What Will It Take to Reduce Total Residential Source Energy Use By Up to 60%?

Armin Rudd, Philip Kerrigan, Jr., and Kohta Ueno, Building Science Corporation

ABSTRACT

Initially, the Building America program set out to reduce mainstream residential heating, cooling, and hot water use by 50% over MEC 93. On a large scale, we were able to accomplish more than 30% site energy reduction with production homebuilders through a systems engineering process that also included durability and indoor air quality factors. Cost tradeoffs to permanently improve the building envelope were found by producing a test-verified quality product that allowed smaller capacity space conditioning equipment. As these products began to distinguish themselves in the marketplace, some builders sought higher levels of efficiency to outpace competition. HERS scores above 86 became normal, and 89+ became the bragging right. In the latest year of the Building America program, a multi-year target has been established to boost energy use savings up to 60% of total source energy use, including lighting, appliances, and plug loads in addition to the original heating, cooling, and domestic hot water. Another reference point, the BA Benchmark, was created to allow evaluation of uses that the MEC 93 did not address. Our simulations for five climate zones have shown that costly measures will be required to meet the new goals–measures that will likely not be adopted for a large number of houses in the near-term. One completed project yielded 37% total source energy savings. Two ongoing projects will approach 43% and 26% savings not including the photovoltaic site generation.

Background

Integration of our private consultations to national home builders with research conducted through the federally sponsored Building America (BA) Program has produced dividends for business and government. Business seeks to increase profit by offering more competitive products with value added features, while government seeks to improve standards and security for the common good. In the past decade, we have seen both of these goals being met. Home builders constructing homes to a high level of durability, comfort, and energy efficiency are edging out their competition, while codes and standards development has significantly raised the minimum compliance bar, reducing energy consumption, pollution, and dependence on foreign oil.

Initially, the Building America program set out to reduce mainstream residential heating, cooling, and hot water use by 50% over the CABO Model Energy Code (MEC) 1993. On a large scale, we were able to accomplish more than 30% site energy reduction with production homebuilders through a systems engineering process that also included durability and indoor air quality factors. Cost tradeoffs to permanently improve the building envelope were found by producing a test-verified quality product that allowed smaller capacity space conditioning equipment. As these products began to distinguish themselves in the marketplace, some builders sought higher levels of efficiency to outpace competition. HERS scores above 86 became normal, and 89+ became the bragging right. In the latest year of the Building America program, a multi-year target has been established to boost energy use savings up to 60% of total source energy use, including lighting, appliances, and plug loads in addition to the original heating, cooling, and domestic hot water. Another reference point, the BA Research Benchmark Definition (National Renewable Energy Laboratory 2003), was created to allow evaluation of uses that the MEC 93 did not address.

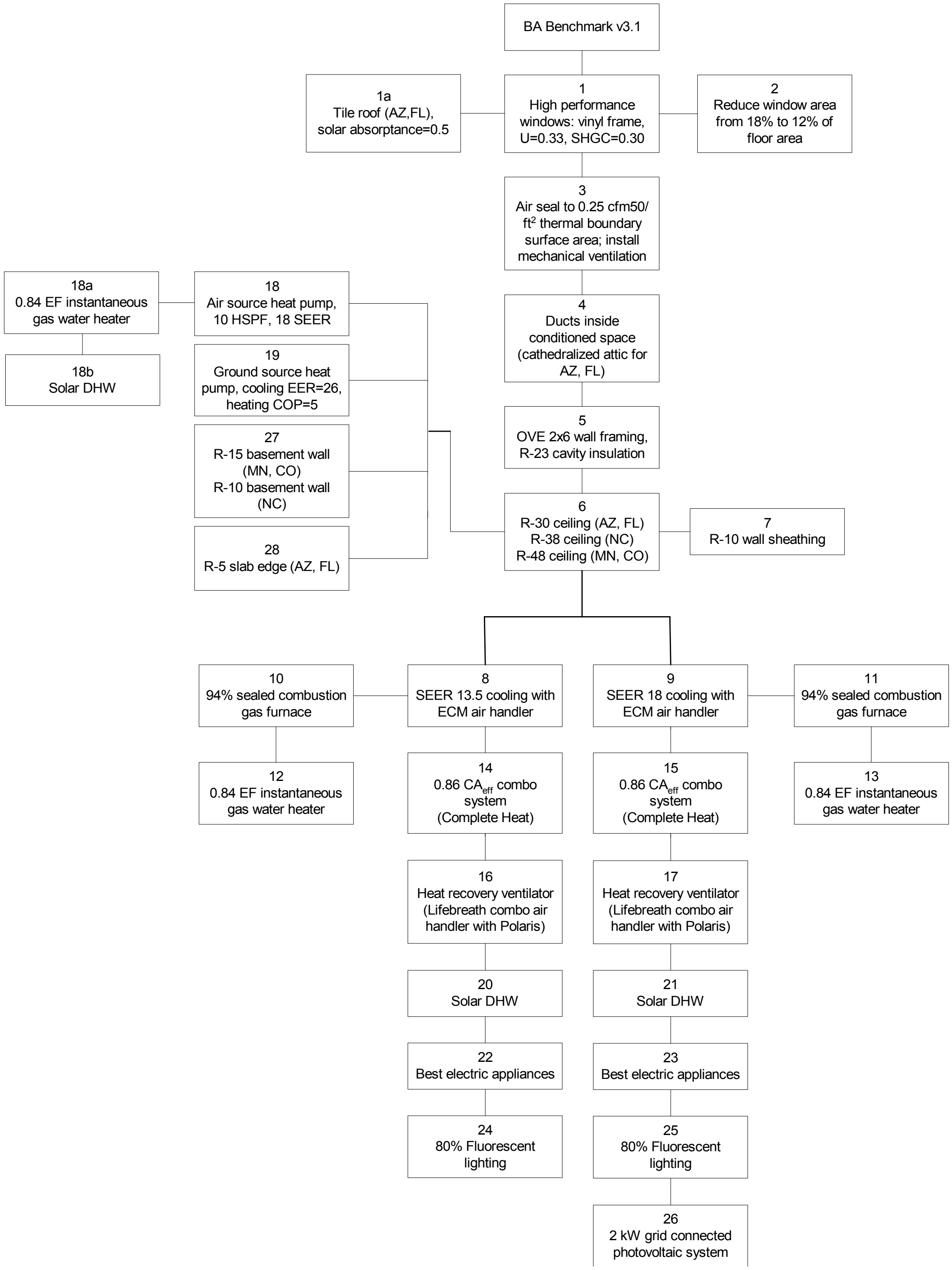
The USDOE Building America program and the USEPA Energy Star® programs have worked closely together over the years. Every house produced by our BA consortium is certified as an Energy Star® home, having at least a HERS rating of 86.

