Case Studies In
Resource-Efficient Residential Building:
The Building America Program

Ann V. Edminster, Natural Resources Defense Council
Betsy Pettit, Building Science Corporation
with Kohta Ueno, Stephanie Menegus, & Steven Baczek, Building Science Corporation

ABSTRACT

The Natural Resources Defense Council is participating in the Building America program as a member of the Building Science Consortium. This paper presents our experience with this program, documenting the program's goals, expectations, and actual outcomes to date.

Building America is a program of the U.S. Department of Energy, in which teams of architects, engineers, builders, equipment manufacturers, and others collaborate in a systems engineering approach to produce homes that use up to 50 percent less energy to operate.

The Building Science Consortium, one of five Building America teams, employs an integrated strategy to achieve the Building America goals, incorporating advanced framing, improved insulation, simplified HVAC systems, high performance windows, and details that ensure durability of the homes. The consortium's projects to date, totaling 884 homes, have resulted in significant and measurable environmental gains.

I. Introduction

The Natural Resources Defense Council is participating in the Building America program as a member of the Building Science Consortium, which is led by the Building Science Corporation, headquartered in Westford, Massachusetts. This paper presents our experience with this program, documenting the program's goals, expectations, and actual outcomes from the program inception in 1995 until March 2000.

About the Building America Program

Building America is an industry-driven, private/public partnership sponsored by the U.S. Department of Energy to accelerate the development and adoption of innovative building processes and technologies for production housing. **The goal of the program is to produce resource-efficient, environmentally sensitive, affordable, and adaptable residences on a community scale.** Building America unites segments of the building industry that traditionally work independently of one another into teams of architects, engineers, builders, equipment manufacturers, and others, to collaborate in a systems engineering approach to achieve the following objectives:

- Produce homes on a community scale that use 30 to 50 percent less energy.
- Reduce construction time and waste by as much as 50 percent.

- Improve builder productivity.
- Provide new product opportunities to manufacturers and suppliers.
- Implement innovative energy- and material-saving technologies.

Currently, there are five teams comprising more than 180 different companies. The teams have built close to 1,500 homes to date.

The Systems Engineering Approach

Throughout the design and construction process, the systems engineering approach considers the interaction between the building site, envelope, mechanical systems, and other factors. It recognizes that one feature of the house can greatly affect others and it enables the teams to incorporate energy-saving strategies at no or minimal extra cost.

Building America teams work to produce houses that incorporate energy- and material-saving strategies from the very start of the building process—the design. Initial cost-effective strategies are analyzed and selected during pre-design. The team then evaluates its design, business, and construction practices to identify cost savings, which can then be reinvested to improve energy performance and product quality.

After the design has been evaluated, the team builds a prototype or "test" house. After a test home is built, the team performs field tests and sets up long-term monitoring. Then DOE's National Renewable Energy Laboratory provides feedback on energy technologies and design strategies implemented by the teams. The results are documented in case studies that enable builders to learn from each other. The Building Science Consortium has adopted from the outset a philosophy of shared information and has chosen not to make its findings proprietary. Consortium members share the goal of disseminating good practice throughout the industry.

After the prototypes are tested and the team makes any changes to the design needed to increase efficiency and cost-effectiveness, the design is retested before it is used in production or community-scale housing.

This approach offers numerous advantages to the builder:

- Reduced construction costs;
- Improved productivity;
- Improved building performance;
- Reduced callback and warranty problems;
- Competitive advantage.

There are also significant advantages to the consumer:

- Increased quality without increased cost;
- Increased comfort and performance;
- Reduced utility bills;
- Access to innovative financing due to predictably lower utility bills.

The Connection With Energy Star Homes

Energy Star Homes is a cooperative program of the U.S. Department of Energy and the U.S. Environmental Protection Agency. Energy Star Homes are built to a set of prescriptive standards and then tested to ensure that they have achieved the performance target of 30 percent less energy use for heating, cooling, and water heating than a reference home based on the Model Energy Code.

Building America homes must, at a minimum, meet the same performance standard as Energy Star Homes and, having done so, may carry the Energy Star rating. However, the Building America program is entirely performance-based.

The Building Science Consortium and NRDC's Role

The Building Science Consortium (BSC) has designed cost-effective, resource-efficient single- and multi-family homes for each of the five U.S. climate types.[1] BSC builder partners have committed to building close to 4,000 Building America homes in 17 communities; more than 800 of these were completed and another 300-plus under construction as of March 2000. Re-engineering and design is underway in eight additional locations.

