community, such as Builders Standard Practice and Regional Standard Practice.

Any community of homes will have substantial house-to-house variation in energy use, even for the same model of home. Nearly an order of magnitude between high and low energy use for a given home model was recently observed [6]. These variations are due to occupant choices and behavior. Some examples of occupant choices that affect energy use are pools, spas, second refrigerators or freezers, fish tanks, large entertainment centers, and multiple TVs. Occupant behavior that affects energy use is a complex sociological field of study. Examples are equipment usage schedules (how things are turned on and off), shower frequency and duration, and thermostat set points.

Minimum Community Sizes

The variation in energy use caused by occupancy effects is a valid research topic in its own right. However, this variation represents noise in the signal that we seek to discern with the utility bill analysis. We can minimize the effect of this noise by examining large

communities with large expected energy savings. In reality we have a limited number of communities and a limited number of houses to choose from. We can use statistics to describe the difference between two populations as guidance for the minimum number of homes we need in each community to discern a statistically significant difference [7]. For these calculations, we assume normal distributions and unbiased samples.

With these assumptions, the difference between two population means is given by:

$$Q_{\text{Ref}} - Q_{\text{BA}} \pm z_{\alpha/2} SE_{(Q_{\text{Ref}} - Q_{\text{BA}})}$$

Where:

$$SE_{(Q_{\text{Ref}} - Q_{\text{BA}})} = \sqrt{\frac{\sigma_{\text{Ref}}^2}{n_{\text{Ref}}} + \frac{\sigma_{\text{BA}}^2}{n_{\text{BA}}}}$$

Q_{Ref} = mean energy for the reference community

Q_{BA} = mean energy for the BA community

n_{Ref} = sample size for reference community

n_{BA} = sample size for the BA community

σ_{Ref} = standard deviation for the reference community

σ_{BA} = standard deviation for the BA community

$z_{\alpha/2}$ = 1.645 for 90% confidence level

$SE_{(Q_{\text{REF}} - Q_{\text{BA}})}$ = standard error of the mean energy savings

Before initiating a utility bill analysis, the confidence interval ($z_{\alpha/2} SE_{(\bar{x}_{\text{REF}} - \bar{x}_{\text{BA}})}$) must be estimated using this equation at a 90% confidence level. To proceed with the evaluation, the confidence interval must not exceed 20% of the expected average energy savings between the BA and the reference communities. Estimated confidence intervals exceeding 20% indicate that a larger sample size is needed to achieve meaningful results.

Table C1 shows some example sample size estimates based on a 90% confidence level, a 20% confidence interval, and a 40% coefficient of variance (CV = standard deviation [SD] ÷ mean) in each community. The 40% CV estimate is based on 12 months of utility bill data from 9 BA communities in Arizona, Illinois, and Nevada with samples sizes from 12 to 110 homes per community. These data were collected in 1999 and 2000 by Building Science Corporation. In 2007, Danny Parker of the Florida Solar Energy Center found a similar CV (41%) for 160 non-BA homes in central Florida. The sample size required for communities with an expected saving less than 30% compared to the reference community probably rules out community evaluations at these savings levels. The reference community is likely to be more efficient than the BA Benchmark, so the expected energy savings of the BA community relative to the reference community will likely be smaller than the expected savings relative to the BA Benchmark.

A smaller expected CV in each community would result in a smaller required sample size. One way to reduce variance in the sample would be to identify and remove large end uses that are not relevant to the central research question. Examples of these include swimming pools, spas, second refrigerators, and stand-alone freezers, which can be identified with homeowner questionnaires. The disadvantages of relying on homeowner questionnaires are the low response rate, which can often be less than 50%, and the potential for bias (those who are more energy conscious may be more likely to respond to the questionnaire). If only homes with questionnaire responses are included in the analysis, the sample size may be reduced substantially. Therefore, a larger initial sample is needed to achieve a sample of households responding to the questionnaire that meets the minimum sample size to achieve the desired confidence interval. On the other hand, the knowledge of high end-use equipment presents the opportunity to correct for these loads and reduce the CV of the sample. A lower CV means a smaller sample size is required to achieve the desired confidence interval. Data from homes in central Florida (for which information about pools and spas is available) indicate a reduction of about 5 percentage points in the CV if the homes with pools and spas are removed from the sample [8].

Table C1. Required Minimum Sample Size at a 90% Confidence Level

Expected Energy Savings ¹	Desired Confidence Interval (% of savings)	Desired Confidence Interval (%)	BA Energy Use CV	REF Energy Use CV	Required Sample Size for Each Community
Without a homeowner questionnaire					
50%	± 20%	± 10%	40%	40%	54
40%	± 20%	± 8%	40%	40%	92
30%	± 20%	± 6%	40%	40%	179
20%	± 20%	± 4%	40%	40%	444
10%	± 20%	± 2%	40%	40%	1959
With a homeowner questionnaire²					
50%	± 20%	± 10%	35%	35%	41
40%	± 20%	± 8%	35%	35%	70
30%	± 20%	± 6%	35%	35%	137
20%	± 20%	± 4%	35%	35%	340
10%	± 20%	± 2%	35%	35%	1500

¹ Compared to the reference community.

² Required sample size represents number of respondents to the homeowner questionnaire.

Minimizing Biases

Billing comparison between a treated and a nontreated sample is a standard experiment design, where the elimination of other differences/biases is key. To minimize bias between two communities, the reference community should be as similar as possible in the following attributes:

- **Location.** The reference community should be in the same type of neighborhood as the BA community and subject to substantially the same weather conditions year round.
- **Vintage.** The reference community should have been built under the code requirements that were in place when the BA community was built. A major code revision should not have occurred between the construction of the reference and BA

communities. This restriction ensures that the energy savings can be attributed the BA community measures and not to energy code changes.

- **Square footage.** The average square footage of the reference community should be within 20% of the average square footage of the BA community. The diversity in model types and square footage of individual models should also be similar to the BA community.
- **Fuel use.** Fuel use should be the same mix, and each fuel should have the same end uses. If the BA community uses natural gas for water and space heating needs, a reference community that uses natural gas for those same end uses should be chosen. Similarly, if the BA community is all-electric, the reference community should be all-electric.
- **Program influence.** The reference community should not have been built under the BA program. An exception may be, for example, when the reference is “builder’s previous BA practice” that would have to be at significantly lower savings.

Community Characterization

Specific information about the construction of the homes in the BA and reference communities should be collected from the builders and presented. All data that should be collected are addressed in the Builder Information section of this document. Information that characterizes the homes in the communities should be presented in the community characterization section of the community evaluation report.

This information includes:

- Number of homes of each model in each community
- Shell construction details and insulation levels
- Foundation type and insulation levels
- Attic type and insulation levels
- Roof color, reflectivity, and use of radiant barriers
- Window types, U-values, and SHGCs
- Ventilation system details
- Use of nighttime ventilation
- Percentage of ductwork in conditioned space
- Ductwork insulation levels
- HVAC equipment type, fuel used, and capacity and efficiency ratings
- Type of thermostat (programmable or nonprogrammable)
- Water heater type, fuel used, and efficiency rating
- Efficiency of appliances included as standard and the fuels they use
- Type of hard-wired lighting (incandescent, compact fluorescent, etc.)

- Installed wattage of interior lighting
- Installed wattage of exterior lighting
- Energy-related options offered to the homebuyers
- Number of stories of each model
- Square footage and number of bedrooms for each model
- Number and type (wood or natural gas) of fireplaces in each model
- Inclusion of PV or solar thermal
- House orientation and orientation of solar systems

Other builder information is addressed in a separate section of this document.

If a homeowner questionnaire has been done, the information collected about the homes in the communities should be presented here as well. Some examples of the type of information that will be available from homeowner questionnaires include:

- Number of homes in each community with swimming pools, hot tubs or spas, second refrigerators, stand-alone freezers, and other high end-use equipment
- Average number of occupants per house in each community
- Number of natural gas and electric stoves in each community

See the section on Homeowner Questionnaires for additional information.

Utility Billing Data and Calculations

Bills can be obtained by using a release from the homeowner, or by obtaining data directly from a utility partnership. Obtaining releases is difficult and yields low percentages (typically less than 50%, and as low as 10%). This makes the utility bill sample size difficult to estimate for a given community size.

If possible, a utility partnership is preferred because of the lower cost and effort required to obtain data about all the homes (rather than some typically low percentage of the homeowners who respond to release requests). The utility will “sanitize” the data, perhaps eliminating all addresses, to protect confidentiality. It would be advantageous if the data could still be correlated to model type, perhaps with a confidentiality agreement with the local utility that allows one analyst to correlate bills with addresses, model types, and the orientation of the homes and solar systems. The research team may have to collect and supply the correlation of model type to address to the utility.

The billing data must have energy consumption as well as energy cost information. There must be at least the same 12 months of postoccupancy billing data for homes in the BA and reference communities for each fuel used. This may involve separate utilities for electricity and gas. Fewer than 12 months of data have limited use because of seasonal variations in energy use.

The utility billing structures in force for the communities during the billing period should be clearly presented.

Raw data consist of the utility billing data for each house “h”, for the two communities (comm = BA, Ref). The data consist of consumption and cost data for fuels (fuel = electricity, gas, source) by utility month (m), denoted $Q_{\text{fuel,comm,h,m}}$ and $\$_{\text{fuel,comm,h,m}}$. (The utility month roughly corresponds roughly to real months.) The utility will usually supply billing data in convenient electronic form, but the data may have to be manually extracted from copies of bills.

Utility partners may be interested in providing additional metering to determine time of use and time of production from PV.

Plotting of Raw Data

All the raw data should be plotted as monthly point time series and presented in an appendix. An example should be given in the text, as shown in Figure C1. Gas and electricity consumption should be plotted on separate graphs as shown. The plotting is done for basic information to the reader, and because plotting and visual screening of the data for outliers are useful.

Data Filtering

Possible anomalies can be identified easily from the raw data plots. This includes reading errors, very high users, very low users, and “intermittent” users. High users presumably have high equipment loads (pool, spa, multiple refrigerators and freezers, home entertainment, etc.) and high energy use habits (high or low heating or cooling set points, leaving lights on, etc.). Although visual screening is fairly consistent, data are best filtered by defining a quantitative criterion and cross-checking the results visually by looking at the plots for the rejected houses.

Identifying Outliers

The criterion known as “mild outliers” will be applied to identify high and low use outliers. Mild outliers are data points that lie outside the “inner fences” of the data. The inner fences are shown in Figure C2 and are calculated as follows:

1. Find the median of the sample
2. Find the quartile values. The first quartile (Q_1) includes 25% of the data points in the sample. The third quartile (Q_3) includes 75% of the data points. These are called the “hinge points.”
3. Find the difference between Q_3 and Q_1 . This is called the “inner quartile range” (IQR).
4. The inner fences are defined by the $Q_3 - 1.5 \cdot \text{IQR}$ and $Q_1 + 1.5 \cdot \text{IQR}$.
5. Points outside the inner fences are identified as mild outliers.

In a normal distribution about 1 in 150 points are mild outliers.

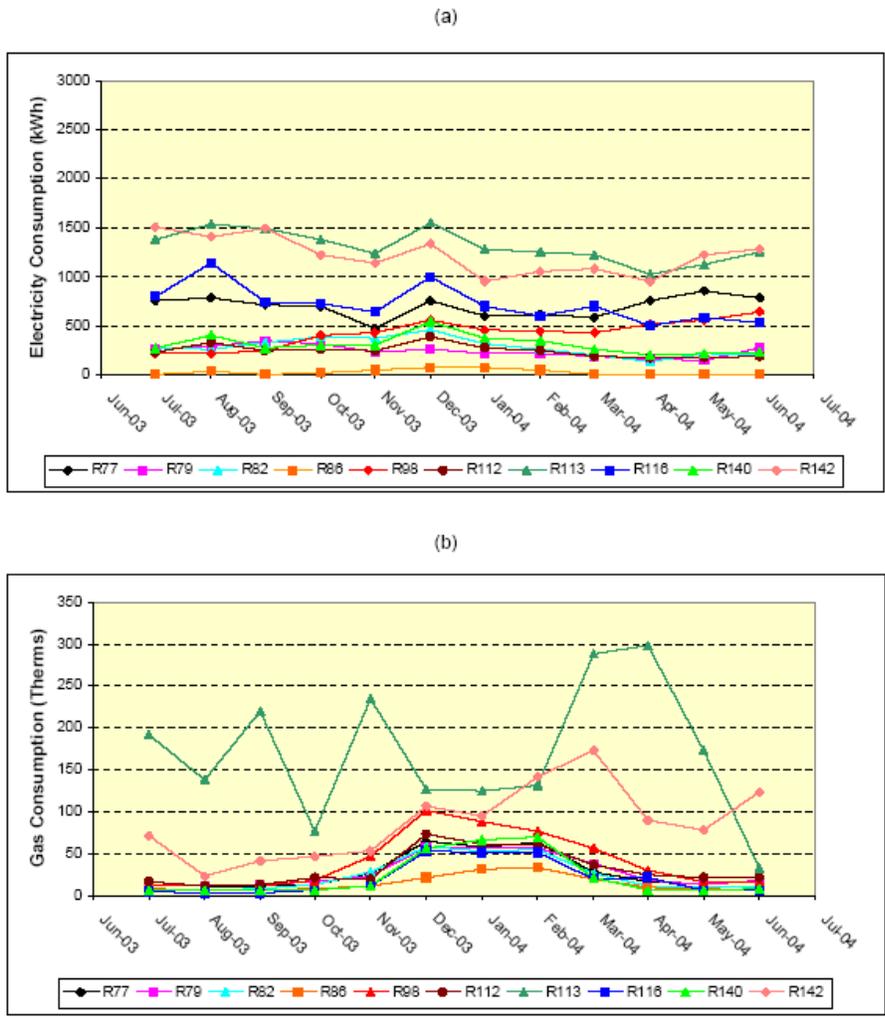


Figure C1. Example raw data plots for electricity (a) and natural gas (b) consumption, plotted over the analysis period [4]

○ Mild outlier

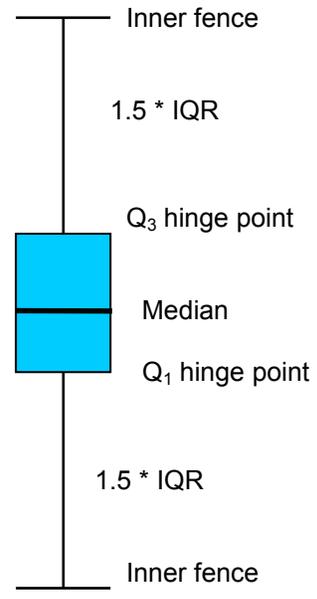


Figure C2. Identifying mild outliers

Present box plots for electricity and natural gas use in each community. Each plot should show the median, hinge points, inner fences, and mild outliers (see Figure C2) for each community. Homes that are mild outliers for electricity or natural gas should be excluded from community average energy use calculations.