Approach

To determine a logical path to accomplish the goal of reducing total source energy by up to 60% over the BA Benchmark, we sequentially simulated various energy efficiency improvements using the DOE2.1E-based EnergyGaugeUSA™ software (Florida Solar Energy Center 2003). The house modeled was a current production builder plan that was modeled as slab-on-grade for Phoenix and Orlando, unvented crawlspace for Raleigh, and unconditioned basement for Denver and Minneapolis. It was a single-family, detached, single-story house, with 2,214 ft^2 conditioned floor area, 4 bedrooms, and an attached 2 car garage.

Five climates were chosen as follows: Phoenix, AZ (hot-dry), Orlando, FL (hot-humid); Raleigh, NC (mixed-humid), Denver, CO (cold), Minneapolis, MN (severe cold). Figure 1 is a block flow chart showing the sequence of improvements that were simulated for each climate. In general, improvements were first made to the more permanent building envelope and air distribution systems, followed by mechanical system improvements. In some cases (boxes 1a, 2, 7, 27, and 28), the improvements stand out on their own as dead ends rather than being inserted in the sequential flow. This was done to allow observation of their relative merit without effecting the cumulative savings of following improvements. The farthest sequence of improvements was purposely made dependent on the combination space and domestic hot water heating system which conveniently attacks energy consumption of both end uses with a single gas heat source. Since the site to source conversion factor given in the prescribed BA Benchmark reporting format is 3.16 for electricity and 1.02 for natural gas, natural gas is the best choice for a heat source to achieve the greatest source energy savings. Passive solar techniques were not included here since our focus was on production-built homes where proper site orientation, occupant interaction, and tolerance to temperature swing is difficult to assure.

Figure 1. Flow Chart for Parametric Simulations to Achieve up to 60% Source Energy Savings over the BA Benchmark



Results

Results from the simulations for each climate are shown in Figures 2 through 6. Table 1 gives a detailed description of the contents of each column in those Figures.

Table 1. Description of the Contents of Each Column in Figures 2 - 6

Col.	Contents
1	Parametric Run ID, giving a numeric descriptor
2	A word description of the parametric change(s) and the Run ID upon which it builds if applicable.
3	Cost of the specific parametric change(s) pertaining to that run only, not including changes from previous runs. These costs were estimated based on experience from previous projects and from cost information provided by builders, subcontractors, and suppliers.
4	Cumulative cost of the specific parametric change(s) and all dependent changes embodied in the Run ID upon which it builds
5	Cumulative percent total source energy savings over the BA Benchmark, including source energy for heating, cooling, domestic hot water, lighting (interior and exterior), appliances, and plug loads.
6	Percent savings of the current Run ID over the specified Run ID upon which it builds
7	Predicted annual energy cost for heating, cooling, domestic hot water, appliances, and plug loads, based on the electricity and gas rates of $0.10/kW-h and $0.50/therm prescribed in the BA Benchmark
8	Simple payback in years, calculated as the Cumulative Cost of Change (4^{th} column) divided by the difference in annual energy cost between the current run and the Benchmark run
9	Energy performance rating as defined by the Home Energy Rating System (Residential Energy Services Network 1999)