The Natural Resources Defense Council (NRDC) is a national environmental non-profit organization with more than 400,000 members worldwide. Our resource-efficient building project aims to reduce resource use (in particular energy and wood) in home building. We are working with builders who are interested in adopting environmental building approaches to develop and publicize successful projects that will serve as models for others in the industry. As a consortium member, NRDC serves as pro bono green building consultant to BSC builder partners, advising on wood-use, forestry, and energy issues, as well as other building materials and processes. In addition, NRDC has recruited new builder partners to the consortium. NRDC is the only environmental member of a Building America consortium.

II. BSC'S Approach

BSC's basic approach is to invest more money to improve the building envelope while saving by downsizing the mechanical equipment, so that the total construction cost remains roughly the same. BSC has established performance metrics that allow the prediction and quantification of building performance. BSC has developed construction techniques, equipment, and systems to allow production home builders to meet these performance metrics at little or no incremental cost.

Integrated Construction Strategy

The Building Science Consortium employs an integrated strategy to achieve the Building America goals:

- Using advanced framing/optimum value engineering;
- Incorporating higher levels of insulation and better installation details;

[1] BSC's climate types are based on Herbertson's Thermal Regions, a modified Koppen classification, the ASHRAE definition of hot-humid climates, and average annual precipitation data from the U.S. Department of Agriculture and Environment Canada. (A map is shown at www.buildingscience.com/buildamerica.html.)

- Simplifying heating, ventilating, and air conditioning systems;
- Reinvesting energy cost savings in high performance windows and other advanced building features;
- Incorporating details that ensure durability of the homes.

Advanced Framing. BSC uses advanced framing and insulation methods to increase efficiency and comfort while decreasing costs. Although advanced framing has been around for 30 years, it has—with some limited exceptions—not been widely adopted. BSC believes this is due to a lack of systems integration. BSC has integrated advanced framing into a complete approach to building envelope design and mechanical system layout, using modular dimensioning, detailed construction drawings, and structural mock-up testing to refine an updated approach to advanced framing.

On many Building America projects, BSC has used 2x6- instead of 2x4-inch studs, set 24 instead of 16 inches apart. This allows room for more and thicker insulation, enhances the strength of the house, and reduces thermal bridging. It also reduces the amount of framing wood and, because 30 percent fewer pieces have to be assembled, framing takes less time and labor costs are significantly lower.[2]

Working with the U.S. Army's Civil Engineering Research Laboratory, BSC is facilitating code approval of new advanced framing techniques by jurisdictions subject to severe earthquake and wind loads. Full-scale assemblies are being tested under the new seismic loading protocols developed after the 1994 Northridge, California, earthquake.

Tightly Sealed House Envelopes. To construct a tight thermal envelope, BSC has put a great deal of effort into air leakage control, identifying and eliminating large holes, and developing innovative closure details. Oriented strand board has been replaced with rigid foam exterior sheathing. The insulation board joints are taped, or a system of vertical panel laps and horizontal flashings is used, to create an exterior air barrier as well as a drainage plane for rain control. This eliminates the need for building paper or housewrap.

In cold northern locations, BSC has sealed and insulated interior basement walls with R-7.5 rigid polyisocyanurate board or with "wrapped batt" insulation. Other interior insulation systems are currently being tested for cost-effectiveness. Interior basement insulation helps prevent heat loss and reduces chance of condensation-related mold problems.

Simplified Central HVAC System. BSC has moved the ducts into the conditioned space, eliminating heat loss to the exterior and limiting the temperature difference at the ducts. This, along with placing the heating/cooling system in a central location, shortens duct runs and cuts material and installation costs—sometimes by more than 50 percent—also saving energy. Some homes also use new round ducts only 8 inches in diameter, which are cheaper to install and easier to maintain.

BSC's building envelope designs for hot-dry and hot-humid climates, with ductwork and air handlers located within the conditioned space/building pressure boundary, have led to subsequent innovations in roof insulation systems and building code changes. The unvented

---

[2] Considering both materials and labor, BSC's approach to advanced framing on BA homes has typically reduced framing costs by $250 per house. See Tables 2 through 5.

roof designs developed for hot-humid climates (see Figure 1) significantly reduce latent loads (moisture) and allow the use of simple off-the-shelf components to provide controlled ventilation with dehumidification.[3]