Identifying Intermittent Users

Intermittent users are those for whom the monthly data show anomalous oscillation between very-low/very-high and normal, such as would be caused by frequent long vacations, unoccupied periods between occupancy changes, startup or intermittent pool use, etc. Homes with intermittent use can be visually identified from the monthly raw data graphs. Mild outliers and intermittent users should be rejected from community averages. Rejected data should always be examined case by case to ensure they are anomalous.

Correcting for Pools and Spas

Some optional end-use equipment can be large enough energy consumers to significantly affect the whole house average energy use. The largest of these are swimming pool pumps and spa systems, which include pumps and heaters. A summary of reported monthly average energy use of pools is shown in Figure C3. Spas may be heated with electricity or natural gas. A report by the California Energy Commission (CEC) indicates the energy use of spas. The CEC reported the standby energy use of 124 models of portable electric spas from eight manufacturers in March 2007 [9]. The results are given in Figure C4.

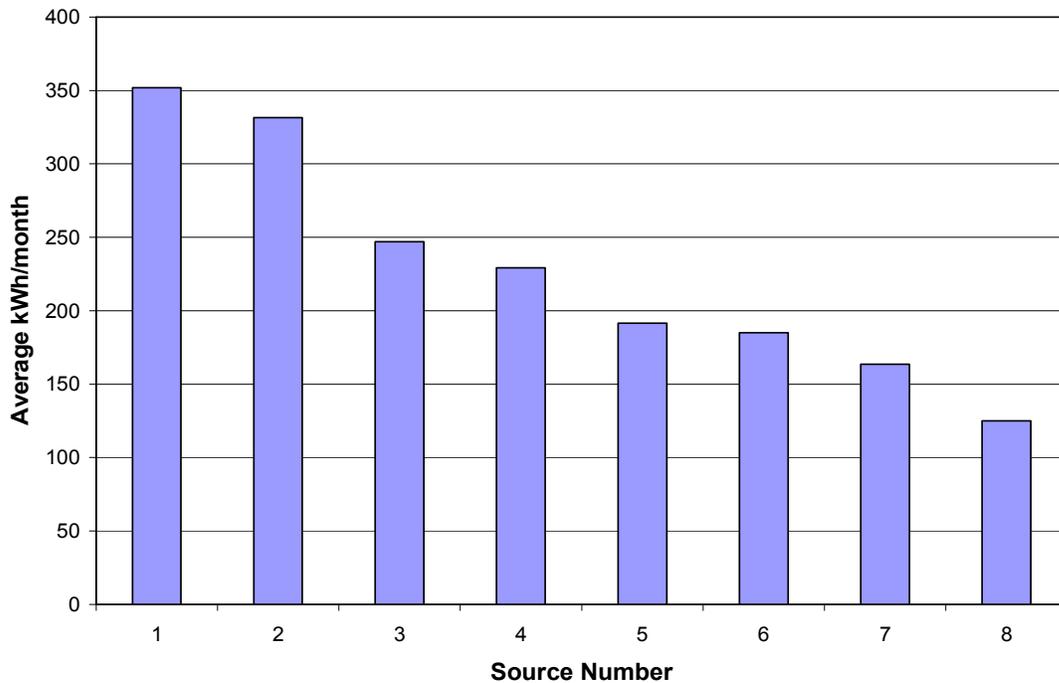


Figure C3. Average monthly pool pump energy use from various sources:

1. Danny S. Parker, personal communication, 2007. Submetering of pools in 26 homes in central Florida.
2. Davis Energy Group, *Two-Speed Pool Pump Project*, for Southern California Edison, December 1994 – High end of reported range.
3. Danny S. Parker, *Monitored Residential Space Cooling Electricity Consumption in a Hot-Humid Climate: Magnitude, Variation and Reduction from Retrofits*, Florida Solar Energy Center, FSEC-PF-213-90, 1990. Submetering of pools in 13 homes in central Florida.
4. California Energy Commission, *California Energy Demand 2000*, quoted in: Davis Energy Group, *Analysis of Standards Options for Residential Pool Pumps, Motors, and Controls*, prepared for Pacific Gas and Electric Company, 2004.
5. Pacific Gas and Electric, *Swimming Pool Pump Operating Practices*, December 2000, quoted in: Davis Energy Group, *Analysis of Standards Options for Residential Pool Pumps, Motors, and Controls*, prepared for Pacific Gas and Electric Company, 2004.
6. Davis Energy Group, *Two-Speed Pool Pump Project*, for Southern California Edison, December 1994 – Low end of reported range.
7. SCE, 1992 Residential Appliance End Use Study, Quantum Consulting, December 1993, quoted in: Davis Energy Group, *Analysis of Standards Options for Residential Pool Pumps, Motors, and Controls*, prepared for Pacific Gas and Electric Company, 2004.
8. Energy Information Administration, 1997. Energy Data Sourcebook for the U.S. Residential Sector, referenced to Lawrence Berkeley National Laboratory. LBNL-40297.

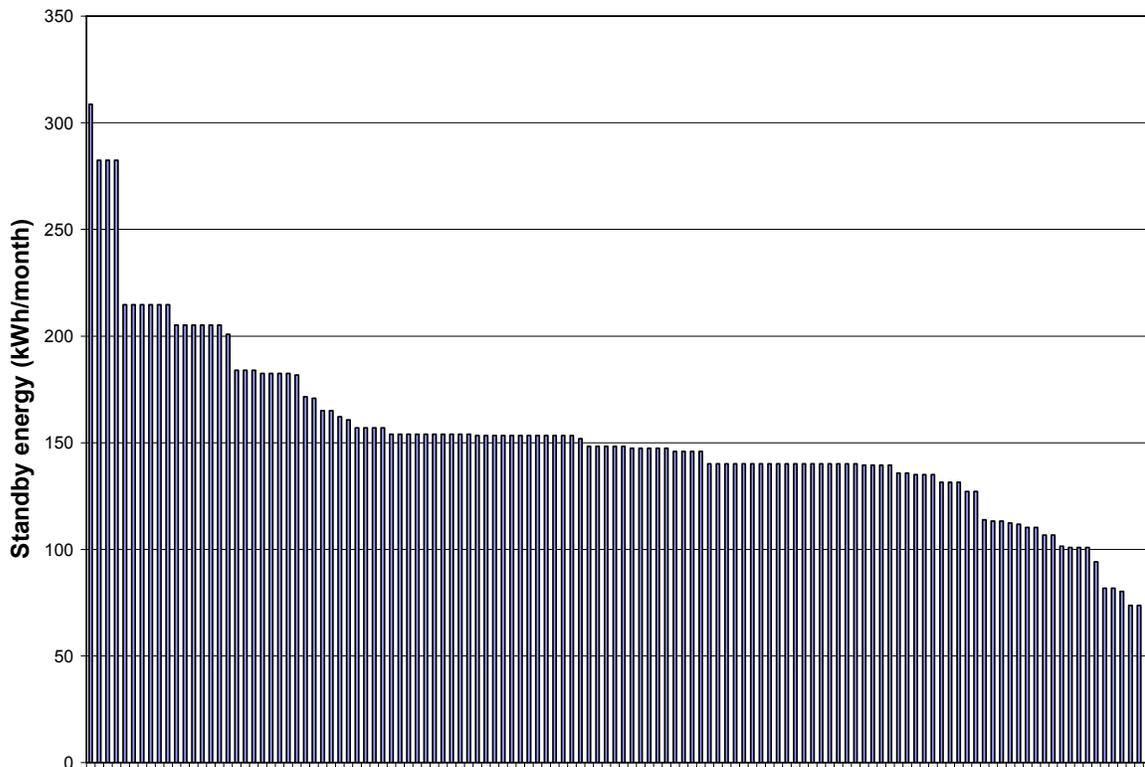


Figure C4. Standby energy use of 124 models of portable electric spas from eight manufacturers

Pools and spas may affect the CE in two ways:

1. Their presence in some homes may increase the CV of the community's annual energy use of the community, thereby requiring a larger sample size to achieve statistically significant results.
2. They may have large energy consumption to bias community averages if they are unequally distributed between the BA and reference communities.

Homes with pools may be identified by aerial or satellite photography, by visual inspection in the communities, or with homeowner questionnaires. However, homes with spas can probably be identified only with homeowner questionnaires.

For CE that do not include an assessment of pools and spas in the community, the sample size should be based on the largest CV values of 40% to address the increased CV of the sample. The bias cannot be known and may affect the savings measured.

If homes with pools or spas, or both, have been identified, one of three approaches can be used to eliminate the bias between communities:

1. Eliminate all homes with pools, spas, or both from both community averages. This approach reduces the sample size, but should also reduce the CV of the annual energy use in both communities. This may be the best approach if the available sample size is significantly larger than the minimums presented in the Selection of Building America and Reference Communities section.
2. Eliminate enough homes from the community with more pools, spas, or both such that the ratio of homes with pools or spas, or both, to the total number of homes is the same for both communities. This approach will be less effective than the previous approach in reducing the CV of the annual energy use, but it will maintain a larger sample size. If the sample size marginally fulfills the minimums presented in the Selection of Building America and Reference Communities section, this may be a better approach.
3. Submeter the pools and spas in both communities and subtract their energy use from the total home energy use. The submetered data should be reported, but excluded from community averages. This approach excludes no homes from the samples and lowers the CV of the samples and removes the bias, but it has a higher cost and requires that the equipment be installed at the beginning of the evaluation period, thereby precluding retrospective analysis of utility bills.

Approaches 1 and 2 can both be tried to see which yields a tighter confidence interval. Simply correcting the measured energy whole-house energy use by an assumed energy use value for a pool or spa is not recommended because of the wide spread in reported energy use for pools and spas, and because there is probably a large use-driven variation in the actual consumption.

Reporting Houses Excluded from Averages

The number of houses rejected should be reported in a table, by type of rejection. An example is given in Table C1. If homeowner questionnaire data are available, the analyst

should determine whether the bill outliers are correlated with the questionnaire results (e.g., multiple refrigerators or freezers, pools, or spas).

Table C1. House Rejections by Cause for the Rejection

Reason for Data Rejection	Number of Houses Rejected	
	BA Community	Reference Community
Mild outliers – high users	2	3
Mild outliers – low users	1	1
Intermittent users	2	1
Homes with pools	0	3
Homes with spas	0	1
Homes with both a pool and a spa	0	2

Annual Totals by House

From the billing data, compute the annual total consumption by fuel type for each house in each community:

$$Q_{\text{fuel,comm,h}} = \sum_m Q_{\text{fuel,comm,h,m}}$$

The sum extends over a year for each house. The analysis year should be the same for each house in both communities, to eliminate variability in weather as a bias. For each community and fuel, plot a bar chart of highest to lowest house consumption (including outliers being rejected), as in Figure C5. Also, plot a frequency distribution, as shown in Figure C6 (excluding outliers). Choose the number of bins to give a reasonable approximation of a continuous distribution.

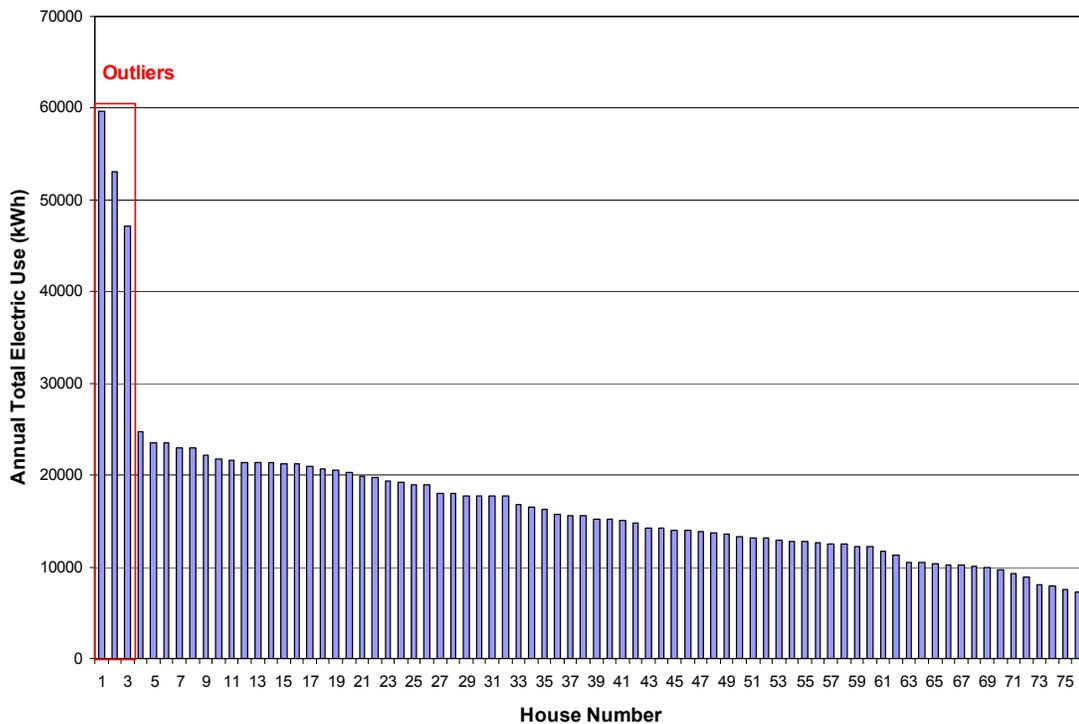


Figure C5. Example of total annual electrical energy use ordered highest to lowest