Figure 2. Simulation Results for Phoenix, AZ

				Phoenix, AZ (slab) **Total Source Energy Savings (heating, cooling, dhw, lighting, appliances, plug loads)**				
Parametric Run ID	**Description of change**	**Individual Cost of change**	**Cumulative Cost of change**	**over BA** Benchmark[1]	Incremental	**Annual** energy cost	**Simple** payback (yr)	**HERS** rating
Benchmark		--	--	--	--	$ 2,213	--	81.1
1	Vinyl windows U=.33, SHGC=.30	$ 700	$ 700	10%	10%	$ 1,981	3.0	84.3
1a	1 + Tile roof, solar abs=0.5	$ 1,100	$ 1,800	12%	2%	$ 1,912	6.0	85.2
2	1 + Reduce window area from 18% to 12% CFA	$ (650)	$ 50	13%	3%	$ 1,900	0.2	85.4
3	1 + Air seal, mechanical ventilation	$ 350	$ 1,050	9%	-1%	$ 1,993	4.8	83.8
4	3 + ducts inside, cathedralized attic	$ 700	$ 1,750	16%	7%	$ 1,822	4.5	86.1
5	4 + OVE 2x6, R-23 cavity	$ 250	$ 2,000	18%	2%	$ 1,778	4.6	86.8
6	5 + R-30 ceiling	$ 498	$ 2,498	20%	2%	$ 1,741	5.3	87.3
7	6 + R-10 sheathing	$ 1,200	$ 3,200	21%	1%	$ 1,716	6.4	87.6
8	6 + SEER 13.5 with ECM fan	$ 600	$ 3,098	28%	8%	$ 1,534	4.6	90.0
9	6 + SEER 18 with ECM fan	$ 1,200	$ 3,698	33%	13%	$ 1,423	4.7	91.5
10	8 + 94% furnace	$ 500	$ 3,598	29%	1%	$ 1,528	5.3	90.2
11	9 + 94% furnace	$ 500	$ 4,198	34%	1%	$ 1,417	5.3	91.7
12	10 + .84 EF instantaneous gas DHW	$ 1,000	$ 4,598	32%	3%	$ 1,494	6.4	91.3
13	11 + .84 EF instantaneous gas DHW	$ 1,000	$ 5,198	37%	3%	$ 1,383	6.3	92.8
14	8 + 86% CA combo system (Complete Heat)	$ 1,000	$ 4,098	32%	4%	$ 1,494	5.7	91.3
15	9 + 86% CA combo system (Complete Heat)	$ 1,000	$ 4,698	37%	4%	$ 1,383	5.7	92.8
16	14 + HRV (Lifebreath combo w/Polaris)	$ 500	$ 4,598	34%	2%	$ 1,457	6.1	91.8
17	15 + HRV (Lifebreath combo w/Polaris)	$ 500	$ 5,198	39%	2%	$ 1,350	6.0	93.2
18	6 + Air source heat pump, 10 HSPF 18 SEER	$ 900	$ 3,398	33%	13%	$ 1,464	4.5	91.4
18a	18 + .84 EF instantaneous gas DHW	$ 1,000	$ 4,398	37%	4%	$ 1,430	5.6	92.4
18b	18a + solar DHW	$ 2,000	$ 6,398	40%	3%	$ 1,396	7.8	92.8
19	6 + Ground source heat pump (best available)	$ 5,000	$ 7,498	39%	19%	$ 1,335	8.5	93.0
20	16 + solar DHW	$ 2,000	$ 6,598	37%	3%	$ 1,423	8.4	92.1
21	17 + solar DHW	$ 2,000	$ 7,198	42%	3%	$ 1,316	8.0	93.5
22	20 + best electric appliances	$ 2,100	$ 8,698	43%	6%	$ 1,275	9.3	92.1 *
23	21 + best electric appliances	$ 2,100	$ 9,298	47%	5%	$ 1,173	8.9	93.5 *
24	22 + 80% fluorescent lighting	$ 750	$ 9,448	50%	7%	$ 1,131	8.7	92.1 *
25	23 + 80% fluorescent lighting	$ 750	$ 10,048	54%	7%	$ 1,032	8.5	93.5 *
26	25 + 2 kW grid connect photovoltaic	$ 16,000	$ 26,048	67%	13%	$ 705	17.3	93.5 *
27	n/a							
28	6 + R-5 slab edge insulation	$ 500	$ 2,998	23%	3%	$ 1,717	6.0	87.6