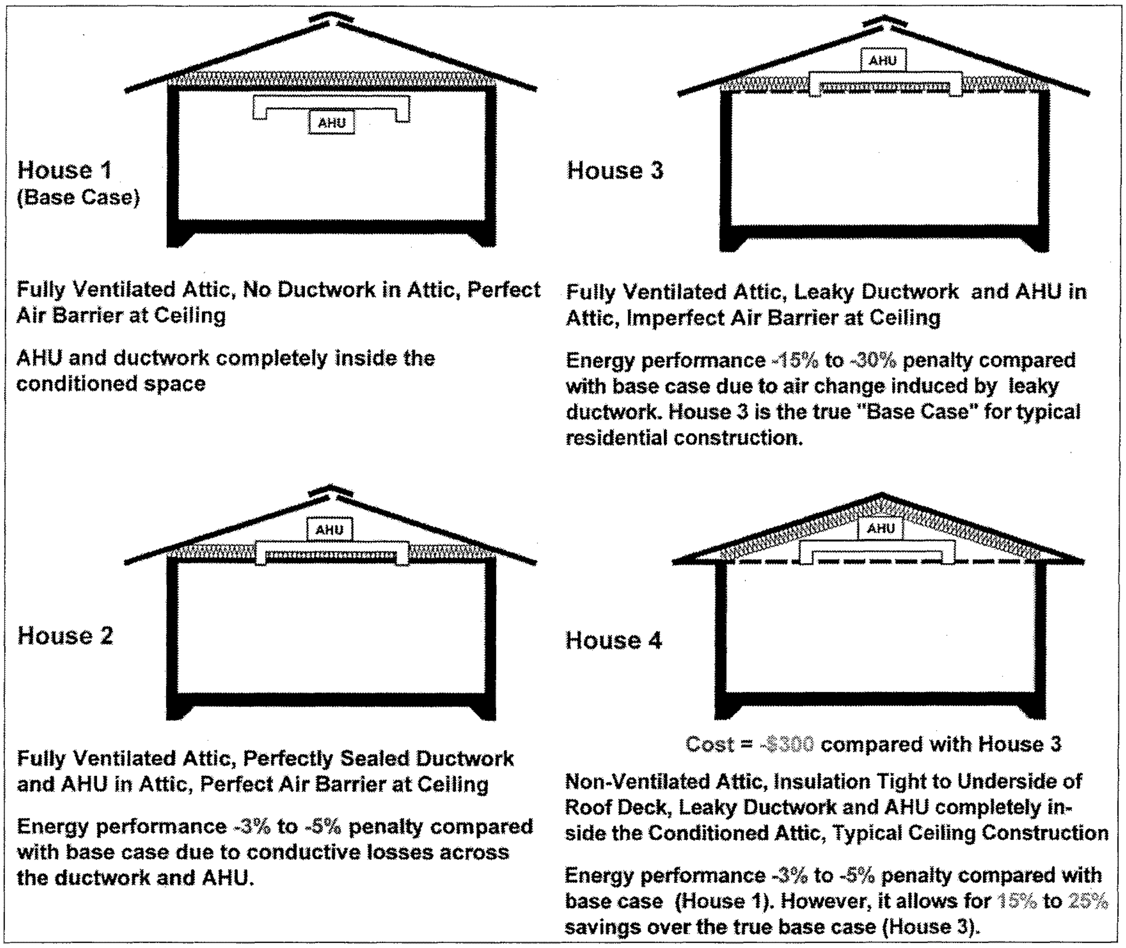


Figure 1. Unvented Roof Designs

Disentangled Infrastructure. With the ductwork, plumbing, and wiring all placed inside the conditioned space, the house envelope is no longer broken by entry and exit points. This saves labor and material costs and contributes to a tighter seal, thus further increasing the home's energy efficiency. The use of open-web floor trusses allows for fast, easy installation of ducts, plumbing, and wiring in the conditioned space, saving construction time and costs. The trusses also permit the use of more efficient, less expensive, 8-inch ducts.

Smaller Mechanical Systems. Once the house is tightly sealed, a smaller and substantially less costly system is needed to heat and cool it. The houses typically require one ton less cooling capacity than comparable non-BSC homes. New BSC systems are sized to 85 percent rather than 150 percent of ACCA Manual J, as is standard practice. The cost and energy

[3] Unvented roof designs are currently only recommended with tile roofs. Unvented asphalt shingle roofs are being tested for loss of roof life.