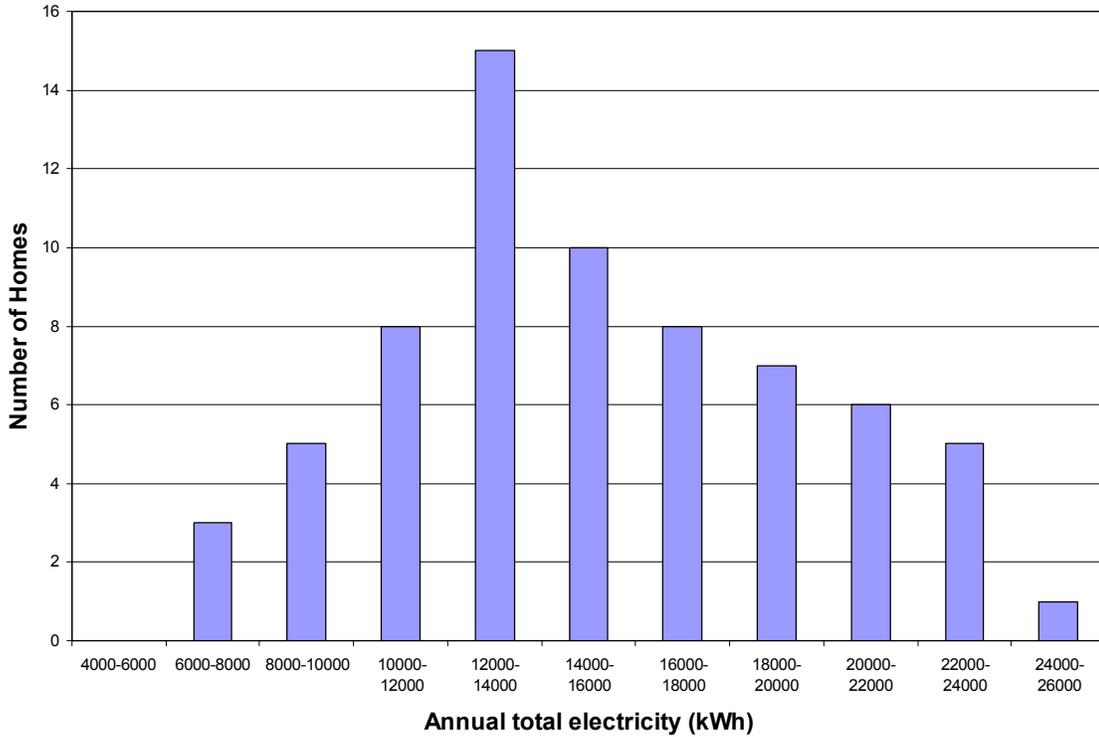


Figure C6. Example of total annual electricity use frequency distribution

Source Energy Conversions

The separate electricity and gas annual consumptions for each house are now converted into primary energy savings through national average conversion factors $F_{\text{site-src,fuel}}$. The conversion factors used here are the same as those required in BA program simulations [2] and are shown in Table C2. Total source energy is computed as:

$$Q_{\text{src,comm}} = F_{\text{site-src,elec}} Q_{\text{elec,comm,h}} + F_{\text{site-src,gas}} Q_{\text{gas,comm,h}}$$

Table C2. Site-to-Source Energy Conversion Factors

Fuel	Site-to-Source Conversion Factor
Natural Gas	$F_{\text{site-src,gas}} = 1.02$
Electricity	$F_{\text{site-src,elec}} = 3.16$

Community Average Consumption, Cost, and Descriptive Statistics

For each community and fuel, compute the mean, median, SD, and CV for the energy consumption and cost. In addition, compute the SD of the mean.

The means of the samples are computed as:

$$Q_{\text{fuel,comm}} = \sum_h Q_{\text{fuel,comm,h}} / N_{\text{comm}}$$

$$\$_{\text{fuel,comm}} = \sum_h \$_{\text{fuel,comm,h}} / N_{\text{comm}}$$

The SDs of the samples are computed as:

$$\sigma Q_{\text{fuel,comm}} = \sqrt{[\sum_h(Q_{\text{fuel,comm,avg}} - Q_{\text{fuel,comm,h}})^2 / (N_{\text{comm}} - 1)]}$$

$$\sigma \$_{\text{fuel,comm}} = \sqrt{[\sum_h(\$_{\text{fuel,comm,avg}} - \$_{\text{fuel,comm,h}})^2 / (N_{\text{comm}} - 1)]}$$

The CVs are computed as:

$$CV Q_{\text{fuel,comm}} = 100(\sigma Q_{\text{fuel,comm}} / Q_{\text{fuel,comm}})$$

$$CV \$_{\text{fuel,comm}} = 100(\sigma \$_{\text{fuel,comm}} / \$_{\text{fuel,comm}})$$

The SDs of the means of the distributions are computed as:

$$\sigma_{\text{mean}} Q_{\text{fuel,comm}} = \sigma Q_{\text{fuel,comm}} / \sqrt{N_{\text{ccomm}}}$$

$$\sigma_{\text{mean}} \$_{\text{fuel,comm}} = \sigma \$_{\text{fuel,comm}} / \sqrt{N_{\text{ccomm}}}$$

The SD of the sample characterizes the spread of the bill distribution. It encloses roughly two-thirds of the data. The SD of the mean is a measure of how much the random noise is not averaged out and thus causes errors in the mean value.

A table for consumption and cost minimum value, maximum value, averages and descriptive statistics should be presented for each community. The numbers in this table should exclude outliers. An example for energy consumption is shown in Table C3. The cost tables will not have a source energy column.

Table C3. Example of Averages and Descriptive Statistics for a Community

	Annual Electricity Consumption (kWh)	Annual Natural Gas Consumption (therms)	Annual Source Energy Consumption (MBtu)
Minimum			
Mean			
Median			
Maximum			
SD			
CV			
SD of mean			

Energy Savings: $\Delta Q_{\text{fuel,BA-Ref}}$

We can now calculate the energy consumption and cost savings between the two communities, BA-Ref, by fuel type (gas, electricity, and source). Unless the homes in both communities have virtually the same average square footage, these computations should be repeated using average annual energy use per square foot for each community.

$$\Delta Q_{\text{fuel,BA-Ref}} = (Q_{\text{fuel,REF}} - Q_{\text{fuel,BA}})$$

$$\Delta \$_{\text{fuel,BA-Ref}} = (\$_{\text{fuel,REF}} - \$_{\text{fuel,BA}})$$

Compute the 90% confidence interval given by:

$$Q_{\text{Ref}} - Q_{\text{BA}} \pm z_{\alpha/2} SE_{(Q_{\text{Ref}} - Q_{\text{BA}})}$$

Where:

$$SE_{(Q_{Ref}-Q_{BA})} = \sqrt{\frac{\sigma_{Ref}^2}{n_{Ref}} + \frac{\sigma_{BA}^2}{n_{BA}}}$$

Q_{Ref} = mean energy for the reference community

Q_{BA} = mean energy for the BA community

n_{Ref} = sample size for reference community

n_{BA} = sample size for the BA community

σ_{Ref} = SD for the reference community

σ_{BA} = SD for the BA community

$z_{\alpha/2}$ = 1.645 for 90% confidence level

$SE_{(Q_{REF}-Q_{BA})}$ = standard error of the mean energy savings

Compute percent savings, uncertainty, and 90% confidence interval:

$$\%Q_{fuel,BA-Ref} = 100 * \Delta Q_{fuel,BA-Ref} / Q_{fuel,Ref}$$

$$\%\$_{fuel,BA-Ref} = 100 * \Delta \$_{fuel,BA-Ref} / \$_{fuel,Ref}$$

Two tables should be prepared that give the consumptions and costs of the two communities, the savings (with confidence interval), and the percent savings (with confidence interval). Table C4 shows an example of a consumption table. The cost table will not include the source energy column.

Table C4. Example Table of Consumption and Savings, with Errors

	Annual Average Electricity (kWh)	Annual Average Natural Gas (therms)	Annual Average Source Energy (MBtu)
BA consumption			
Ref consumption			
Savings (confidence interval)			
Percent savings (confidence interval)			

Summary of Basic Billing Data Analysis

1. Line plots of monthly electricity and natural gas use for each house
2. Data filtering
 - a. Identify mild outliers
 - b. Box plot for electricity and natural gas use for both communities
 - c. Identify intermittent users
 - d. Identify pools and spas

3. Annual total electricity and natural gas use by house
 - a. Plot in descending use order for each community
 - b. Plot in frequency distribution for each community
4. Source energy by house
5. Community average consumption and cost:
 - a. Mean and median electricity, natural gas, and source energy consumption and cost
 - b. Community SD and CV
 - c. SD of the mean
6. Energy and cost savings: BA versus reference community
 - a. Electricity, natural gas, and source energy and cost savings
 - b. Percent savings
 - c. Confidence interval at 90%

Monthly Regression Analysis

Software is available to perform a regression analysis on monthly utility bill data as a function of heating and cooling degree days or outdoor temperature. These software packages are designed primarily to analyze the effects of weatherization and retrofit projects where the energy consumption before and after changes to a building are compared. Compensating for the difference in weather during the periods before and after the changes is the main purpose of the programs.

The most often cited of these programs is PRISM. PRISM applies a variable-base degree-day linear regression model. It generates a weather-adjusted index of energy consumption called the normalized annual consumption (NAC). The NAC before and after a building retrofit can be directly compared.

ETracker is a similar software package that uses four or five parameter change-point ambient temperature regression models. A change-point model finds the temperature points where heating and cooling begin. In a five-parameter model the parameters are:

1. Temperature where cooling begins
2. Temperature where heating begins
3. Base energy use when there is no heating or cooling
4. Slope of the heating energy versus temperature
5. Slope of the cooling energy vs. temperature.

ETracker is available as a free download from Dr. Kelley Kissock at the University of Dayton: (<http://www.engr.udayton.edu/faculty/jkissock/http/RESEARCH/ETracker.htm>).

ETracker is designed to analyze the performance of one building. A more powerful version of the software, ETracker C (ETracker Corporate) can analyze multiple sites, define two to five parameter models, include additional independent variables in the model, and calculate savings, NAC, or a sliding NAC. ETracker C is available directly from Dr. Kissock (kkissock@udayton.edu).

These models can provide outlier detection, detection and repair of estimated meter readings, desegregation of base, heating and cooling energy, balance point temperatures, heating and cooling energy as a function of degree days or outdoor temperature, and NAC.

Regression analysis provides separation of base energy usage (which includes appliances, miscellaneous electricity loads [MELs], and water heating) from envelope/HVAC loads. The two community distributions of heating and cooling loads and coefficients provide better resolution of savings from envelope and HVAC improvements, compared to analyzing annual totals only. If measures that affect base energy use (e.g., solar water heating, appliance/lighting/MEL measures) are taken, the difference in distribution of base energy provides a measure of savings from those measures. Base energy distributions may also broaden understanding of occupant behavior and provide useful data for future revisions of benchmark occupancy assumptions.

The cost estimates for applying a monthly regression analysis range from \$18k to \$24k for two communities of 50 homes each.

Comparing Savings to Expectations

The analysis yields the annual average energy savings between the BA and reference communities. This section discusses developing expectations for what those savings should be and comparing the savings to expectations. BA savings expectations are based on annual energy simulations following the BA Performance Analysis Procedures [2]. In this section, the superscript ^{sim} will be used to distinguish values based on simulation from those based on the billing data of the actual communities.

Building energy simulations in Stage 3 of the BA program compare the energy performance of a prototype home to the builder's standard practice home, the regional standard practice home, and the BA Benchmark home. The simulations use typical weather data and BA Benchmark assumptions for occupant effects. The BA Benchmark represents a home built to code in the mid-1990s. In Stage 4, BA teams work with builders to analyze at least 10 homes in a community. Simulations of one or more home models within the BA community will be available from Stages 3 and 4 and can be used in this section of the Project Closeout CE.

Weather Data for Simulations

The real weather experienced by the BA community should be used to drive the energy use simulations whenever it is available. BA teams involved with builders in Stage 3 or 4 should install a weather station in the community if a utility bill analysis is anticipated.

If there is no weather station in the community being evaluated, nearby weather data may be available from the National Climatic Data Center (NCDC – <http://www.ncdc.noaa.gov/oa/ncdc.html>). These typically include temperature, wind, and cloud data, but not solar radiation measurements. Solar radiation data are required for the simulations, so the solar irradiance would have to be estimated. One approach is to use the models used in constructing typical meteorological year (TMY) solar radiation from the available observations (particularly cloud cover data).

If the community has no measured weather data and NCDC is unavailable or insufficient, TMY2 data can be used for the simulation, because the difference between the actual and the TMY2 weather is the same for both communities.

Simulating Communities

In each community, several home “models” will likely differ in floor area and other characteristics. Simulations of one or more home models within the BA community will be available from BA program Stages 3 and 4 and from the standard practice homes. These simulations provide the starting point for developing community average energy savings expectations.

Each home in both communities may be a unique combination of home model and orientation. To develop the best expectations for energy use in the communities, each home would need to be modeled. The expected average annual consumption of the community would then simply be the average of the annual consumption of each simulated home. This detailed approach can become quite expensive to implement if several home models in each community need to be modeled separately. Spinning the simulated building to represent different orientations is less time consuming.

Four approaches to developing the community annual energy use expectations are listed here. The comprehensive approach is listed first; increasingly simpler approaches follow. The more sophisticated approaches will yield more accurate performance expectations but will require a higher level of effort. The BA team must decide which approach to apply based on the attributes of the actual communities being studied and the level of effort anticipated to execute each approach. The best available weather data should be used to apply each approach. All these options include BA Benchmark assumptions for occupant choices and behavior so the occupant effects are the same for all models. Each approach assumes that there is no bias in occupant effects between the communities and that the occupant effects are similar to those assumed by the BA Benchmark.

1. Simulate each home in the community.

Starting with Stage 3 simulations, create simulations of each model of home in the BA and reference communities. Tune these simulations with any measured data available from Stage 3 such as infiltration rates and duct leakage. Use the appropriate home model simulation and the actual orientation to simulate each home in the community. Average the results to create the community average energy use expectations.

2. Simulate each home model in the community.

Starting with Stage 3 simulations, create simulations of each home model in the BA and reference communities. Tune these simulations with any measured data available from Stage 3 such as infiltration rates and duct leakage. Spin each simulation in the four cardinal directions and average the energy consumption. Create community average energy use expectations by weighting each house model simulation by the number of homes of that model in the community.

3. Represent the community by a single, tuned, “average home” simulation.

Modify Stage 3 simulations to better represent the “average” (square footage, one story versus two stories, etc.) homes in the BA and reference communities. Tune these simulations with any measured data available from Stage 3 such as infiltration rates and duct leakage. The results of these simulations are taken as the expected average annual energy use of the homes in each community.

4. Represent the community by a single home simulation.

Simply use the annual energy results for the prototype and standard practice homes developed in Stage 3 without modification.

The Building America Benchmark Community

Programmatic energy savings numbers are reported with respect to the BA Benchmark. Therefore, an additional measure of interest in the utility bill analysis is the BA community savings relative to the BA benchmark. This is by nature an apples-to-oranges comparison, because the BA community energy consumption is based on utility bill data and the BA Benchmark energy consumption is based on a simulation. Because the BA Benchmark represents a code-built mid-1990s home, the homes in the reference community are likely to be more efficient than the BA Benchmark. To make a comparison to the BA Benchmark, a benchmark community annual energy use expectation is developed, as was done for the BA and reference communities. The BA Benchmark simulations are based on the BA community simulations as prescribed in the Building America Analysis Procedures.