* HERS rating does not currently account for this improvement

Figure 3 Simulation Results for Orlando, FL

				Orlando, FL (slab) Total Source Energy Savings (heating, cooling, dhw, lighting, appliances, plug loads)				
Parametric Run ID	Description of change	Individual Cost of change	Cumulative Cost of change	over BA Benchmark[1]	Incremental	Annual energy cost	Simple payback (yr)	HERS rating
Benchmark		--	--	--	--	$ 1,704	--	82.1
1	Vinyl windows U=.33, SHGC=.30	$ 700	$ 700	8%	8%	$ 1,555	4.7	85.3
1a	1 + Tile roof, solar abs=0.5	$ 1,100	$ 1,800	11%	3%	$ 1,508	9.2	86.2
2	1 + Reduce window area from 18% to 12% CFA	$ (650)	$ 50	11%	3%	$ 1,511	0.3	86.2
3	1 + Air seal, mechanical ventilation	$ 350	$ 1,050	5%	-3%	$ 1,612	11.4	83.8
4	3 + ducts inside, cathedralized attic	$ 700	$ 1,750	9%	4%	$ 1,542	10.8	85.2
5	4 + OVE 2x6, R-23 cavity	$ 250	$ 2,000	10%	1%	$ 1,525	11.2	85.6
6	5 + R-30 ceiling	$ 498	$ 2,498	12%	2%	$ 1,503	12.4	86.0
7	6 + R-10 sheathing	$ 1,200	$ 3,200	12%	0%	$ 1,492	15.1	86.3
8	6 + SEER 13.5 with ECM fan	$ 600	$ 3,098	19%	7%	$ 1,356	8.9	89.0
9	6 + SEER 18 with ECM fan	$ 1,200	$ 3,698	23%	11%	$ 1,279	8.7	90.5
10	8 + 94% furnace	$ 500	$ 3,598	19%	0%	$ 1,353	10.3	90.2
11	9 + 94% furnace	$ 500	$ 4,198	23%	0%	$ 1,276	9.8	91.7
12	10 + .84 EF instantaneous gas DHW	$ 1,000	$ 4,598	24%	5%	$ 1,316	11.9	91.3
13	11 + .84 EF instantaneous gas DHW	$ 1,000	$ 5,198	28%	5%	$ 1,239	11.2	92.8
14	8 + 86% CA combo system (Complete Heat)	$ 1,000	$ 4,098	24%	5%	$ 1,315	10.5	90.7
15	9 + 86% CA combo system (Complete Heat)	$ 1,000	$ 4,698	28%	5%	$ 1,238	10.1	92.3
16	14 + HRV (Lifebreath combo w/Polaris)	$ 500	$ 4,598	27%	3%	$ 1,273	10.7	91.6
17	15 + HRV (Lifebreath combo w/Polaris)	$ 500	$ 5,198	30%	2%	$ 1,204	10.4	93.0
18	6 + Air source heat pump, 10 HSPF 18 SEER	$ 900	$ 3,398	24%	12%	$ 1,287	8.1	90.6
18a	18 + .84 EF instantaneous gas DHW	$ 1,000	$ 4,398	29%	5%	$ 1,250	9.7	92.1
18b	18a + solar DHW	$ 2,000	$ 6,398	32%	3%	$ 1,206	12.8	92.6
19	6 + Ground source heat pump (best available)	$ 5,000	$ 7,498	28%	16%	$ 1,118	12.8	92.2
20	16 + solar DHW	$ 2,000	$ 6,598	30%	3%	$ 1,227	13.8	92.0
21	17 + solar DHW	$ 2,000	$ 7,198	34%	4%	$ 1,158	13.2	93.4
22	20 + best electric appliances	$ 2,100	$ 8,698	38%	8%	$ 1,118	14.8	92.0 *
23	21 + best electric appliances	$ 2,100	$ 9,298	41%	7%	$ 1,053	14.3	93.4 *
24	22 + 80% fluorescent lighting	$ 750	$ 9,448	47%	9%	$ 969	12.9	92.0 *
25	23 + 80% fluorescent lighting	$ 750	$ 10,048	50%	9%	$ 908	12.6	93.4 *
26	25 + 2 kW grid connect photovoltaic	$ 16,000	$ 26,048	64%	14%	$ 637	24.4	93.4 *
27	n/a	$ 750	$ 3,248					
28	6 + R-5 slab edge insulation	$ 500	$ 2,998	13%	1%	$ 1,509	15.4	85.9

* HERS rating does not currently account for this improvement

Figure 4. Simulation Results for Raleigh, NC

Parametric Run ID	Description of change	Individual Cost of change	Cumulative Cost of change	Raleigh, NC (crawlspace) Total Source Energy Savings (heating, cooling, dhw, lighting, appliances, plug loads) over BA Benchmark[1]	Incremental	Annual energy cost	Simple payback (yr)	HERS rating
Benchmark		--	--	--	--	$ 1,627	--	81.9
1	Vinyl windows U=.33, SHGC=.30	$ 700	$ 700	3%	3%	$ 1,549	9.0	83.6
1a	1 + Tile roof, solar abs=0.5	$ 1,100	$ 1,800	4%	1%	$ 1,525	17.6	84.1
2	1 + Reduce window area from 18% to 12% CFA	$ (650)	$ 50	5%	2%	$ 1,520	0.5	84.2
3	1 + Air seal, mechanical ventilation	$ 350	$ 1,050	2%	-1%	$ 1,591	29.2	82.3
4	3 + ducts inside conditioned space	$ 700	$ 1,750	10%	8%	$ 1,486	12.4	84.8
5	4 + OVE 2x6, R-23 cavity	$ 250	$ 2,000	11%	1%	$ 1,473	13.0	85.1
6	5 + R-38 ceiling	$ 498	$ 2,498	12%	1%	$ 1,452	14.3	85.6
7	6 + R-10 sheathing	$ 1,200	$ 3,200	15%	3%	$ 1,427	16.0	86.2
8	6 + SEER 13.5 with ECM fan	$ 600	$ 3,098	16%	4%	$ 1,375	12.3	86.8
9	6 + SEER 18 with ECM fan	$ 1,200	$ 3,698	17%	5%	$ 1,344	13.1	87.5
10	8 + 94% furnace	$ 500	$ 3,598	20%	4%	$ 1,339	12.5	88.7
11	9 + 94% furnace	$ 500	$ 4,198	21%	4%	$ 1,308	13.2	89.3
12	10 + .84 EF instantaneous gas DHW	$ 1,000	$ 4,598	24%	4%	$ 1,293	13.8	90.5
13	11 + .84 EF instantaneous gas DHW	$ 1,000	$ 5,198	26%	5%	$ 1,262	14.2	91.1
14	8 + 86% CA combo system (Complete Heat)	$ 1,000	$ 4,098	23%	7%	$ 1,308	12.8	89.9
15	9 + 86% CA combo system (Complete Heat)	$ 1,000	$ 4,698	24%	7%	$ 1,277	13.4	90.5
16	14 + HRV (Lifebreath combo w/Polaris)	$ 500	$ 4,598	27%	4%	$ 1,253	12.3	91.0
17	15 + HRV (Lifebreath combo w/Polaris)	$ 500	$ 5,198	29%	5%	$ 1,225	12.9	91.6
18	6 + Air source heat pump, 10 HSPF 18 SEER	$ 900	$ 3,398	25%	13%	$ 1,451	19.3	89.6
18a	18 + .84 EF instantaneous gas DHW	$ 1,000	$ 4,398	30%	5%	$ 1,405	19.8	91.4
18b	18a + solar DHW	$ 2,000	$ 6,398	34%	4%	$ 1,359	23.9	92.1
19	6 + Ground source heat pump (best available)	$ 5,000	$ 7,498	30%	18%	$ 1,339	26.0	91.2
20	16 + solar DHW	$ 2,000	$ 6,598	32%	5%	$ 1,207	15.7	91.7
21	17 + solar DHW	$ 2,000	$ 7,198	33%	4%	$ 1,179	16.1	92.2
22	20 + best electric appliances	$ 2,100	$ 8,698	38%	6%	$ 1,071	15.6	91.7 *
23	21 + best electric appliances	$ 2,100	$ 9,298	39%	6%	$ 1,032	15.6	92.2 *
24	22 + 80% fluorescent lighting	$ 750	$ 9,448	44%	6%	$ 940	13.8	91.7 *
25	23 + 80% fluorescent lighting	$ 750	$ 10,048	45%	6%	$ 917	14.2	92.2 *
26	25 + 2 kW grid connect photovoltaic	$ 16,000	$ 26,048	57%	12%	$ 655	26.8	92.2 *
27	6 + R-10 crawlspace wall	$ 750	$ 3,248	14%	2%	$ 1,448	18	87.5
28	n/a							