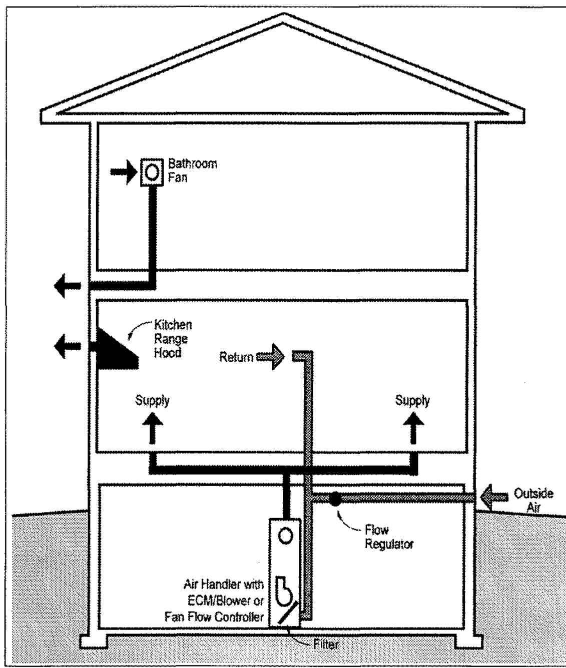
savings associated with this approach are enormous and represent the single greatest achievement of this program.

Oversizing of ACCA Manual J is pervasive due to compensation for duct leakage to the exterior, constricted airflow, and inappropriate refrigerant charge. BSC has eliminated duct leakage to the outside by moving ductwork to within the building thermal and pressure envelope. In addition, consortium member Proctor Engineering has developed a computer-based refrigerant charge quality control program that is used to assure optimum system operation, eliminating the need to oversize the system.

Innovative Air Distribution and Ventilation Systems. Providing durability for little or no incremental cost is a goal of the Building America program. Durability and maintenance cost are direct functions of moisture, heat, and ultraviolet light, of which moisture is the most significant. Durability with respect to moisture can be ensured by designing the building envelope so it can dry should it get wet, installing controlled mechanical ventilation systems, and preventing excessive pressurization and depressurization of occupied spaces and cavities.

BSC has developed controlled mechanical ventilation strategies for all climates, using a central fan-integrated supply of outside air. This system is augmented in cold climates with continuously operating exhaust fans (see Figure 2) and in hot-humid climates with a dehumidification system (see Figure 3). These strategies are models for implementing ASHRAE Standard 62.2 –Ventilation for Indoor Air Quality in Residential Buildings.

BSC has also developed innovative air distribution systems that address the problems of interstitial pressurization/depressurization and intra-zone air pressure imbalances. These systems (shown in Figures 4, 5, and 6) work better and cost less than conventional practices.



Supply Ventilation System with Integrated Heating and A/C

- Air handler with ECM/blower runs continuously (or operated based on time of occupancy) pulling outside air into the return system.
- A flow regulator provides fixed outside air supply quantities independent of air handler blower speed.
- House forced air duct system provides circulation and tempering.
- Point source exhaust is provided by individual bathroom fans and a kitchen range hood.
- In supply ventilation systems, and with heat recovery ventilation, pre-filtration is recommended as debris can affect duct and fan performance reducing air supply.
- Kitchen range hood provides point source exhaust as needed.
- Outside air duct should be insulated and positioned so that there is a fall/slope toward the outside to control any potential interior condensation. Avoid using long lengths of flex duct that may have a dip that could create a reservoir for condensation.
- Mixed return air temperatures (return air plus outside air) should not be allowed to drop below 50° Fahrenheit at the design temperature in order to control condensation of combustion gases on heat exchanger surfaces