Comparing Actual Savings to Expectations

A representation of the actual and simulated communities is shown in Figure C7. The “ ΔQ ” lines in the figure represent the difference in average annual energy use between the communities.

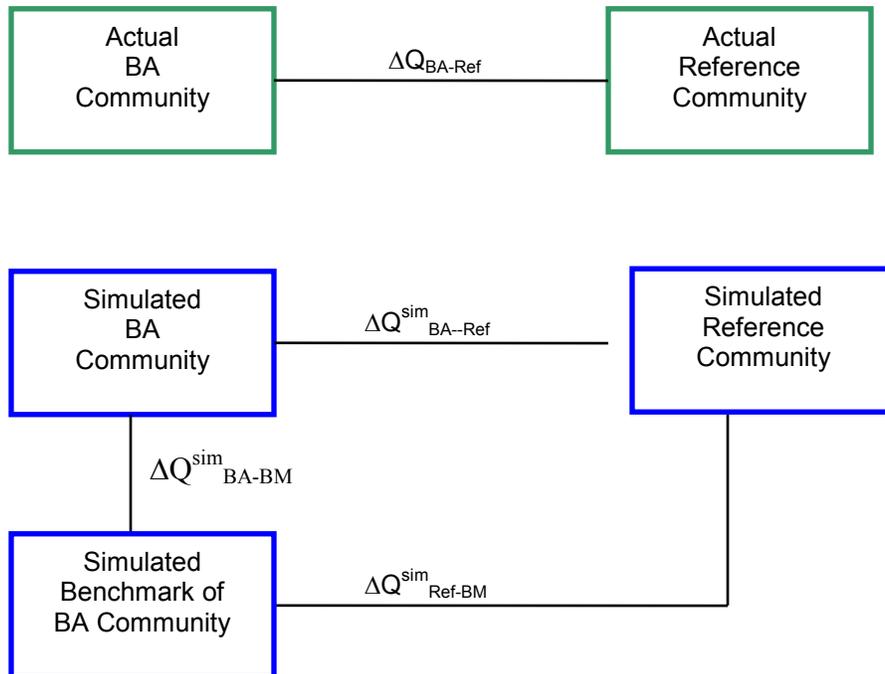


Figure C7. Actual and simulated communities

Building America Community Relative to Reference Community

Once the utility bill analysis and community simulations are completed, the comparison of utility bill results to expectations based on simulations is straightforward. First, the savings $\Delta Q_{\text{fuel,BA-Ref}}$ are to be compared to simulated savings $\Delta Q_{\text{fuel,BA-Ref}}^{\text{sim}}$:

Does $\Delta Q_{\text{fuel,BA-Ref}} \approx \Delta Q_{\text{fuel,BA-Ref}}^{\text{sim}}$?

The uncertainty in the savings is given as the quadrature sum of the uncertainties of the two mean values:

$$(\sigma_m \Delta Q_{\text{fuel,BA-Ref}}) = \sqrt{[(\sigma_m Q_{\text{fuel,BA}})^2 + (\sigma_m Q_{\text{fuel,Ref}})^2]}$$

(Remember, $\sigma_m X$ stands for standard deviation of the mean of X.) In this comparison, measured and simulated are said to agree if the difference between measured and modeled savings is less than twice the error:

If $|\Delta Q_{\text{fuel,BA-Ref}} - \Delta Q_{\text{fuel,BA-Ref}}^{\text{sim}}| < 2\sigma_m \Delta Q_{\text{fuel,BA-Ref}} \Rightarrow$ modeled and measured agree within error

The comparison should also be presented on a fractional basis. The fractional savings by fuel relative to the reference community (FS_{fuel}) is

$$FS_{\text{fuel,BA-Ref}} = \Delta Q_{\text{fuel,BA-Ref}} / Q_{\text{fuel,Ref}}$$

The uncertainty in the measured fractional savings is given as

$$\sigma_m FS_{\text{fuel,BA-Ref}} = \sqrt{[(\sigma_m Q_{\text{BA}} / Q_{\text{Ref}})^2 + (Q_{\text{BA}} * \sigma_m Q_{\text{Ref}} / Q_{\text{Ref}})^2]}$$

Similarly, for the simulated quantities,

$$FS_{\text{fuel,BA-Ref}}^{\text{sim}} = \Delta Q_{\text{fuel,BA-Ref}}^{\text{sim}} / Q_{\text{fuel,Ref}}$$

The comparison asks:

$$\text{Does } FS_{\text{fuel,BA-Ref}} \approx FS_{\text{fuel,BA-Ref}}^{\text{sim}} ?$$

The ratios agree if they are within two SDs of the mean from each other:

If $|FS_{\text{fuel,BA-Ref}} - FS_{\text{fuel,BA-Ref}}^{\text{sim}}| < 2\sigma_m FS_{\text{fuel,BA-Ref}} \Rightarrow$ modeled and measured agree within error.

Building America Community Relative to the Building America Benchmark

To compare the energy savings in the actual communities ($\Delta Q_{\text{BA-Ref}}$) to the expected savings between the BA community and the BA Benchmark ($\Delta Q_{\text{BA-BM}}^{\text{sim}}$), the difference between the simulated reference community and the simulated BA Benchmark ($\Delta Q_{\text{Ref/BM}}^{\text{sim}}$) is added to the observed BA-Ref savings:

$$\Delta Q_{\text{fuel,BA-BM}}^{\text{data+sim}} = \Delta Q_{\text{fuel,BA-Ref}} + \Delta Q_{\text{fuel,Ref/BM}}^{\text{sim}}$$

The error in this value is due to the error in $\Delta Q_{\text{fuel,BA-Ref}}$, and we have

$$\sigma_m \Delta Q_{\text{fuel,BA-BM}}^{\text{data+sim}} = \sigma_m \Delta Q_{\text{fuel,BA-Ref}} = \sqrt{[(\sigma_m Q_{\text{BA}})^2 + (\sigma_m Q_{\text{Ref}})^2]}$$

The (totally) simulated difference between BA and reference communities is given as

$$\Delta Q_{\text{fuel,BA-BM}}^{\text{sim}} = Q_{\text{fuel,BA}}^{\text{sim}} - Q_{\text{fuel,Ref}}^{\text{sim}}$$

The benchmark savings are then compared to the simulated expectations:

$$\text{Does } \Delta Q_{\text{fuel,BA-BM}}^{\text{data+sim}} \approx \Delta Q_{\text{fuel,BA-BM}}^{\text{sim}} ?$$

Measured and simulated savings are said to agree if the difference between measured and modeled savings is less than twice the error:

If $|\Delta Q_{\text{fuel,BA-BM}}^{\text{data+sim}} - \Delta Q_{\text{fuel,BA-BM}}^{\text{sim}}| < 2\sigma_m \Delta Q_{\text{fuel,BA-BM}}^{\text{data+sim}} \Rightarrow$ modeled and measured agree within error.

The comparison should also be presented on a fractional basis. The fractional savings by fuel FS_{fuel} relative to the BA benchmark is

$$FS_{\text{fuel,BA-BM}}^{\text{data+sim}} = \Delta Q_{\text{fuel,BA-BM}}^{\text{data+sim}} / Q_{\text{fuel,BM}}^{\text{sim}}$$

The uncertainty in the measured fractional savings is given as

$$\sigma_m FS_{\text{fuel,BA-BM}}^{\text{data+sim}} = \sqrt{[(\sigma_m Q_{\text{BA}} / Q_{\text{Ref}})^2 + (Q_{\text{BA}} * \sigma_m Q_{\text{Ref}} / Q_{\text{ref}})^2]}$$

For the simulated quantities, the fractional savings is

$$FS_{\text{fuel,BA-BM}}^{\text{sim}} = \Delta Q_{\text{fuel,BA-BM}}^{\text{data+sim}} / Q_{\text{fuel,BM}}^{\text{sim}}$$

The comparison asks

Does $FS_{\text{fuel,BA-Ref}}^{\text{data+sim}} \approx FS_{\text{fuel,BA-Ref}}^{\text{sim}}$?

The ratios agree if the ratios are within two SDs of the mean from each other:

If $|FS_{\text{fuel,BA-Ref}}^{\text{data+sim}} - FS_{\text{fuel,BA-Ref}}^{\text{sim}}| < 2\sigma_m FS_{\text{fuel,BA-BM}}^{\text{data+sim}} \Rightarrow$ modeled and measured agree within error.

Checking for Occupant Effects Bias

Occupant effects include differing equipment in the house (pools, spas, multiple refrigerators and freezers, etc.), differing usage patterns of the equipment, differing heating and cooling set points, and differing habits of ventilation by opening windows and doors. The BA and reference communities were chosen to minimize bias. This section outlines two approaches to check the differences in occupant behavior between the communities. The first approach is data based, but assumes that the simulations and installation of energy features were correct. The second approach uses a monthly regression on the billing data to separate base energy use from the heating and cooling energy use.

Occupancy Bias Check by a Double-Differencing Approach

To estimate the differences in energy consumption from occupancy, compute the differences between the simulated and the actual communities, and then the difference of these differences:

$$\Delta Q_{\text{fuel,comm}}^{\text{data-sim}} = Q_{\text{fuel,comm}} - Q_{\text{fuel,comm}}^{\text{sim}}, \text{ comm} = \text{BA and Ref}$$

$$\delta \Delta Q_f = \Delta Q_{\text{fuel,BA}}^{\text{data-sim}} - \Delta Q_{\text{fuel,Ref}}^{\text{data-sim}}$$

If $\delta\Delta Q_f$ is small (e.g., $< 0.2 \Delta Q_f$), the total bias is considered small. The assumption here is that the systematic biases between the simulated and actual communities are mostly due to unmodeled occupancy effects and weather (TMY2 weather used in simulations, versus actual weather driving the real communities). These differences ought to be similar in the two communities, and the difference of the difference ought to cancel out these biases if they are the same in the two communities. Although occupant variations are eliminated in simulations by definition, occupant impacts are unknown in any real community without massive submetering. The simulations of the installed features are assumed to be accurate, and the measures are assumed to be installed correctly. Although these are tenuous assumptions, this procedure provides a check on consistency of internal gains between communities, as bias errors in the simulation of the house features caused by occupant behavior should be mostly consistent between the two subdivisions.

Occupancy Bias Check by Difference of Q_{base} Distributions

A second approach to looking at bias is to analyze differences in the community base use that result from a monthly regression analysis.. This approach should be used only when no energy conservation measures are introduced into the BA community that would make $Q_{\text{base,BA}}$ and $Q_{\text{base,ref}}$ differ by design and not by chance. The method should not be used when solar water heaters, PV, or significantly more efficient lighting or other builder-controlled equipment are present in the BA community.

In monthly regressions, the annual energy profile from each house is decomposed into two HVAC terms and a base energy. The latter is denoted as $Q_{\text{fuel,comm,h}}^{\text{regr/base}}$. We are concerned here with the base energy use only. Each community distribution of base energy is characterized by its mean, SD, and SD of the mean σ_m :

$$\begin{aligned} Q_{\text{fuel,comm}}^{\text{regr/base}} &= \sum_h Q_{\text{fuel,comm,h}}^{\text{regr/base}} / N_h \\ \sigma Q_{\text{fuel,comm}}^{\text{regr/base}} &= \sum_h (Q_{\text{fuel,comm,h}}^{\text{regr/base}} - Q_{\text{fuel,comm}}^{\text{regr/base}}) / \sqrt{(N_h - 1)} \\ \sigma_m Q_{\text{fuel,comm}}^{\text{regr/base}} &= \sigma Q_{\text{fuel,comm}}^{\text{regr/base}} / \sqrt{(N_h)} \end{aligned}$$

The difference in average base usage is:

$$\Delta Q_{\text{fuel}}^{\text{regr/base}} = Q_{\text{fuel,Ref,avg}}^{\text{regr/base}} - Q_{\text{fuel,BA,avg}}^{\text{regr/base}}$$

The uncertainty in the difference of base usage is given as

$$\sigma_m \Delta Q_{\text{fuel}}^{\text{regr/base}} = \sqrt{[(\sigma_m Q_{\text{fuel,BA}}^{\text{regr/base}})^2 + (\sigma_m Q_{\text{fuel,Ref}}^{\text{regr/base}})^2]}$$

The two distributions of $Q_{\text{fuel,comm,h,base}}$ are to be plotted (see Figure C8). First, establish whether the two distributions are different. A simple estimate of difference is based on the ratio of the uncertainty in the difference to the difference ($R_{\sigma\Delta/\Delta}$):

$$R_{\sigma\Delta/\Delta, \text{fuel}} = \sigma_m \Delta Q_{\text{fuel}}^{\text{regr/base}} / \Delta Q_{\text{fuel}}^{\text{regr/base}}$$

If $R_{\sigma\Delta/\Delta, \text{fuel}} < 0.3$, the two distributions are considered different enough that a correction should be considered. The correction is basically adding the difference of the Q_{base} means to the reference consumption:

$$Q_{\text{fuel,Ref,corrected-Qbase}} = Q_{\text{fuel,Ref}}^{\text{data}} + \Delta Q_{\text{fuel}}^{\text{regr/base}}$$

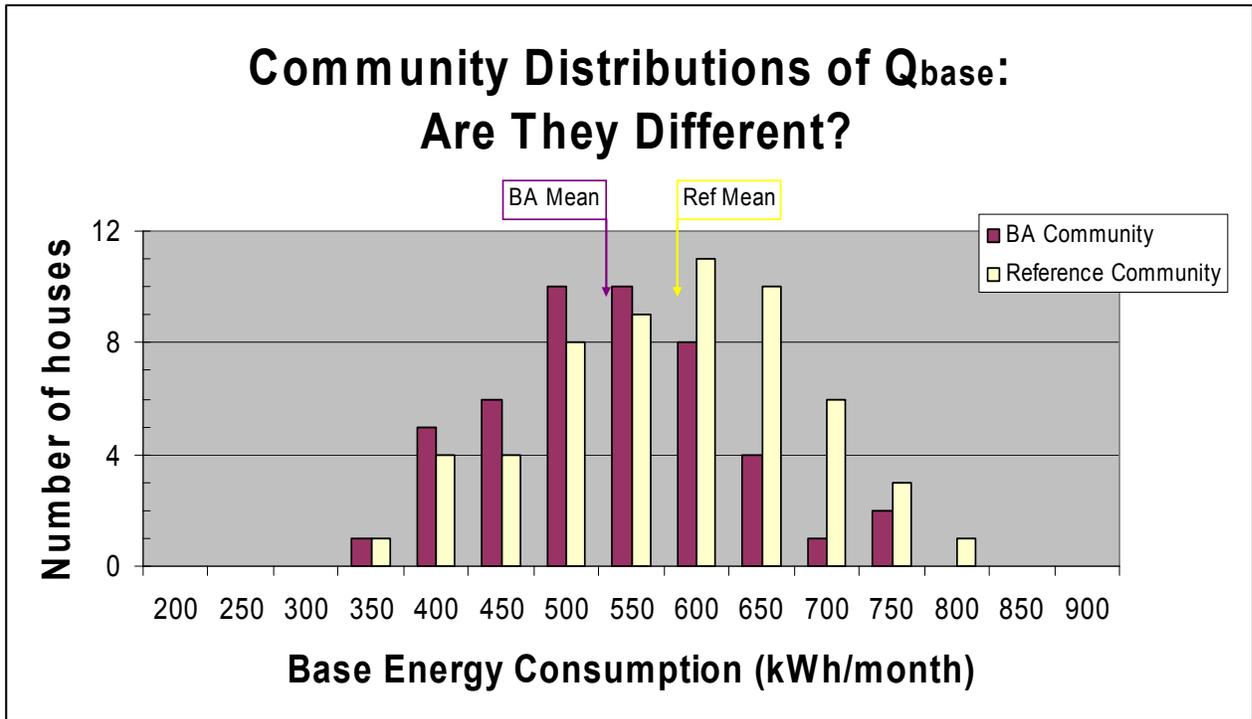


Figure C8. Schematic distributions of $Q^{\text{regr/base}}$ for BA and reference communities

Appendix D End-Use Monitoring

End-use monitoring selects energy end uses in a sample of homes and monitors the energy they use over time. End-use monitoring allows the overall energy use of the home to be disaggregated into components and shed light on how the energy is being used. This can help determine how much home energy is saved and how it was saved. If the savings are lower than expected, end-use monitoring can shed light on why. Challenges with end-use monitoring include potentially high equipment, installation, and analysis costs.