* HERS rating does not currently account for this improvement

Figure 5. Simulation Results for Denver, CO

Parametric Run ID	Description of change	Individual Cost of change	Cumulative Cost of change	Denver, CO (basement) Total Source Energy Savings (heating, cooling, dhw, lighting, appliances, plug loads) over BA Benchmark[1]	Incremental	Annual energy cost	Simple payback (yr)	HERS rating
Benchmark		--	--	--	--	$ 1,547	--	82.1
1	Vinyl windows U=.33, SHGC=.30	$ 700	$ 700	-5%	-5%	$ 1,575	n/a	81.3
1a	1 + Tile roof, solar abs=0.5	$ 1,100	$ 1,800	-5%	0%	$ 1,574	n/a	81.4
2	1 + Reduce window area from 18% to 12% CFA	$ (650)	$ 50	-4%	1%	$ 1,554	n/a	81.8
3	1 + Air seal, mechanical ventilation	$ 350	$ 1,050	0%	5%	$ 1,539	n/a	82.1
4	3 + ducts inside conditioned space	$ 700	$ 1,750	3%	3%	$ 1,505	42	83.0
5	4 + OVE 2x6, R-23 cavity	$ 250	$ 2,000	4%	1%	$ 1,493	37	83.2
6	5 + R-48 ceiling	$ 498	$ 2,498	5%	1%	$ 1,478	36	86.3
7	6 + R-10 sheathing	$ 1,200	$ 3,200	9%	4%	$ 1,429	27	84.8
8	6 + SEER 13.5 with ECM fan	$ 600	$ 3,098	6%	1%	$ 1,443	30	83.9
9	6 + SEER 18 with ECM fan	$ 1,200	$ 3,698	7%	2%	$ 1,439	34	84.0
10	8 + 94% furnace	$ 500	$ 3,598	13%	7%	$ 1,379	21	87.1
11	9 + 94% furnace	$ 500	$ 4,198	13%	6%	$ 1,375	24	87.2
12	10 + .84 EF instantaneous gas DHW	$ 1,000	$ 4,598	17%	4%	$ 1,336	22	89.0
13	11 + .84 EF instantaneous gas DHW	$ 1,000	$ 5,198	17%	4%	$ 1,332	24	89.1
14	8 + 86% CA combo system (Complete Heat)	$ 1,000	$ 4,098	14%	8%	$ 1,363	22	87.8
15	9 + 86% CA combo system (Complete Heat)	$ 1,000	$ 4,698	15%	8%	$ 1,359	25	87.9
16	14 + HRV (Lifebreath combo w/Polaris)	$ 500	$ 4,598	20%	6%	$ 1,295	18	89.3
17	15 + HRV (Lifebreath combo w/Polaris)	$ 500	$ 5,198	21%	6%	$ 1,292	20	89.4
18	6 + Air source heat pump, 10 HSPF 18 SEER	$ 900	$ 3,398	12%	7%	$ 1,809	n/a	87.1
18a	18 + .84 EF instantaneous gas DHW	$ 1,000	$ 4,398	16%	4%	$ 1,766	n/a	89.0
18b	18a + solar DHW	$ 2,000	$ 6,398	22%	6%	$ 1,712	n/a	89.9
19	6 + Ground source heat pump (best available)	$ 5,000	$ 7,498	22%	17%	$ 1,599	n/a	89.4
20	16 + solar DHW	$ 2,000	$ 6,598	26%	6%	$ 1,241	22	90.1
21	17 + solar DHW	$ 2,000	$ 7,198	26%	5%	$ 1,238	23	90.2
22	20 + best electric appliances	$ 2,100	$ 8,698	30%	4%	$ 1,124	21	90.1 *
23	21 + best electric appliances	$ 2,100	$ 9,298	30%	4%	$ 1,121	22	90.2 *
24	22 + 80% fluorescent lighting	$ 750	$ 9,448	35%	5%	$ 1,008	18	90.1 *
25	23 + 80% fluorescent lighting	$ 750	$ 10,048	36%	6%	$ 1,005	19	90.2 *
26	25 + 2 kW grid connect photovoltaic	$ 16,000	$ 26,048	49%	13%	$ 706	31	90.2 *
27	6 + R-15 basement wall	$ 750	$ 3,248	8%	3%	$ 1,467	41	89.3
28	n/a							