Figure 2. Cold Climate Ventilation System

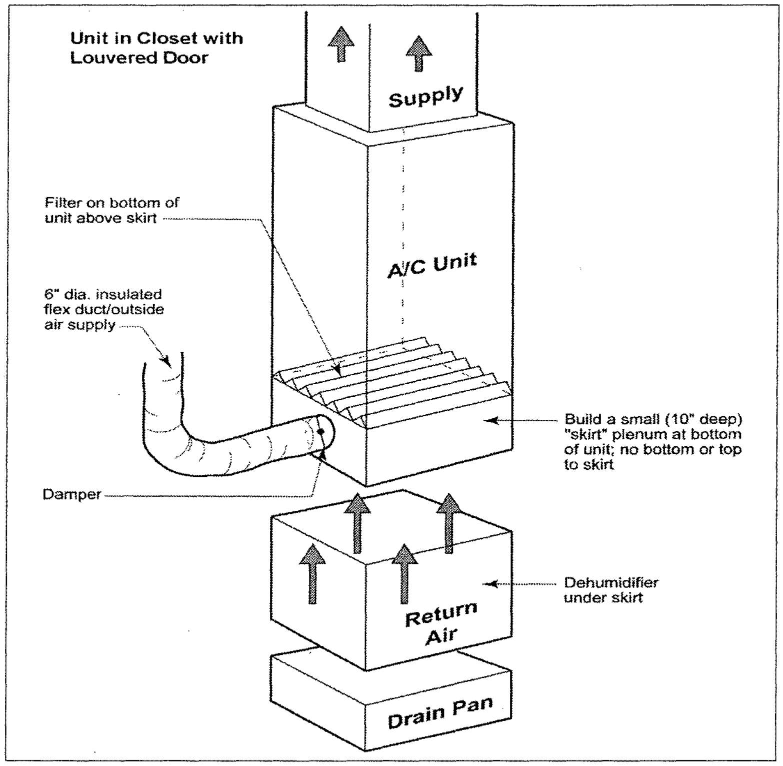


Figure 3. Hot-Humid Climate Dehumidification System

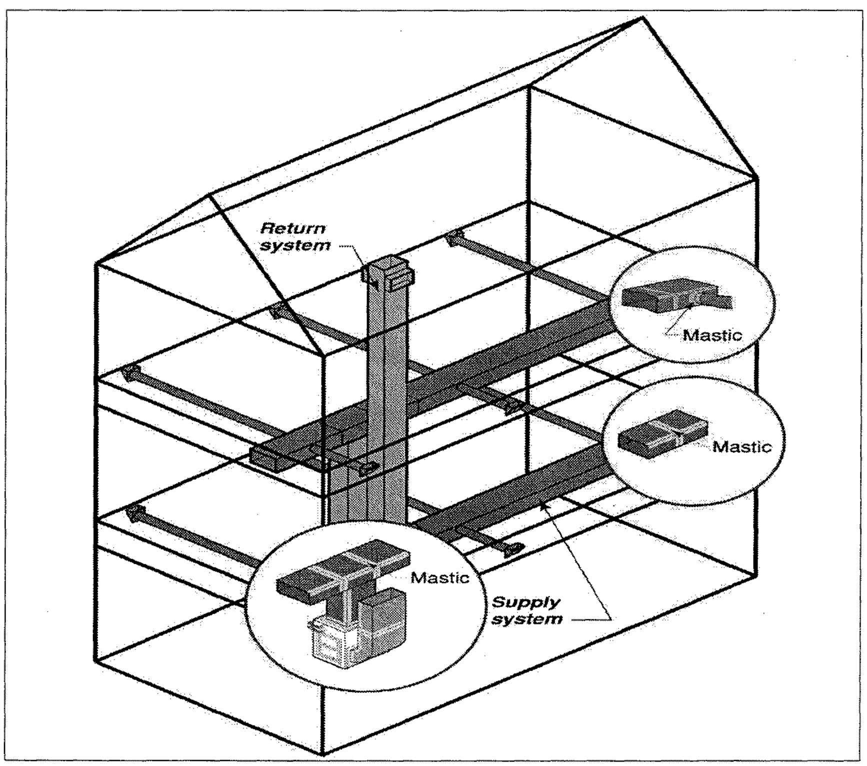
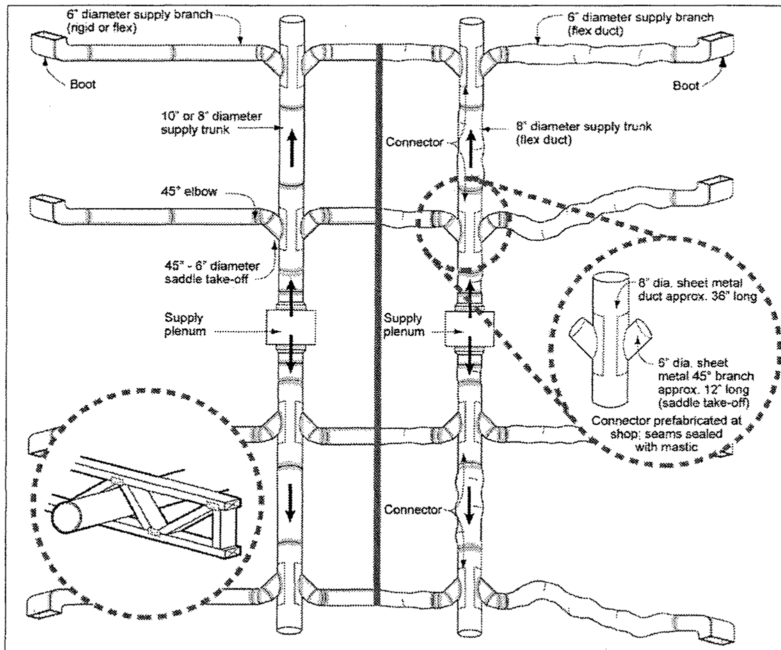