This tool addresses Must-Meet Gate Criterion 1 – *Source Energy Savings*, and Should-Meet Gate Criterion 4 – *Gaps Analysis*.

End-use monitoring (or submetering) verifies component installation and operation in a production context. It allows the energy use of specific equipment of interest to be monitored and the total energy to be disaggregated into end-use categories. This information provides a clearer understanding of how energy is being used and provides a powerful tool for troubleshooting energy use problems. End-use monitoring can also be used to characterize occupant behavior and its influence on performance, characterize seasonal performance changes, and catch equipment operational problems or malfunctions.

For two communities of 50 homes each, the estimates of the cost range from \$930,000 to \$2.9 million for minimum end-use monitoring and from \$1.2 million to \$9.1 million for full end-use monitoring.

Design of Monitoring System

If end-use monitoring will be used in the community evaluation, the monitoring system should be designed to respond to the specific needs of the study. The design is dictated by a clear definition of the objectives of the study. Three steps in monitoring system design are outlined below:

1. Define the objectives of the end-use monitoring. What research questions will be answered by the monitored data?
2. Determine exactly what data and data intervals are required to meet these objectives and answer all research questions.
3. Determine what equipment is needed to collect the data require at the appropriate intervals.

The objective of the study may be as broad as understanding how the major energy flows differ from house to house and between the communities, or as focused as understanding the energy performance of a specific new piece of equipment. For studies that use end-use monitoring for a broad understanding of home energy flows, at least the following data should be monitored:

- Whole house electricity
- Space heating energy
- Space cooling energy

- Hot water use and water heating energy
- Alternating current (AC) PV energy production (if applicable)
- Indoor temperature and relative humidity (RH)
- Weather: Ambient temperature, RH, and solar radiation for each community. (If communities are close together, one weather station may be used.)
- Any large energy consumers such as pools and spas

The data intervals required may be dictated by project partners' needs. For example, utility partners will likely be interested in 15-minute peak energy demand. For research projects, NREL often collects and stores 1-hour and 1-minute data simultaneously. The 1-hour data are used for most analyses; the 1-minute data are used for demand analyses and troubleshooting.

Most monitoring systems use a programmable data logger that can read multiple channels of different types of sensors. An example of this type of logger is the Campbell CR1000 (<http://www.campbellsci.com/cr1000>). An alternative approach is to use small stand-alone battery powered loggers that are manually downloaded periodically. An example of this type of logger is the Hobo series by Onset (<http://www.onsetcomp.com/>). There are also whole-house energy meters that attempt to disaggregate end uses by applying power signature recognition algorithms to data on the on/off times, the voltage, the real power, and the reactive power. An example of this type of meter is the Enetics SPEED™ (Single Point End-user Energy Disaggregation) recorder (<http://www.enetics.com/app-REM.html>). Details of disaggregation capabilities should be carefully considered before this type of meter is used in a community evaluation. If only annual totals are needed, using utility-type meters with analog or digital readouts on the major end uses may be a low-cost approach. The meters can be read seasonally or annually.

If end-use monitoring was used on any of the homes in the BA community as part of BA Stages 3 or 4, these data should be presented in the community evaluation report.

Appendix E Monitoring Case Study: NREL/Habitat for Humanity Zero-Energy Home

Abstract

The design of this 1280-ft², three-bedroom Denver ZEH carefully combines envelope efficiency, efficient equipment, appliances and lighting, a PV system, and passive and active solar thermal features to exceed the net zero energy goal. In January, 2006 a data acquisition system was installed in the home to monitor its performance over the course of a year. This appendix presents full year of energy performance data on the home.

From April 2006 through March 2007 the home's 4-kW PV system produced 5,127 kWh of AC electricity. Only 3,585 kWh of electricity and 57 therms of natural gas were used during this period. On a source energy basis, the home produced 24% more energy than it used. The energy used for space heating, water heating, and lighting were dramatically reduced through superinsulation, passive solar tempering, solar water heating, compact fluorescent lights, and other efficiency measures. The energy used in the home is now dominated by appliance and plug loads that are determined by occupant choices and behavior. These loads constitute 58% of all the source energy used in the home. Because these loads are generally outside the control of the home designer and vary considerably with different occupants, sizing a PV system to achieve zero net energy performance is challenging.

This case study demonstrates that efficient, affordable ZEHs can be built in cold climates with standard building techniques and materials, simple mechanical systems, and off-the-shelf equipment.

Home Design

The home, shown in Figure E1, was designed using an early version of the BEOpt building optimization software (Christensen et al. 2006) and additional analysis using DOE2 (LBNL 2004) and TRNSYS (Klein et al. 1996) separately. This engineering approach was tempered by regular discussions with Habitat for Humanity construction staff and volunteers. These discussions weighed the applicability of the optimized solutions to the special needs and economics of a Habitat house—moving the design toward simple, easily maintained mechanical systems and volunteer-friendly construction techniques. We chose solutions that avoided interconnected equipment with complex control systems. The home specifications are summarized in Table E1. Further details on the design process and the final design of the home is presented in an earlier paper (Norton and Christensen 2006).



Figure E1. The NREL/Habitat ZEH

Table E1. Summary of NREL/Habitat ZEH Attributes

Square footage	1280 ft ²
Number of bedrooms	3
Number of occupants	3
Design heating load	15,000 Btu/h
Walls	Double stud wall Fiberglass batt insulation Nominal R-value = 40 h ft ² F/Btu
Ceiling	2-ft raised heel trusses Blown-in fiberglass insulation Nominal R-value = 60 h ft ² F/Btu
Floor	Fiberglass batt insulation Nominal R-value = 30 h ft ² F/Btu
South windows	Low-e, high SHGC U = 0.30 Btu/h ft ² F, SHGC = 0.58
North, west, and east windows	Low-e heat mirror U = 0.23 Btu/h ft ² F, SHGC = 0.27
Solar tempered	96 ft ² of south-facing windows 3-ft overhangs for summer shading
Water heating	Drainback solar system 96-ft ² collectors with 200-gal storage tank Natural gas tankless water heater for backup
Ventilation	Energy recovery ventilation system with electronic control modules
Space heating	Direct vent ductless natural gas heater in living room Electric baseboard heaters (750 W each) in bedrooms
Lighting	Compact fluorescent lamps throughout the house
Appliances	ENERGY STAR clothes washer and refrigerator
Solar electric	Nominal 4-kW _p DC PV system
Other features	All mechanical equipment is within conditioned spaces Light-colored roof shingles Increased attic ventilation

The envelope of the home is a double stud wall design; the outer load-bearing walls were constructed of 2×4 s on 16-inch centers. On the inside of the load-bearing wall we constructed a second wall of 2×4 s on 24-inch centers. There is a $3 \frac{1}{2}$ -inch gap between these two stud walls. The finished double stud wall construction allows for three layers of R-13 fiberglass batts: two laid vertically in the cavities of the outer and inner stud walls and a third stacked horizontally between them. This leads to a nominal R-40 wall with very few thermal breaks, as the studs do not continue through the entire wall thickness. Two-foot raised heel trusses were used to accommodate R-60 blown-in fiberglass insulation. Fiberglass batts rated R-30 were used in the floor. All mechanical equipment is contained within this thermal envelope. The crawlspace is vented and uninsulated. An energy recovery ventilation (ERV) system is used to supply fresh air to the home. Ducting for this system is contained in a drop ceiling in the hallway.

The home is designed with large southern glazing for solar gain. The southern windows are double-glazed low-e with a high SHGC of 0.58. Three-foot overhangs provide window shading when solar gain is not needed. Double-glazed, low-emissivity, low SHGC windows were used on the north, east, and west sides of the home.

With these shell efficiency features, the peak design heating load is very small, about 15,000 Btu/h (4.4 kW). This load was met by using a single point sealed combustion furnace in the living room and small (750-W) electric resistance baseboard heaters in the bedrooms. Heat distribution is enhanced by the ERV system, which pulls stale air from the kitchen and bathroom and delivers fresh air to the living room and bedrooms. A solar thermal system with a natural gas tankless heater for backup is used to heat water. The solar system has 96 square feet of collector area and 200 gallons of water for thermal storage. The system is sized to provide a high solar saving fraction year round, and a drainback configuration is used to avoid potential glycol overheating problems during summer stagnation. To keep the system simple, and because the combination of passive solar and superinsulation is already predicted to meet the space heating loads on sunny winter days, active solar space heating is not used.

Data Acquisition System Design

A data acquisition system was installed to determine whether the home met its energy design goal of zero energy. The system was designed to allow the PV energy production and some end uses to be disaggregated. A summary of the data collected and the equipment used is given in Table E2.

Data were collected at 1-minute and 1-hour intervals. Most of the analysis of the home performance was done using the 1-hour data. The 1-minute data were used for troubleshooting and to investigate transient behavior of the solar water heating system. An Excel spreadsheet with array formulas was created to aggregate daily and monthly averages and sums and to create graphics on the performance of the home. All electrical end-use measurements were in place by February 2006. However, the water flow and natural gas end-use monitoring was not complete until April 2006. Unless otherwise stated, all annual figures in this report include the period from April 2006 through March 2007.

Table E2. Measurements and Components of the Data Acquisition System

Measurements	Component	Make	Model
<i>Electrical energy measurements</i>			
PV energy production Baseboard electric heaters Hard-wired lights Kitchen range Ventilation system Solar pump Space and water heating controls All other loads	Pulse output Watt-hour transducers	Continental Controls	Wattnode WNA-1P-240-P
<i>Natural gas measurements</i>			
Space heater Backup water heater	Diaphragm gas meters with pulse output	American Meters	 AM250TC
<i>Indoor and water temperatures</i>			
Living room North bedroom Southeast bedroom Cold water supply Solar tank Solar - water to collectors Solar - water from collectors Solar - water to backup heater Hot water supply to house	Type T thermocouples	Omega Engineering	FF-T-20S- TWSH
<i>Water flow</i>			
Hot water use	Water meter	Omega Engineering	FTB-6107-A-PS
<i>Weather related measurements</i>			
Outdoor temperature and RH	T&RH sensor w/shield	Campbell Scientific	CS500-L
Solar radiation - horizontal	Pyranometer	Li-Cor, Inc.	LI-200SZ
Solar radiation - plane of collectors	Pyranometer	Li-Cor, Inc.	LI-200SZ
<i>Data Logging Equipment</i>			
	Logger	Campbell Scientific	CR-10
	Thermocouple multiplexer	Campbell Scientific	AM25T
	Switch closure multiplexer	Campbell Scientific	SDM-SW8A
<i>Communications</i>			
	Cell phone modem	Redwing	Airlink 100

Home Energy Performance

The home received a Colorado E-star rating of 95. Blower door results yielded a natural ventilation rate of 0.15 air changes per hour (ACH), indicating that the construction crew did an excellent air sealing job.

The home's net source energy performance exceeded expectations. The PV system was sized to achieve net zero annual source energy using TMY2 weather data for Boulder, Colorado (Marion and Urban 1995) and BA Benchmark assumptions for occupant effects such as temperature set points and miscellaneous energy use (Hendron et al. 2004). The BA Benchmark represents U.S. average occupancy choices and behavior. It turns out that the owner/occupants of the NREL/Habitat ZEH use less energy than the BA Benchmark occupants average energy users. Therefore, the home performed beyond zero and was a net source energy producer. A summary of the overall home performance is given in Table E3.

Table E3. 12-Month Performance Summary of NREL/Habitat ZEH

	kWh	MBtu
Site Energy Summary		
Total site electricity consumption	3585	12
Total AC site PV electricity production	5127	17
Net site electricity production	1543	5.3
Total site natural gas consumption	1665	5.7
Source Energy Summary*		
Total source energy consumption	13025	44
Total source energy offset	16201	55
Net source energy offset	3176	11
Percent of source energy consumption offset via on site renewable production	124%	124%

* The site-to-source energy conversions are U.S. national averages according to the BA Analysis Procedures (Hendron et al. 2004): site-to-source multiplier for electricity = 3.16; site-to-source multiplier for natural gas = 1.02.

The monthly site electricity and natural gas consumption by end uses are shown in Figures E2 and E3. The monthly source energy consumption by end use is shown in Figure E4. These figures are consumption only – they do not include the electricity generated by the PV system. Rather than being separately monitored for the entire year, the average refrigerator energy use over an 84-day period was measured and applied to each day of the year.

The ventilation energy use in the home was lower than expected. When we investigated we found that the adjustment for the continuous ventilation rate installed in the mechanical room actually turned off the ventilation system when set to the low setting. The ventilation system was often off during the year of monitoring, so many of the monitored ventilation data represent only the standby power draw. A stop on the adjustment that maintains the minimum ventilation rate at ASHRAE 62.2 recommendations would solve the problem.