* HERS rating does not currently account for this improvement

Figure 6. Simulation Results for Minneapolis, MN

Parametric Run ID	Description of change	Individual Cost of change	Cumulative Cost of change	Minneapolis, MN (basement) Total Source Energy Savings (heating, cooling, dhw, lighting, appliances, plug loads)				
				over BA Benchmark[1]	Incremental	Annual energy cost	Simple payback (yr)	HERS rating
Benchmark		--	--	--	--	$ 1,890	--	79.5
1	Vinyl windows U=.33, SHGC=.30	$ 700	$ 700	-4%	-4%	$ 1,918	n/a	78.8
1a	1 + Tile roof, solar abs=0.5	$ 1,100	$ 1,800	-4%	0%	$ 1,915	n/a	78.9
2	1 + Reduce window area from 18% to 12% CFA	$ (650)	$ 50	-2%	2%	$ 1,877	4	79.6
3	1 + Air seal, mechanical ventilation	$ 350	$ 1,050	3%	7%	$ 1,832	18	80.6
4	3 + ducts inside conditioned space	$ 700	$ 1,750	7%	4%	$ 1,777	15	81.7
5	4 + OVE 2x6, R-23 cavity	$ 250	$ 2,000	7%	0%	$ 1,780	18	81.6
6	5 + R-48 ceiling	$ 498	$ 2,498	8%	1%	$ 1,761	19	82.0
7	6 + R-10 sheathing	$ 1,200	$ 3,200	9%	1%	$ 1,747	22	82.2
8	6 + SEER 13.5 with ECM fan	$ 600	$ 3,098	10%	2%	$ 1,711	17	82.3
9	6 + SEER 18 with ECM fan	$ 1,200	$ 3,698	10%	2%	$ 1,702	20	82.4
10	8 + 94% furnace	$ 500	$ 3,598	17%	7%	$ 1,609	13	86.1
11	9 + 94% furnace	$ 500	$ 4,198	18%	8%	$ 1,600	14	86.2
12	10 + .84 EF instantaneous gas DHW	$ 1,000	$ 4,598	21%	4%	$ 1,566	14	87.6
13	11 + .84 EF instantaneous gas DHW	$ 1,000	$ 5,198	21%	3%	$ 1,557	16	87.8
14	8 + 86% CA combo system (Complete Heat)	$ 1,000	$ 4,098	17%	7%	$ 1,610	15	86.1
15	9 + 86% CA combo system (Complete Heat)	$ 1,000	$ 4,698	18%	8%	$ 1,601	16	86.2
16	14 + HRV (Lifebreath combo w/Polaris)	$ 500	$ 4,598	24%	7%	$ 1,518	12	87.8
17	15 + HRV (Lifebreath combo w/Polaris)	$ 500	$ 5,198	24%	6%	$ 1,509	14	87.9
18	6 + Air source heat pump, 10 HSPF 18 SEER	$ 900	$ 3,398	7%	-1%	$ 2,555	n/a	85.5
18a	18 + .84 EF instantaneous gas DHW	$ 1,000	$ 4,398	11%	4%	$ 2,512	n/a	87.1
18b	18a + solar DHW	$ 2,000	$ 6,398	14%	3%	$ 2,463	n/a	87.7
19	6 + Ground source heat pump (best available)	$ 5,000	$ 7,498	18%	10%	$ 2,221	n/a	88.0
20	16 + solar DHW	$ 2,000	$ 6,598	28%	4%	$ 1,470	16	88.3
21	17 + solar DHW	$ 2,000	$ 7,198	28%	4%	$ 1,461	17	88.5
22	20 + best electric appliances	$ 2,100	$ 8,698	31%	3%	$ 1,349	16	88.3 *
23	21 + best electric appliances	$ 2,100	$ 9,298	31%	3%	$ 1,342	17	88.5 *
24	22 + 80% fluorescent lighting	$ 750	$ 9,448	35%	4%	$ 1,231	14	88.3 *
25	23 + 80% fluorescent lighting	$ 750	$ 10,048	35%	4%	$ 1,225	15	88.5 *
26	25 + 2 kW grid connect photovoltaic	$ 16,000	$ 26,048	44%	9%	$ 976	28	88.5 *
27	6 + R-15 basement wall	$ 750	$ 3,248	10%	2%	$ 1,753	24	82.1
28	n/a	$ 500	$ 2,998					

* HERS rating does not currently account for this improvement

Discussion

Of the five climates, Phoenix and Orlando had the greatest potential for source energy savings over the BA Benchmark, up to 54%, and also had the best economic return on investment. This was mostly due to the large benefit of using low SHGC glazing and high SEER cooling in those climates. Phoenix showed higher benefit than Orlando. Raleigh showed potential source energy savings up to 45%.