Figure 4. Sample Air Handler and Branching System Layout



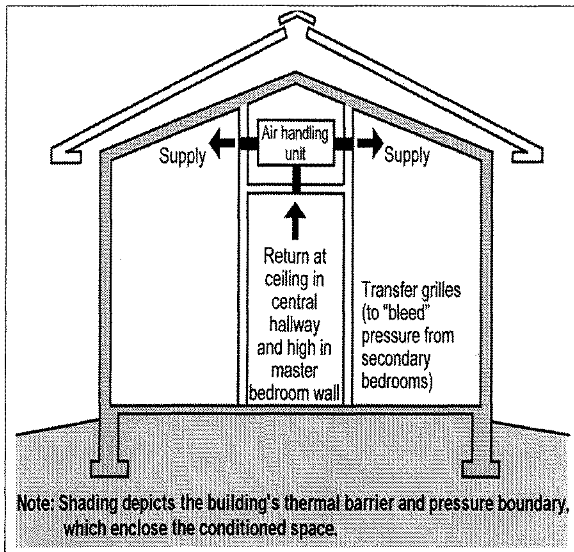
Supply Duct System

- Must be sized/designed on a case-by-case basis
- Supply duct system sized to fit within 14"-deep or 12"-deep open webbed floor trusses
- Trunk ducts can be 10"-diameter for 14"-deep for trusses or 8"-diameter for 12"-deep floor trusses depending on air flows and heat losses
- Branch supply ducts can be insulated flex
- Rounded ducts, 45° take-offs and 45° elbows reduce air flow resistance so ducts can be made smaller to fit in floor system

Flex Duct System

- Flex ducts fit within floor truss system
- Sheet metal connector prefabricated in shop

Figure 5. Supply and Flex Duct Systems



Slab-on-Grade Dropped Ceiling with a Vented Attic

- The air handling unit is located in an interior closet and the supply and return ductwork is located in a dropped hallway
- Transfer grilles bleed pressure from secondary bedrooms
- Ductwork does not have to extend to building perimeters when used with thermally efficient windows (low E, spectrally selective) and thermally efficient building envelopes (well insulated 2x6 frame walls with 1" insulating sheathing); throw-type of registers should be selected.
- Typical low-efficiency gas appliances that are prone to spillage or backdrafting are not recommended in this type of application; heat pump water heaters, or sealed combustion furnaces or hot water heaters should be used
- A hot water-to-air fan coil in an air handling unit can be used to replace the gas furnace/gas burner. The fan coil can be connected to a standard gas water heater with a draft hood located in the garage exterior to the building envelope pressure boundary. Alternatively, the gas water heater can be sealed combustion (or power vented) and located in the conditioned space.

Figure 6. Vented Attic Design

Construction Requirements and Performance Metrics

Specific construction requirements and target performance metrics for the program are as follows:

- Overall energy consumption for heating, cooling, and water heating to Energy Star requirements as determined by an accredited home energy rating system procedure.
- Air leakage (determined by pressurization testing) less than 2.5 square inches/100 square feet leakage ratio.

- Ductwork leakage to the exterior for ducts distributing conditioned air limited to 5.0 percent of the total air handling system rated air flow at high speed determined by pressurization testing at 25 Pa.
- Controlled mechanical ventilation when building is occupied at a minimum of 20 cfm per master bedroom plus 10 cfm per additional bedroom. Capability for intermittent ventilation of 0.05 cfm per square foot of conditioned area, 100 cfm for each kitchen. Intermittent spot ventilation of 50 cfm or continuous ventilation of 20 cfm when the building is occupied for each washroom/bathroom. Positive indication of shutdown or improper system operation provided to occupants.
- Ventilation system airflow to be tested after completion of the building.
- Mechanical ventilation to use less than 0.5 Watt/cfm for systems without heat recovery or less than 1.0 Watt/cfm for systems with heat recovery (recommended in severe heating climates, at recovery rate greater than 65 percent including effectiveness of distribution).
- Total ductwork leakage limited to 10.0 percent of the total air handling system rated air flow at high speed determined by pressurization testing at 25 Pa.
- Only sealed combustion or power vented direct combustion appliances in occupied spaces, rated to vent properly at largest expected negative pressure. Gas cooktops and gas ovens only installed with exhaust fans.
- Major appliances to be Energy Star rated or in the top one-third of the DOE Energy Guide rating scale.
- Lighting power density not to exceed 1.0 Watts per square foot.
- Controls for space conditioning, hot water, or lighting energy use to be clearly marked. Information relating to the operation and maintenance of such systems to be provided to occupants.
- Designer and contractor to provide comprehensive information to occupants regarding the safe, healthy, comfortable operation of building systems.