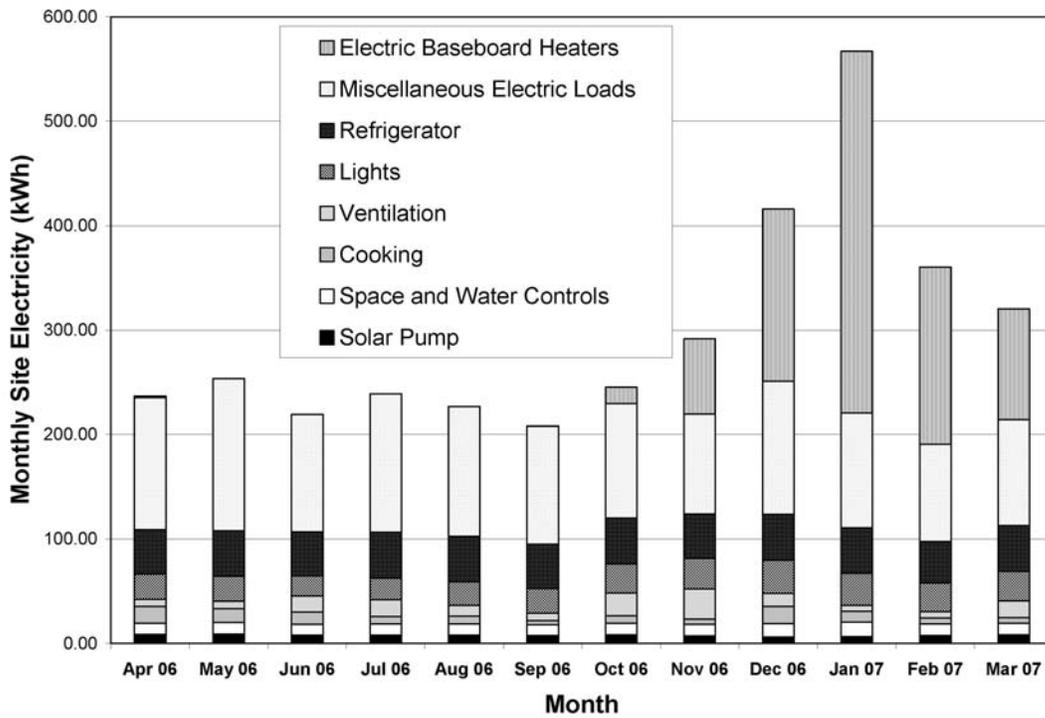


Figure E2. Monthly site electricity consumption by end use

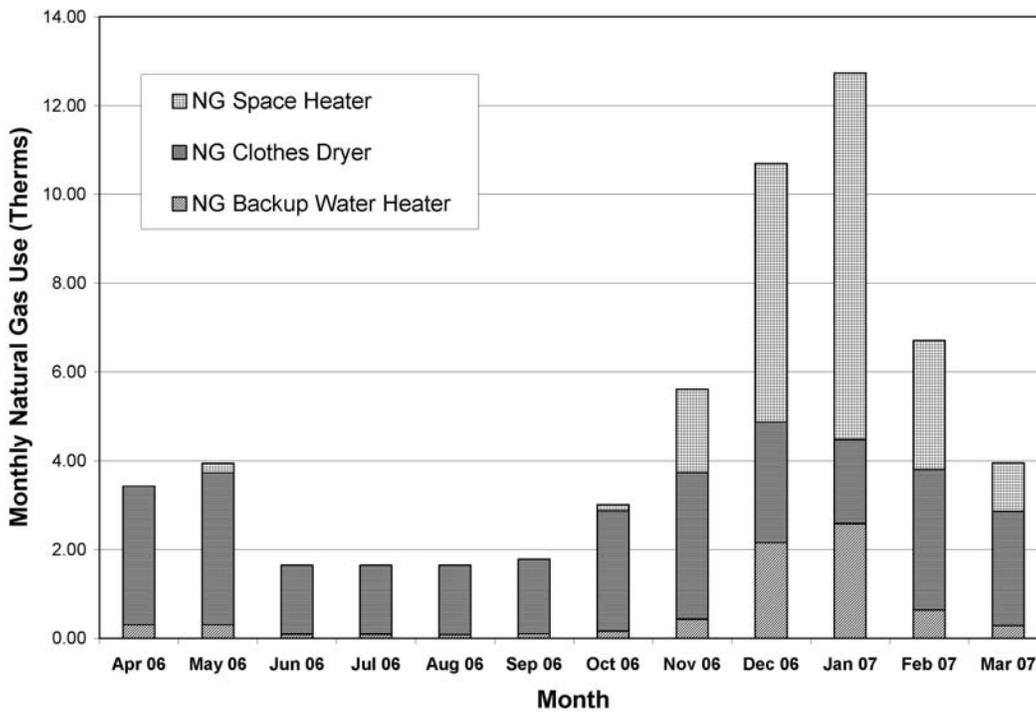


Figure E3. Monthly site natural gas consumption by end use

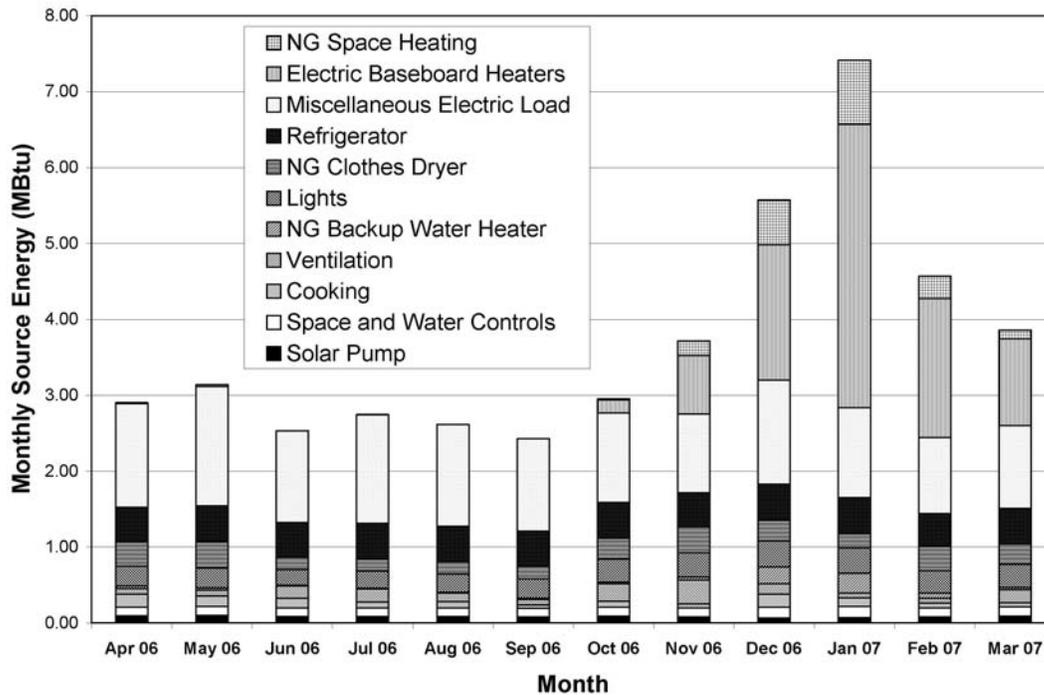


Figure E4. Monthly source energy consumption by end use

As expected, space heating is largest electricity, natural gas, and source energy consumer in the winter months. In the design phase of the project we assumed the natural gas heater in the living room would provide the bulk of the home heating. This assumption was based on conversations with builders who had built similarly sized double stud wall homes in colder climates and used point source heating with favorable results. The natural gas heater was sized to meet the entire design heating load. The baseboard heaters were seen as backup to the natural gas heater if the distribution of the heat to the bedrooms was inadequate. However, in reality the baseboard electric heaters accounted for 60% of the total space heating site energy and 82% of the total space heating source energy. This indicates the heat distribution to the bedrooms from the natural gas heater was not adequate. For the house to rely more on natural gas for heating, additional natural gas heaters or a heat distribution system would be needed.

Despite submetering of most large end uses, the “other electricity loads” was the largest single year-round end use category. The annual average power draw of the other electricity loads is about 164 W. Nearly half of this power draw (84 W) varies hour by hour; peaks occur in the morning before the occupants leave for school or work and in the evening when they return but before they retire for the day. The remaining 80 W is drawn continuously, day and night, whether or not the occupants are in the house. We investigated these base electricity loads using plug-in energy meters that can measure energy draws larger than 5 W. The results are given in Table E4. The measured end uses account for about half of the baseline electricity loads. Some hard-wired end uses that may contribute to the remaining half include ground fault interrupters, doorbell transformer, smoke alarms, and our data acquisition system (estimated to be about 7 to 9 Watts).

Table E4. Measure Baseline Electric Loads

End Use	Power Consumption (W)
Entertainment center standby*	26
Additional TV	6
Computer, monitor, printer standby	5
Digital clock (rated power draw)	3
Microwave oven standby	0 (< 5)
Clothes washer standby	0 (< 5)
Clothes dryer standby	0 (< 5)
Totals	40

* includes TV, stereo, cordless phone, DVD player, and digital clock

The annual source energy by end use is given in Table E5. Other electricity loads are the largest energy use category. Generally speaking, the end uses within the control of the building designer include the space conditioning, water heating, ventilation, and lighting. If we sum all other loads (often referred to as appliance and plug loads) they account for 58% of the total source energy consumption. These loads result primarily from occupant choices and behavior. They vary substantially with homeowner and time. This presents a challenge for ZEH designers. The PV system output must be sized to match all energy consumption to reach the ZEH goal, but the energy consumption is dominated by loads that are out of the designers' control, vary substantially with different homeowners, and are unknowable in advance for a specific home.

Table E5. Annual Source Energy by End Use

End Use	Annual Source Energy (MBtu)	Annual Source Energy (kWh)	Percent of Total
Other electric loads	15.5	4,550	34%
Electric baseboard heaters	9.2	2,690	21%
Refrigerator	5.6	1,630	13%
Lights	3.3	970	7%
Natural gas clothes dryer	2.8	830	6%
Natural gas space heating	2.0	590	5%
Ventilation	1.6	460	4%
Space and water controls	1.5	420	3%
Cooking	1.3	370	3%
Solar pump	1.0	300	2%
Natural gas backup water heating	0.7	220	2%
Totals	44.5	13,030	100%

Photovoltaics Production

A free PV performance calculator, called PVWatts, is available on NREL's Renewable Resource Data Center Web site (<http://rredc.nrel.gov>). The PVWatts simulation of the 4-kW_p direct current (DC) PV system using TMY2 weather data from Boulder, Colorado, predicts the system will deliver 5,756 kWh (19.6 MBtu) of AC electricity per year with no shading. The PVWatts default DC-to-AC derate factor of 0.77 was used for this prediction. A Solar Pathfinder shading analysis indicated a 15% loss of solar radiation caused by shading from mature trees on the site, reducing the expected annual PV production to 4,892 kWh (16.7 MBtu). The actual energy delivered was 5,127 kWh (17 MBtu), exceeding the prediction by 5%. The production exceeded prediction even though the measured total horizontal radiation was about 4% lower than that in the TMY2

data and the PV system was covered in snow and produced no electricity for 35 days (during the unusually snowy weather in December 2006 and January 2007). This indicates that the PVWatts default derate factor may be conservative or that the Solar Pathfinder shading analysis overestimated the impact of the shading.

The daily and cumulative net electricity use is shown in Figure E5. The PV system produces more electricity than was used in the home nearly every day throughout the spring, summer, and fall. Despite the long period of net use with no production in January 2007, the home completed the 12-month period with a net production of 1,543 kWh (5.3 MBtu).

We calculated a simple monthly average PV system efficiency by dividing the monthly total AC electricity production by the monthly total solar radiation on the plane of the collectors times the area of the collectors. The monthly average efficiency varied from a low of 2.1% in January 2007 when the collectors were snow covered for many days, to a high of 13.1% in November 2006. The annual average efficiency was 10.2%.

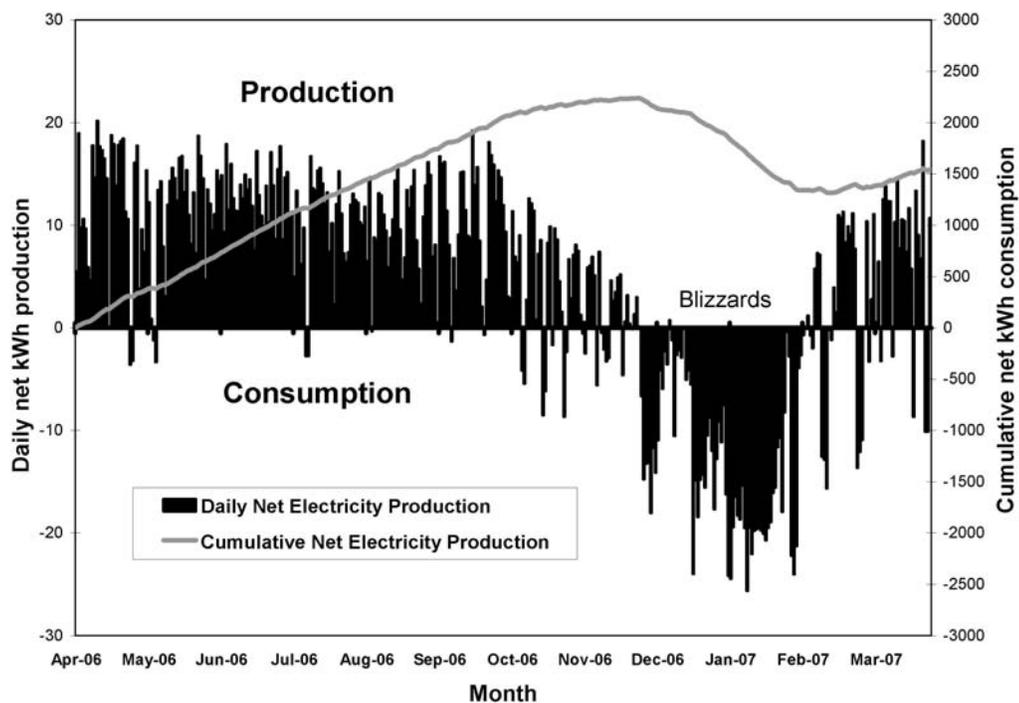


Figure E5. Daily and cumulative net site electricity use

Solar Water Heating

We used TRNSYS modeling software (Klein et al. 1996) to develop design expectations for the solar water heating system. We used the model to investigate tradeoffs with tilt angle, collector size, and storage tank size. The initial BEopt results indicated an investment in a high savings fraction system was justified. The final design incorporated a drainback system with 96 ft² (8.9 m²) collector lying directly on the roof (tilt angle = 27 degrees), with 200 gallons (757 liters) of water for thermal storage.