The least improvement in source energy savings, up to 36%, was found in Denver and Minneapolis due mostly to the dominance of heating energy consumption and the relatively high level of efficiency built into the Benchmark for those climates. Cooling system improvements were nearly insignificant in those climates. These climates also brought to light an inconsistency in the Benchmark specification, whereby, the specified combination of glazing U-value and SHGC give the Benchmark a distinct passive solar heating advantage, but glass with both those characteristics is not commercially available. The Benchmark window U-value (Btu/h-ft^2-F) for Denver and Minneapolis was 0.378 and 0.326, respectively, while the SHGC was 0.581. Our research of windows available from major manufacturers shows that U-value and SHGC generally do not deviate by more than 0.1.

Very low glazing U-value in hot climates can slightly increase annual energy consumption because interior heat is not as easily rejected to outdoors when the outdoor temperature falls below indoor temperature. Likewise, low SHGC in cold climates can increase annual energy consumption because less solar heat is gained to the interior. However, there are comfort benefits to both low U-value and low SHGC that probably outweigh any energy consumption disbenefit.

Figure 7 gives a summary of the best performing improvements for each climate yielding annual source energy savings of 5% or greater.

Figure 7. Summary of Best Performing Parameters for Each Climate

	Annual source energy savings over Benchmark				
Parametric change	**Phoenix**	**Orlando**	**Raleigh**	**Denver**	**Minneapolis**
Vinyl windows U=.33, SHGC=.30	10%	8%			
Air seal, mechanical ventilation				5%	7%
Ducts inside (cathedralized attic for AZ, FL)	7%		8%		
SEER 13.5 with ECM fan	8%	7%			
SEER 18 with ECM fan	13%	11%	5%		
94% AFUE gas furnace				6%	7%
84% EF instantaneous gas DHW		5%			
86% CA combo system (Complete Heat)		5%	7%	8%	7%
HRV (Lifebreath combo w/Polaris)				6%	6%
Air source heat pump, 10 HSPF 18 SEER	13%	12%	13%	7%	
Ground source heat pump (26 EER, 5.0 COP)	19%	16%	18%	17%	10%
Solar domestic hot water				5%	
Best electric appliances (30% reduction)	5%	7%	6%		
80% fluorescent lighting	7%	9%	6%	5%	
2 kW grid connected photovoltaic system	13%	14%	12%	13%	9%

Case Studies

SIPS Cottage by the State of Georgia. The SIPS Cottage was constructed by the State of Georgia, Department of Natural Resources in the Okefenokee Swamp north of Jacksonville, Florida. Energy performance was simulated for this house using the EnergyGaugeUSA software and compared to the BA Benchmark. Figure 9 describes the components changed from the previous Run and gives the final results. The house was constructed as Group #1. Group #2 illustrates the potential energy performance using the best available air source heat pump. Using the best available ground source heat pump, Group #3 illustrates the ultimate performance for an all-electric home in that climate, reaching over 50% total source energy saving compared to the BA Benchmark.

Figure 8. Summary of Parametric Components and Energy Performance for the IPS Cottage

Parametric Run ID	Description	Source Energy Savings over BA Benchmark	Annual energy cost	HERS rating
Benchmark	BA Benchmark criteria for Jacksonville	--	$ 1,402	82.4
Group #1		43%	$ 1,067	91.5
Building enclosure				
Ceiling/Roof	R-38 SIP, white metal (solar abs=0.35)			
Walls	R-23 SIP			
Crawlspace walls	R-10 XPS			
Windows	U=0.35 SHGC=0.33			
Infiltration	0.25 cfm50/ft^2 thermal enclosure			
Mech/Elec/Plum systems (MEP)				
Cooling/Heating	13.5 SEER, 8.5 HSPF heat pump			
Domestic hot water (DHW)	0.94 EF electric with R-8.5 wrap			
Solar DHW	Integral Collector Storage (ICS)			
Duct leakage	5% to outside max			
Ventilation	41 cfm continuous, 15 W			
Lighting	80% fluorescent interior lighting			
Appliances	30% lower consumption			
Site Generation	4 kW grid connected PV	69%	$ 590	
Group #2 (changes)		47%	$ 1,001	92.8
Mechanical systems		(72% w/PV)	($524 w/PV)	
Cooling/Heating	18 SEER, 10 HSPF heat pump			
Group #3 (changes)		51%	$ 910	94.4
Mechanical systems		(77% w/PV)	($433 w/PV)	
Cooling/Heating	Ground source HP, 26 EER, 5 COP			

Low-Energy House by Pulte. The Low-Energy House was constructed by Pulte Homes in Tucson, Arizona. Energy performance was simulated for this house using the EnergyGaugeUSA software and compared to the BA Benchmark. Monitoring of energy use for space conditioning and domestic hot water, and indoor and outdoor temperature and relative humidity has been ongoing for one year. Actual energy use, based on the monitoring and actual utility bills has been generally less than the simulation predictions. Comfort conditions have been maintained throughout, and the homeowner has expressed the highest level of satisfaction.