Homes built meeting the performance metrics also comply with current versions of:

- All applicable building codes;
- ASHRAE Standard 62.2 – Ventilation for Acceptable Indoor Air Quality;
- ASHRAE Standard 55 – Thermal Comfort;
- ASHRAE Standard 90.1 – Energy Conservation;
- EPA Energy Star (30 percent better than the Model Energy Code);
- American Lung Association Health House Program.

III. Project Outcomes & Conclusion

Cost Results

The cost implications (materials and labor) of the climate-specific strategies developed by BSC are summarized below, in Table 1. The cost trade-offs for each climate type are shown in Tables 2 through 5.

Table 1. Cost Summary by Climate Type

Climate Type	Total Incremental Cost to Builder	Typical Yearly Heating & Cooling Savings to Homeowner
Cold	+$350	$300 to $500
Hot-Dry	-$100	$200 to $300
Mixed-Dry	-$200	not yet available
Hot-Humid	+$300	not yet available

Table 2. Typical Cold Climate Design and Cost Trade-offs

Advanced framing: 2x6s @ 24"o.c. instead of 2x4s @ 16"o.c.	- $ 250	
Insulating sheathing (R-5) in place of OSB and housewrap		+$ 100
High performance windows[4]		+$ 300
Savings on duct system	- $ 300	
Savings on air conditioning system, 1-ton reduction	- $ 500	
Air flow retarder system		+$ 200
No poly vapor barrier	- $ 100	
Controlled ventilation system		+$ 150
Basement insulation		+$ 600
Direct vent gas water heater		+$ 150
Total Incremental Cost		**+$ 350**

Table 3. Typical Hot-Dry Climate Design and Cost Trade-offs

Unvented roof, savings on not installing vents	- $ 250	
Unvented roof, increased cost of moving insulation		+$ 700
Advanced framing: 2x6s @ 24"o.c. instead of 2x4s @ 16"o.c.	- $ 250	
High performance windows[4]		+$ 400
Savings on air conditioning system, 2-ton reduction	- $ 1,000	
Controlled ventilation system		+$ 150
Higher capacity hot water heater		+$ 150
Total Incremental Cost	**-$ 100**	

Table 4. Typical Mixed-Dry Climate Design and Cost Trade-offs

Advanced framing: 2x6s @ 24"o.c. instead of 2x4s @ 16"o.c.	- $ 250	
High performance windows[4]		+$ 300
Savings on air conditioning system, 1 ½-ton reduction	- $ 750	
Air flow retarder system		+$ 200
Controlled ventilation system		+$ 150
Larger gas water heater located in garage		+$ 150
Fan-coil in place of furnace		+$ 0
Total Incremental Cost	**-$ 200**	

[4] Energy Star-rated windows or equivalent (Energy Star-rated windows are not yet available everywhere).

Table 5. Typical Hot-Humid Climate Design and Cost Trade-offs

Unvented roof, savings on not installing vents	- $100	
Unvented roof, increased cost of moving insulation		+$700
Advanced framing: 2x6s @ 24"o.c. instead of 2x4s @ 16"o.c.	- $ 250	
High performance windows[5]		+$ 300
Savings on air conditioning system, 2-ton reduction	- $ 750	
Controlled ventilation system		+$ 150
Dehumidifier		+$ 250
Total Incremental Cost		**+$ 300**

Performance Results

BSC's completed Building America homes demonstrate typical energy savings of approximately 50 percent for heating and 30 percent for cooling compared with standard code construction. (These homes consume cooling energy at approximately 65 percent of ACCA Manual J.) At the same time, the homes are built to be more comfortable and durable.

The projected energy savings have been substantiated by electronic monitoring of 30 representative homes in various climate zones for a full year. In 2000, BSC plans to obtain utility records for a year for 1,000 homes built to date and compare them to records for 1,000 similar (non-BA) homes in the same areas.

BSC's Building America homes have significantly reduced warranty costs and callbacks. Town & Country Homes reports that warranty claims and callbacks have fallen by more than 70 percent, saving $400,000 per year since starting the program in 1995.