Energy delivered to the backup water heater by the solar system was tracked by measuring the water temperature entering the solar tank heat exchanger, the water temperature entering the backup water heater from the solar tank heat exchanger, and the water flow rate. The flow*ΔT calculation is performed continuously by the data logger and stored on a 1 minute basis. We also logged the electricity used by the solar pump and the natural gas used by the tankless back-up water heater. Using this information we have defined three solar savings fractions:

1. Thermal site solar savings fraction = $Q_s / (Q_s + Q_{ng})$
2. Total site solar savings fraction = $(Q_s - E_p) / (Q_s + Q_{ng})$
3. Total source solar savings fraction = $(Q_s - (E_p M_e)) / ((Q_s + Q_{ng} M_g))$

Where:

- Q_s = Thermal energy delivered by the solar system to the backup water heater
- Q_{ng} = Energy content of the natural gas consumed by the backup water heater
- E_p = Electrical energy used by the solar pump
- M_e = 3.16 = site to source multiplier for electricity (Hendron et al. 2004)
- M_g = 1.02 = site to source multiplier for natural gas (Hendron et al. 2004)

Table E6 lists the predicted and measured performance characteristics of the solar thermal system.

Table E6. Predicted and Measured Performance of the Solar Water Heating System

	Predicted	Measured	Percent Difference
Average daily hot water use	63.4 gal	20.5 gal	-68%
Delivered energy	12.29 MBtu (3,602 kWh)	2.21 MBtu (647 kWh)	-82%
Pump energy	0.638 MBtu (187 kWh)	0.321 MBtu (94 kWh)	-50%
Ratio of pump energy to delivered energy	0.052	0.145	179%
Maximum monthly thermal site solar saving fraction	1.00	0.95	-5%
Annual thermal site solar savings fraction	0.92	0.75	-18%
Annual site solar savings fraction	0.88	0.64	-27%
Annual source solar savings fraction	0.78	0.40	-49%

The delivered energy of the solar water heater was a small fraction of the predicted value. The main reason for this appears to be that the occupants used less than one-third of the predicted average daily hot water. The prediction is based on the BA Benchmark, which represents national average hot water use. Although the thermal site solar savings fraction was nearly unity during the summer months, the delivered energy was small because of the light hot water demand, which increased the significance of the pump energy. Also, the total site solar savings fraction was only 0.66 compared to the prediction of 0.88. On a source energy basis the savings fraction drops to 0.39 because of the site-to-source multiplier for the electricity used by the pump.

We calculated a simple overall system efficiency for the solar water heater by dividing the thermal energy delivered from the solar tank to the backup water heater by the total solar radiation on the plane of the collectors times the area of the collectors. The monthly average

efficiency varied from 2.8% in August to 7.4% in December. The annual average efficiency was 4.8%.

Utility Bills

Zero energy performance does not necessarily equate to zero utility bills. The NREL/Habitat ZEH was designed to use natural gas for space heating, backup water heating, and clothes drying. In addition, the Xcel Energy net metering arrangement calls for any excess energy accumulated by the end of the calendar year to be zeroed out and compensated for at the “average hourly incremental cost of electricity supply over the most recent calendar year” (Xcel Energy 2006). In a heating-dominated climate, a ZEH produces more energy than it consumes in the summer when daylight hours are long, and consumes more energy than it produces in the winter when daylight hours are shorter and energy is consumed for space heating. Because the accumulated excess energy is zeroed out in the winter when PV production is low, the homeowner will likely have to pay for net electricity consumption in January and February. Because the cost of production is less than the retail cost of the electricity, the compensation the homeowner receives for the excess energy accumulated by December 31 will be less than the cost of the net electricity used in February and March. A better time (for the homeowner) to zero out the accumulated net production would be near the Spring equinox, when the accumulation would be closest to zero. In addition to charges for energy use, utility bills include fixed monthly charges for electricity and natural gas. In the design phase of the project we used simulated energy performance to estimate a monthly average utility bill of \$30 for the house under the current Xcel rate structure.

As energy use is reduced, fixed charges become a larger portion of the utility bill. For the NREL/Habitat ZEH, there was no use charge for electricity most months because of net production rather than consumption, but the fixed charge for electricity still applied. This made it easy to determine the fixed charge for electricity. Disaggregating the natural gas fixed charge from the use charge on the utility bill was surprisingly difficult. Instead, we applied the fixed charge from the rate tariff and assumed the remainder was the use charge.

Some billing problems occurred with the house, probably because it was one of the first net metered houses under Colorado’s renewable portfolio Amendment 37. The home began with an analog meter that ran backward as the PV produced more electricity than the house used. The first bill was not received until the home had been occupied for four months. When it arrived, the meter reading was interpreted as indicating a large positive number rather than a small negative number, and the occupant received a \$939.68 electricity charge on her first bill! Billing continued to be somewhat erratic throughout the first year. An additional hitch came when the analog meter was replaced by a digital net meter. An incorrect final analog meter reading was later corrected. Rather than zero out the accumulated net positive electricity at the end of December, it was zeroed out when the analog meter was replaced on November 8, 2006. At this time the home had generated 2,517 kWh more than it had consumed since the meter was installed in October 2005. The homeowner was reimbursed for this excess generation at a rate of \$.04291/kWh. In January 2006 she received a check from Xcel energy for \$108.00.

The total annual and average monthly electricity and natural gas costs are given in Table E8. The average total utility bill was about \$17/month.

Table E8. Total Annual and Average Monthly Utility Bills for the Monitored Period

	Fixed Charge	Use Charge	Total
Total annual electricity	\$94.69	\$69.58	\$164.27
Reimbursement for net production		-\$108.00	-\$108.00
Total annual natural gas	\$106.43	\$43.03	\$149.46
Total annual bill	\$201.12	\$4.61	\$205.73
Average monthly electricity	\$7.89	\$5.80	\$13.68
Reimbursement for net production		-\$9.00	-\$9.00
Average monthly natural gas	\$8.86	\$3.58	\$12.46
Average monthly total utility bill	\$16.75	\$0.38	\$17.14

Comparing Performance to Expectations Based on Simulations

The final design energy simulation of the building was done with DOE2 software. This simulation uses assumptions for set points, appliance and plug loads, lighting and plug load schedules, and hot water use based on the BA Performance Analysis Procedures. The simulation is driven by TMY2 weather data. After collecting a year of monitored data, we reran the simulation, leaving the building and equipment models unchanged but driving the simulation with measured weather and occupant effects. The changes made to tune the model to actual weather and occupants are listed below:

- Hot water used was reduced to 20.4 gal/day (BA assumption = 65.6 gal/day).
- Appliance and plug loads were reduced to 2,079 kWh/year (BA assumption = 3,053 kWh/yr).
- Dryer energy use was reduced to 28 therms/yr (BA assumption = 76 therms/yr).
- Cooking was changed from natural gas (which was originally anticipated) to electric (which was actually installed).
- Base lighting kWh was adjusted down by 30% and the impact of compact fluorescent lamps increased from 60% reduction to 75% reduction based on measured data.
- The lighting schedule was adjusted based on monitored data.
- The plug load and miscellaneous electricity use schedule was adjusted based on monitored data.
- The hot water use schedule was adjusted based on monitored data.
- Thermostat settings were adjusted based on monitored data.
- Monthly PV was adjusted to monitored values (from 5,274 kWh/yr to 5,127 kWh/yr).
- Ventilation energy was lowered from 298 kWh/yr to 144 kWh/yr.
- Solar domestic hot water effectiveness was adjusted to 80% solar savings fraction annually.

The monthly electricity and natural gas consumption predicted by the original simulation and the tuned simulation are shown with the measured data in Figures E6 and E7.

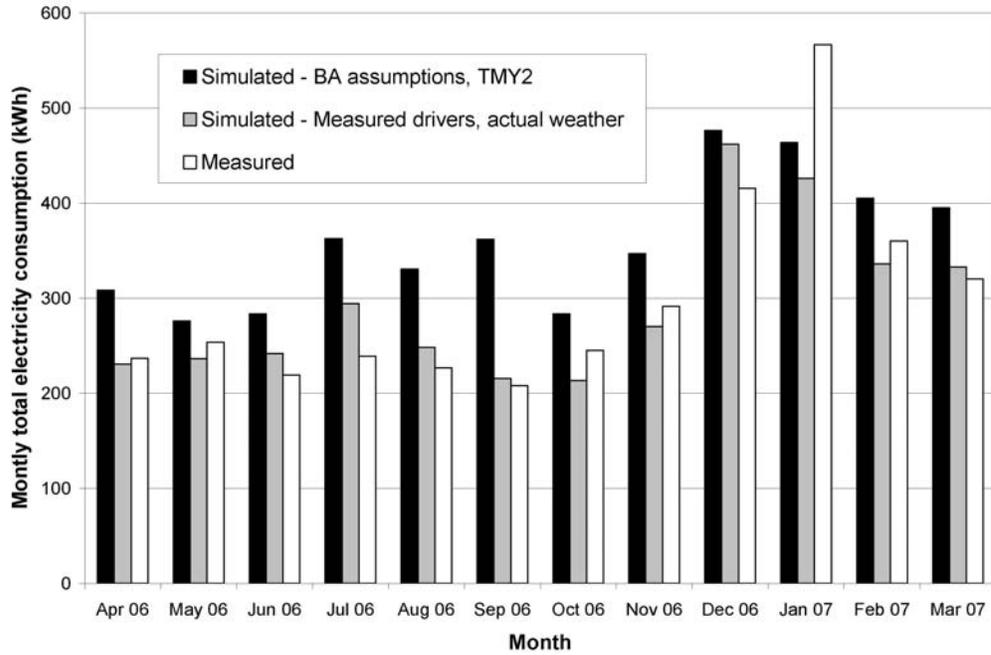


Figure E6. Simulated and measured monthly electricity consumption

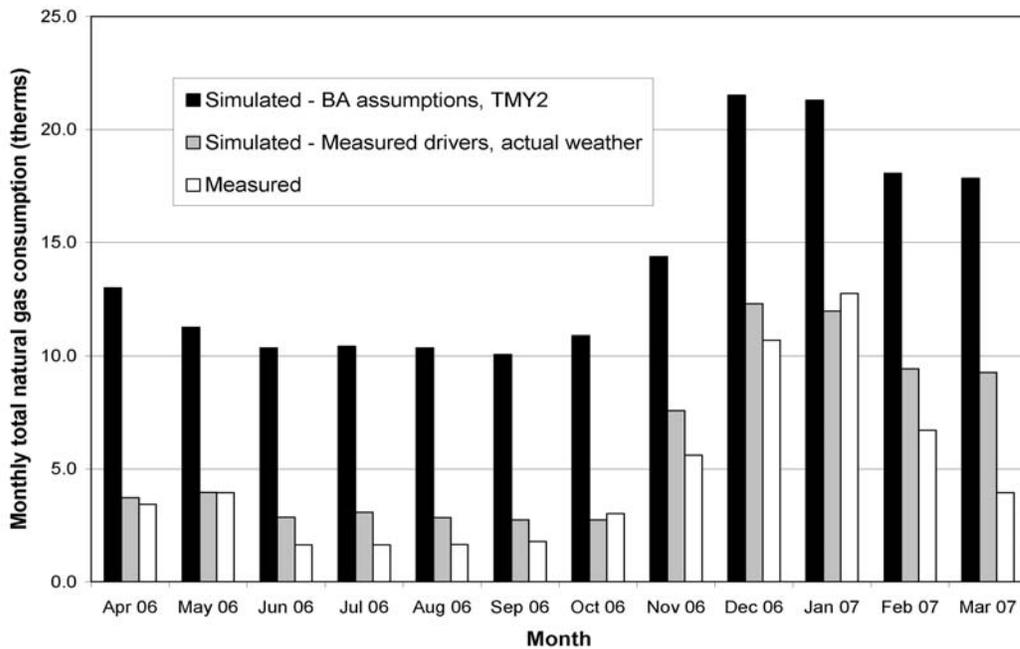


Figure E7. Simulated and measured monthly natural gas consumption

The simulation using BA assumptions and TMY2 weather overestimated the annual electricity consumption by 19%. However, when the simulation used measured occupant and weather drivers, it agreed with the measured data on annual electricity consumption to within 3%.

The simulation using BA assumptions and TMY2 weather overestimated the annual natural gas consumption by more than 200%. The simulation overestimated all natural gas end uses: clothes drying, backup water heating, and space heating. In the tuned simulation, the clothes drying gas use and the hot water use was set to the measured value. The measured annual average solar saving fraction was used to simulate backup water heater gas consumption. Measured room temperatures were used to generate more representative thermostat settings in the simulation. With these changes, the difference between simulated and measured natural gas consumption was reduced to only 17 therms. Because the natural gas consumption of the home is low, this still represents a 32% difference between tuned simulation and measurement. The simulation still overpredicts the space heating natural gas consumption in the coldest months. This difference is probably due to imperfect modeling of the natural gas heater and remaining differences between simulated and actual daily temperature setpoints.

When natural gas and electricity were combined, the tuned simulation was within 8% of the measured annual energy consumption.

Discussion

Installation problems were encountered with the ERV system. In addition to the control problem described previously, some of the ducts were incorrectly connected during the installation. As ERV systems become more common, some ERV commissioning is recommended if the installation contractor is not familiar with these systems.

The built-in thermostats included with the baseboard heaters proved to be imprecise at best. If we use baseboard electric heaters in future projects, we will include a wall-mounted line-voltage thermostat for each heater.

The economics of a ZEH is a function of the specific net metering tariffs for its location. Some tariff structures are more favorable than others. For example, the Tennessee Valley Authority (TVA) buys 100% of the PV generated electricity from home PV systems at \$0.15/kWh. The cost of electricity varies with the TVA area. In Oak Ridge, Tennessee, the electricity use charge is \$0.07543/kWh, so homeowners are paid nearly twice their electricity rate for their PV production. Table E9 shows what the energy costs for the house would be if the Oak Ridge electricity and natural gas rate structure were available in Denver. Rather than having to pay the utilities, the homeowner would have received an average of \$24/month. In locations with incentive programs less favorable than Tennessee's, a ZEH can be seen as a hedging strategy against uncertainty in future energy prices. Owners of affordable homes are generally less able to absorb energy price shocks and would therefore benefit from the low and stable home energy costs of ZEHs.