Figure 9. Summary of Building Simulation Results for Tucson Low-Energy House

Parametric Run ID	Description	Source Energy Savings over BA Benchmark	Annual energy cost	HERS rating
Benchmark	BA Benchmark criteria for Tucson	--	$ 1,525	82.5
Group #1		37%	$ 915	92.0
Building enclosure				
Ceiling/Roof	R-22 catheralized, tile (solar abs=0.5)			
Walls	R-19			
Windows	U=0.33 SHGC=0.33			
Infiltration	tested 1418 cfm50			
Mech/Elec/Plum systems (MEP)				
Heating + DHW	Carrier ECM fan-coil, with Polaris			
combo system	100 kBtu/h, 34 gal, CA_{EF}=0.86			
Cooling	15 SEER			
Duct leakage	3% to outside			
Ventilation	47 cfm supply with fan cycling			
Lighting	80% fluorescent interior lighting			
Appliances	30% lower consumption			

Discovery House by McStain. The Discovery House is being constructed by McStain Enterprises in the Denver, Colorado area. Parametric changes were simulated for this house using the EnergyGaugeUSA software and compared to the BA Benchmark. Figure 8 describes the components changed from the previous Run and gives the final results. The house will probably be constructed as Group #1, although we are encouraging the components in Group #2 which can improve performance at no net increase in cost.

The 19 SEER air conditioner yields a very small benefit in Denver (1% of total source energy over 10 SEER), especially with low SHGC glazing and shading. Reducing the cooling system efficiency to 13.5 SEER saves about $900 in first cost while increasing annual energy use by only 38 kW-h or $4. The money would be better spent on more insulation.

Decreasing the Prototype window area (20% of conditioned floor area) by 33% on all orientations to match the lower Benchmark total area (15% of CFA) yielded only a 1% increase in source energy savings, or only $13 per year. Double-glazed low-e glass doesn't increase annual energy consumption much in Denver if the majority is on the south and the SHGC is relatively high. However, even though it may not be an energy problem, local overheating can cause substantial comfort problems.

Conclusion

Simulations of parametric improvements over the BA Benchmark showed that savings in annual source energy consumption of up to 54% were possible in Phoenix, Arizona with the best available mechanical equipment and a very thermally efficient building envelope, costing about $10,000. The other four cities studied showed lower potential savings, being 50% for Orlando, 45% for Raleigh, 36% for Denver, and 35% for Minneapolis. If the site generation contribution of a 2 kW grid connected photovoltaic system was included, savings could increase further by 9% to 14% depending on the location. Case studies of actual projects in Georgia, Arizona, and Colorado showed savings in annual source energy consumption over the BA Benchmark of 43%, 37%, and 26%, respectively. Costly measures will be required to meet the new BA goals of 60% savings over the Benchmark–measures that will likely not be adopted for a large number of houses in the near-term. However, a number of measures, providing in the range of 30% savings, could have significant near term potential to effect a large number of new homes.

Figure 10. Discovery House Simulation Parameters and Results

Parametric Run ID	Description	Source Energy Savings over BA Benchmark	Annual energy cost	HERS rating
Benchmark	BA Benchmark criteria for Denver	--	$ 1,623	85.8
Group #1		26%	$ 1,174	90.8
Building enclosure				
Ceiling	R-38			
Knee walls	R-19			
Basement and crawlspace walls	R-16			
Garage ceiling	R-19			
Windows	U=0.35 SHGC=0.34			
Basement windows	U=0.46 SHGC=0.57			
Infiltration	0.25 cfm50/ft^2 thermal enclosure			
Mechanical systems				
Heating + DHW	CompleteHeat in basement			
combo system	100 kBtu/h, 34 gal, CA_{EF}=0.86			
Cooling	19 SEER spilt system			
Duct leakage	5% to outside max			
Ventilation	60% eff ERV, 55 cfm continuous,			
Solar DHW	flat plate, closed loop drainback			
Lighting	80% fluorescent interior lighting			
Appliances	30% lower consumption			
Group #2 (changes)		32%	$ 1,104	91.9
Building enclosure				
Ceiling	R-48			
Knee walls	R-38			
Basement and crawlspace walls	R-21			
Garage ceiling	R-30			
South Windows	U=0.46 SHGC=0.57			
Mechanical systems				
Cooling	13.5 SEER spilt system			

Acknowledgement

This work was supported by the United States Department of Energy, Building Technologies Program. We especially appreciate the leadership of George James, Ed Pollock, and the National Renewable Energy Laboratory.

References

National Renewable Energy Laboratory. 2003. *Building America Research Benchmark Definition Version 3.1*. Golden, Colorado.: National Renewable Energy Laboratory.

Florida Solar Energy Center. 2003. *EnergyGaugeUSA™ software, Resrate Pro version 2.2*. Cocoa, Florida: Florida Solar Energy Center.

Residential Energy Services Network. 1999. *National Home Energy Rating Technical Guidelines as published 9 June 2000*, Oceanside, California: Residential Energy Services Network.