Environmental Gains

BSC's Building America homes also achieve measurable environmental gains. Carbon, sulfur dioxide, and nitrogen dioxide emissions are reduced, as is wood use—and with it, forest degradation. Forest protection represents preservation of biodiversity, slowed rate of global warming, and retained capacity for carbon sequestration.

Environmental outcomes to date from BSC projects (shown in Table 6) include:

- 36,568 Mbtu saved;
- Nearly 1.7 million pounds of carbon emissions avoided;
- 8,288 pounds of sulfur dioxide emissions avoided;
- 9,189 pounds of nitrogen dioxide avoided;[6]
- More than one-quarter million cubic feet of wood saved;[7]
- Nearly 177 acres of forest saved.[8]

---

[5] Energy Star-rated windows or equivalent (Energy Star-rated windows are not yet available everywhere).

[6] Energy and emissions outcomes were calculated using REM/Design (Architectural Energy Corporation) software.

[7] Wood savings were estimated based on "before-and-after" takeoffs for two typical houses.

[8] Forest savings were calculated assuming 1,470 cubic feet of wood per acre of forest (based on the generic conversion, 680 acres per million cubic feet, proposed by Richard Haynes, Chief Economist, Pacific Northwest Forest and Range Experiment Station).

Table 6. Environmental Gains To March 2000 From BSC Homes

Builder	State	Climate Type	Number of Homes		Energy	Emissions Avoided (lbs)			Wood & Forest Cover Saved	
			Started or Completed	Total Planned	Mbtu Saved	C	SO2	NOX	Cubic Feet	Acres
Town & Country	MN	severe cold	29	301	1,719	60,021	68	242	8555	5.8
Pulte	MN	severe cold	6	22	260	8,034	2	26	1770	1.2
Hans Hagen	MN	severe cold	10	125	70	2,450	3	10	2950	2.0
Centex	MN	severe cold	2	2	104	3,358	1	10	590	0.4
Sturbridge	IL	cold	153	350	14,703	485,010	1,320	1,763	45135	30.7
Town & Country	IL	cold	99	216	10,286	338,382	854	1,211	29205	19.9
Grossman	ID	cold	17	900	422	13,194	20	46	5015	3.4
RPM	NJ	cold	2	54	37	1,208	3	5	590	0.4
GreenBuilt	OH	cold	1	1	64	2,097	5	7	295	0.2
Randal	OH	cold	1	1	21	1,989	16	16	295	0.2
Pulte	NV	hot-dry	265	1128	5,854	532,084	4,074	4,087	78175	53.2
Watt	NV	hot-dry	58	106	1,833	161,008	1,210	1,222	17110	11.6
VIP	AZ	hot-dry	13	13	0	0	0	0	3835	2.6
Pulte	AZ	hot-dry	184	421	666	37,362	392	345	54280	36.9
Braemar	CA	mixed-dry	21	186	19	1,730	3	37	6195	4.2
Investec	CA	mixed-dry	2	269	97	3,076	0	9	590	0.4
Pulte	CA	mixed-dry	2	2	102	3,416	1	15	590	0.4
The Lee Group	CA	mixed-dry	2	2	83	2,772	0	12	590	0.4
Ashland	GA	mixed-humid	2	10	28	2,976	126	27	590	0.4
Ideal Homes	OK	mixed-humid	2	2	87	3,580	10	19	590	0.4
Pulte	VA	mixed-humid	1	1	47	1,746	10	7	295	0.2
Del Webb	TX	hot-humid	1	1	27	1,896	120	15	295	0.2
Ayden	NC	hot-humid	6	6	0	0	0	0	1770	1.2
Pulte	FL	hot-humid	2	2	39	5,511	50	58	590	0.4
TOTAL			881	4,121	36,568	1,672,900	8,288	9,189	259,895	176.7

Conclusion

The iterative process of redesigning, testing, evaluating results, and refining earlier approaches has yielded excellent outcomes. BSC's Building America homes in all climates have incorporated numerous improvements to energy and resource efficiency, durability, and environmental performance, at per-house costs ranging from $200 less to $350 more than conventional homes. With each new project, the team develops further refinements to resolve past problems, address new concerns, and improve the bottom line. These results hold the promise to measurably advance the state-of-the-art for housing within a few short years.

IV. References

Building America website: www.eren.doe.gov/buildings/building_america/

Building Science Corporation website: www.buildingscience.com

Energy Star Homes web site: http://yosemite.epa.gov/appd/eshomes/eshaware.nsf

Lstiburek, Joseph. *Builder's Guide* (various climates). Building Science Corporation and the Energy Efficient Building Association.

National Association of Home Builders Research Center. 1994. *Cost-Effective Home Building.*