The PV sizing for this project was based on BA Benchmark appliance and plug load use designed to represent national averages. With this sizing strategy, one could expect the home's chances of achieving zero energy performance as 50/50 – half of the occupants will be above

average energy consumers and half will be below average. The NREL/Habitat ZEH appliance and plug load energy use was 32% less than the Benchmark level and still accounts for 58% of all energy used in the home. This is one of the main reasons it exceeded the net zero energy goal and was a net energy producer. Yet the occupants' lifestyle is not one of deprivation for the sake of energy savings. Another sizing strategy that could be adopted would be to size the PV system for a below average user and provide educational material to the occupant that outlines the energy budget to achieve zero energy in the home. An inexpensive whole-house energy meter can be installed in the home for feedback.

Table E9. Cost of Energy at the Oak Ridge, Tennessee, Rate Structure

	Value	Units	Oak Ridge Cost/Unit	Total Cost
PV reimbursement	5127	kWh	-\$0.15	-\$769.05
Electricity fixed charge	12	months	\$7.46	\$89.52
Electricity use charge	3595	kWh	\$0.07543	\$270.42
Natural gas fixed charge	12	months	\$3.50	\$42.00
Natural gas use charge	57	Therms	\$1.4030	\$79.97
Total annual cost				-\$287.14
Total average monthly cost				-\$23.93

It was a design decision to use natural gas in the NREL/Habitat ZEH and displace the gas use with excess PV electricity generation to achieve net zero source energy. The PV system required for this approach is smaller than for an all-electric house with resistive heating, and reduces overall home cost to achieve net zero source energy with the same societal benefits. However, because the occupants are below average energy users, the net *site* energy use was nearly zero. This means the home could use electric resistance heat to meet the loads currently served by natural gas and still come very close to the zero energy goal without additional PV panels. Eliminating the natural gas would further simplify the mechanical equipment and reduce the already very small utility bill. Making the home all-electric and using the PV sizing strategy described above may be a reasonable approach for a cold-climate affordable ZEH.

The person-to-person variability of appliance and plug load energy use makes sizing the PV system for zero energy challenging. One advantage of net metered PV is a 100% utilization factor. If the occupant does not need the energy being provided by the PV, it is sent to the grid for others to use. (As shown earlier, economic compensation for this energy varies considerably.) In contrast, if the homeowner uses less hot water than expected, the solar thermal system stagnates at its maximum temperature and cannot take advantage of additional solar resource. In effect, the energy that could have been collected is lost. Because water use is highly variable, it presents a similar sizing challenge as the PV system. If the water use is less than expected, the savings drop off substantially and the economic value of the system is reduced. For a ZEH that must supply all its energy from renewable resources, the economic value of solar thermal and PV needs to be carefully weighed, taking the uncertainty of the occupant effects into account. This area warrants further investigation.

Conclusions

- The NREL/Habitat ZEH exceeded its goal of zero net source energy and was a net energy producer in the first year.

- PV system sizing for zero energy homes is challenging
 - The prediction of total home energy use for a specific house becomes highly uncertain due to individual occupant choices and behavior.
 - Meeting the ZEH design goal becomes dependent on occupant behavior.
 - The economics of excess annual PV production are dependent on net metering agreements.

- Zero energy does not necessarily mean zero utility bill
 - There are fixed monthly costs for natural gas and electricity service.
 - Natural gas *costs* may not be displaced by net electricity production.

- It is possible to make efficient, affordable ZEHs with standard construction techniques and off-the-shelf equipment.

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Appendix F Community Evaluation Cost Estimates

Input from the BA teams was used to make first-order cost estimates of community evaluations with the tools described in these guidelines. Because specific evaluation projects may use a unique combination of the tools, cost estimates were solicited in a piecemeal fashion. Table F1 shows breakdown of the cost requested from the teams.

Table F1. Breakdown of Cost Estimates for Community Evaluations

Element	Units	Assumptions and Notes
Design and planning of the evaluation project	\$/project	
Billing data procurement and analysis with utility partnership	\$/50 homes	Includes collecting minimum descriptive information on home construction from the builder(s). Includes treatment of outliers, house size, and pools. Includes simple averages and descriptive statistics. Includes writing a final report. Does not include regression analysis.
Billing data procurement and analysis without utility partnership	\$/50 homes	Includes the above and collecting homeowner release forms.
Billing data regression analysis	\$/50 homes	Analysis using software like PRISM or E Tracker C
Collect and report builder information	\$/community	This is an add-on cost to the utility bill analysis. Includes information on incremental costs, installation experiences, and callbacks.
Collect and report sales information	\$/community	This is an add-on cost to the utility bill analysis. Includes home sales and resale information.
Annual energy simulations	\$/community	Includes simulation to predict community annual energy use. Please note assumptions on number of home models simulated and whether house orientation effects are included.
Short-term testing and home inspections	\$/house	Includes blower door, duct blaster, and inventory of insulation levels, equipment, and appliances.
Minimum end-use monitoring – equipment only	\$/house	Includes only whole house electrical, whole house gas, and one temperature. Please note type of logging equipment you would use.
Minimum end-use monitoring – installation and removal only	\$/house	Includes only whole house electrical, whole house gas, and one temperature.
Minimum end-use monitoring – data retrieval, analysis, and reporting	\$/house-year	Includes only whole house electrical, whole house gas, and one temperature.
Full end-use monitoring – equipment only	\$/house	Includes whole house electricity, space heating energy, space cooling energy, hot water use, water heating energy, PV production, indoor temperature and RH, and a weather station for each community.
Full end-use monitoring – installation and removal only	\$/house	Includes whole house electricity, space heating energy, space cooling energy, hot water use, water heating energy, PV production, indoor temperature and RH, and a weather station for each community.

Element	Units	Assumptions and Notes
Full end-use monitoring – data retrieval, analysis, and reporting	\$/house-year	Includes whole house electricity, space heating energy, space cooling energy, hot water use, water heating energy, PV production, indoor temperature and RH, and a weather station for each community.
Homeowner surveys	\$/50 homes	Assume that you will be given a formatted survey that includes the minimum required questions. The estimate should include customizing the survey, distribution, analysis, and reporting.

Figure F1 presents aggregate costs of full production homes for three different scenarios and two different community sizes. The complete cost estimates are given in Table F2. The “Minimum Evaluation” scenario includes the costs for collecting builder and sales information, short term testing and simulations, and homeowner questionnaires for 50 or 100 homes. The other two scenarios add on a utility bill analysis with a reference community and full end use monitoring of every house in the BA and reference communities.

A minimum evaluation designed to meet the BA Project Closeout must-meet criteria is estimated to cost about \$56,000 for 50 homes and \$81,000 for 100 homes. Including a utility bill analysis for the BA community and a comparison reference community increases the costs to several hundred thousand dollars per evaluation. Complete detailed evaluations with full end-use monitoring are estimated to cost several million dollars each.

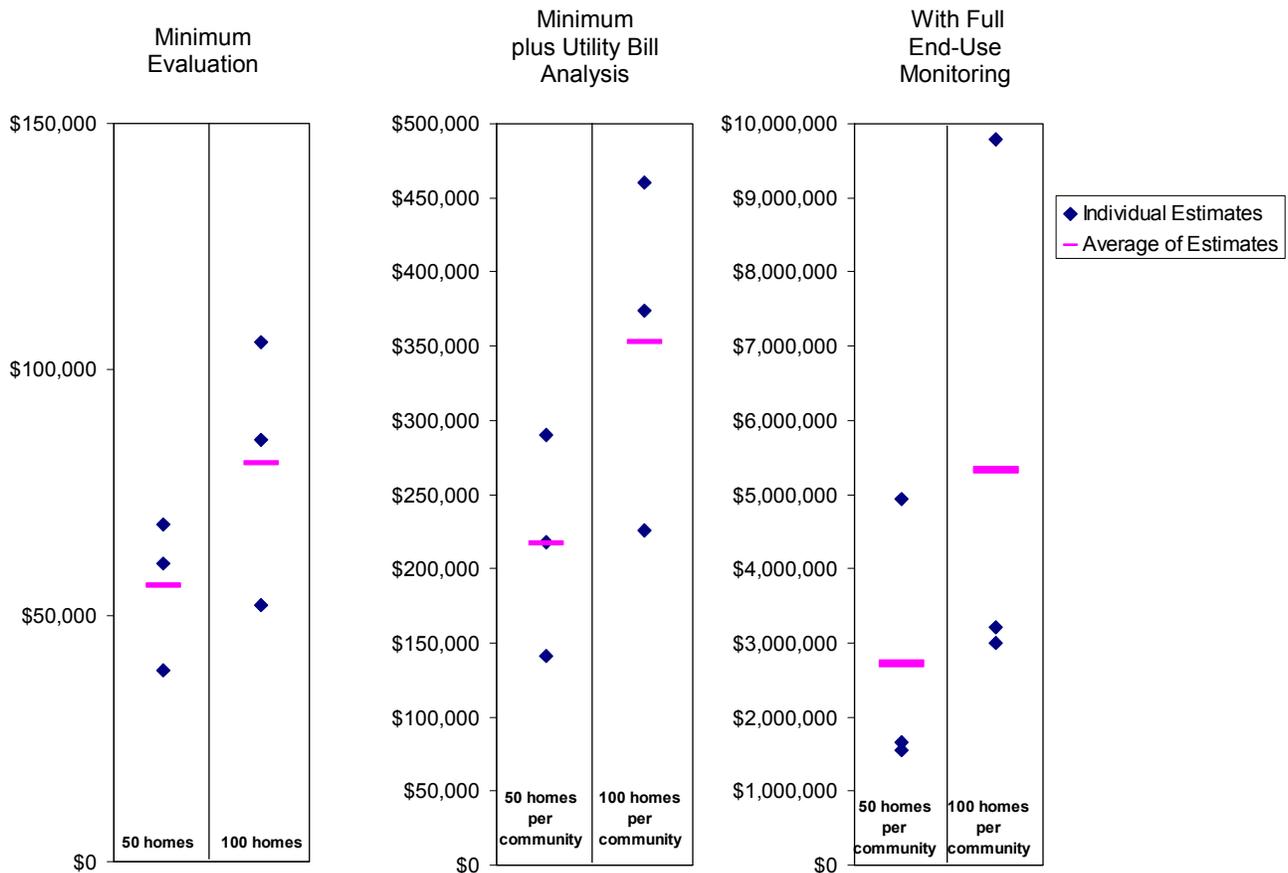


Figure F1. Cost estimates for production home evaluations

Table F2. Complete Cost Estimates Submitted by BA Teams

Element	Units	Team 1	Team 2	Team 3	Assumptions
Design and planning of the evaluation project*	\$/project	\$0	\$50,000	\$10,500	
Billing data procurement and analysis with utility partnership	\$/50 homes	\$23,000	\$35,000	\$22,000	Includes collecting minimum descriptive information on home construction from the builder(s). Includes treatment of outliers, house size, and pools. Includes simple averages and descriptive statistics. Does not include regression analysis. Includes writing a final report
Billing data procurement and analysis without utility partnership	\$/50 homes	\$41,000	\$60,000	\$29,000	Includes the above and collecting homeowner release forms
Billing data regression analysis	\$/50 homes	\$12,000	???	\$9,000	Analysis using software like PRISM or E Tracker C
Collect and report builder information	\$/community	\$10,000	\$15,000	\$8,000	This is an add-on cost to the utility bill analysis. Includes information on incremental costs, installation experiences, and call-backs.
Collect and report sales information	\$/community	\$10,000	\$10,000	\$5,500	This is an add-on cost to the utility bill analysis. Includes home sales and resale information.
Annual Energy Simulations	\$/community	\$11,000	\$10,000	\$10,000	Includes simulation to predict community annual energy use. Please note assumptions on number of home models simulated and whether house orientation effects are included.
Short-term testing and Home inspections	\$/house	\$600	\$600	\$2,500	Includes blower door, duct blaster, and inventory of insulation levels, equipment, and appliances
Monitoring scheduling and logistics**	\$/house	n/a	\$300	n/a	
Minimum end use monitoring - equipment only	\$/house	\$2,600	\$3,000	\$1,000	Includes only whole house electrical, whole house gas, and one temperature. Please note type of logging equipment you would use.
Minimum end use monitoring - installation and removal only	\$/house	\$2,000	\$2,500	\$19,000	Includes only whole house electrical, whole house gas, and one temperature.
Minimum end use monitoring - data retrieval, analysis and reporting	\$/house-year	\$5,000	\$3,500	\$9,000	Includes only whole house electrical, whole house gas, and one temperature.
Monitoring scheduling and logistics**	\$/house	n/a	\$300	n/a	
Full end use monitoring - equipment only	\$/house	\$5,000	\$5,000	\$3,250	Includes Whole house electricity, space heating energy, space cooling energy, hot water use, water heating energy, PV production, indoor T&RH, Weather station for each community
Full end use monitoring - installation and removal only	\$/house	\$3,500	\$3,250	\$26,500	Includes Whole house electricity, space heating energy, space cooling energy, hot water use, water heating energy, PV production, indoor T&RH, Weather station for each community
Full end use monitoring - data retrieval, analysis and reporting	\$/house-year	\$5,000	\$3,500	\$15,500	Includes Whole house electricity, space heating energy, space cooling energy, hot water use, water heating energy, PV production, indoor T&RH, Weather station for each community
Homeowner Surveys	\$/50 homes	\$37,000	\$25,000	\$13,000	Assume that you will be given a formatted survey that includes the minimum required questions. The estimate should include customizing the survey, distribution, analysis, and reporting.

* Team 1 chose to integrate planing costs into the specific task costs

** Team 3 chose to present these costs separately

REPORT DOCUMENTATION PAGE

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1. REPORT DATE (DD-MM-YYYY) March 2008		2. REPORT TYPE Technical Report		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Project Closeout: Guidance for Final Evaluation of Building America Communities				5a. CONTRACT NUMBER DE-AC36-99-GO10337	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) P. Norton, J. Burch, and B. Hendron				5d. PROJECT NUMBER NREL/TP-550-42448	
				5e. TASK NUMBER BET88001	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393				8. PERFORMING ORGANIZATION REPORT NUMBER NREL/TP-550-42448	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S) NREL	
				11. SPONSORING/MONITORING AGENCY REPORT NUMBER	
12. DISTRIBUTION AVAILABILITY STATEMENT National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT (Maximum 200 Words) This report presents guidelines for Project Closeout. It is used to determine whether the Building America program is successfully facilitating improved design and practices to achieve energy savings goals in production homes. Its objective is to use energy simulations, targeted utility bill analysis, and feedback from project stakeholders to evaluate the performance of occupied BA communities.					
15. SUBJECT TERMS building america; project closeout; energy simulation; targeted utility bill analysis					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UL	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (Include area code)

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18