Field Investigation of Energy-Efficient Homes in a Hot, Dry Climate

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ABSTRACT

The purpose of this field investigation was to verify the space conditioning energy performance of nine occupied homes in the community of Civano in Tucson, Arizona. Each home was evaluated against Tucson's Sustainable Energy Standard (SES), representing a 50% energy savings for space conditioning energy relative to the CABO 1995 Model Energy Code. The homes represent a variety of low-mass construction methods including straw-bale, structural insulated panels, light-steel frame with rigid foam insulation, and wood frame with fiberglass insulation. Low emissivity windows and external shading were used extensively to minimize solar gains. Cooling system efficiencies range from 12 to 13 SEER and heating systems include heat pumps and mid-efficiency gas furnaces.

Analysis results determined that the SES annual source heating and cooling energy target was met in six of the nine test homes based on measurement (and measurement-based simulation) information. Predictions made using EnergyGauge® USA simulation software), which uses U.S. Department of Energy (DOE) 2.1-E hourly simulation software and is the main energy analysis tool of the Building America Program, concurred with the monitoring assessment in all nine test house cases. The total energy use measured at each house, included energy generated (if applicable), is noted.

Introduction

Civano: A Sustainable Community

The Community of Civano in Tucson, Arizona is a mixed-use 371 acre neighborhood (the first of three phases) that has promoted resource conservation in new home construction since its inception in 1998. Each home was designed to achieve a 50% reduction in heating, cooling and domestic hot water heating energy consumption compared to the 1995 CABO Model Energy Code (MEC95), the benchmark adopted by the city of Tucson. From this requirement and based on baseline energy consumption studies, a Sustainable Energy Standard (SES) (Tucson/Prima County 1999) for Tucson emerged and would be used to evaluate Civano homes for heating and cooling system performance (Al Nichols Engineering 2003). In addition, the SES continued the promotion of reducing water heating energy usage resulting in the use of solar hot water systems in all most every home and the use of water conservation systems. As one of the first communities in the U.S. to have an energy efficiency design target established for its homes it presents one of the first cases for the validation of energy efficiency goals using measurement information.

Sustainable Energy Standard Conformance

Homes built at Civano would be considered as achieving 50% reduction in heating and cooling energy consumption compared to MEC95 if the annual total source energy targets from the SES, shown in Table 1, are satisfied. Source energy consumption is determined by multiplying annual site energy usage by a factor of 3.10 for electric energy and 1.11 for natural gas energy. The square foot size of each home is based on the gross floor area of the house.

Table 1. Requirements for Heating and Cooling Energy Consumption Conformance

Building	kBtu/Sq. Ft./year (Source Energy Consumption)		
Square Foot Range	Heating	Cooling	Total
<1000	5	22	27
1000 -1399	4	18	22
1400 - 1799	4	16	20
1800 - 2199	4	15	19
>2200	4	14	18

Source: Tucson/Prima County Metropolitan Energy Commission, 1999

Field Investigation Objectives

The objective of the field investigation was to verify that the homes studied were meeting the heating and cooling compliance requirements of the SES. Questions to be answered for all homes in the study include:

1. Did all the test houses meet the Civano goal of 50% reduction in heating and cooling energy relative to typical local construction? If not, provide possible explanations why they didn't?
2. What are the estimated energy savings of each test house?
3. How closely does calibrated hourly energy use simulations match measured heating and cooling energy consumption on a monthly and yearly basis?
4. Should hourly energy use simulations be used for the purpose of verifying larger scale energy performance with minimal monitoring of actual homes?

Nine test homes were used to address all field investigation objectives. Monitoring information exists on six additional homes but hourly energy use simulations could not be completed on them because construction drawings could not be obtained and as a result these homes are not included in the study.

Data Collection

Long-Term Monitoring

A community energy survey was initiated at Civano in August 2000. Each home in the survey was equipped with miniature data loggers to record the energy consumption of the space heating and cooling system, the domestic hot water system, and total electric power on an hourly interval. The indoor temperature was recorded beside the thermostat and can be considered similar to the thermostat set point temperature. Electric current was measured using 100 Amp CT (current transducers) with a 0-5VDC output. Natural gas fuel consumption by furnaces was calculated by multiplying the nameplate hourly input rating by the runtime in hours to produce the number of Btus used by the unit since gas flow measurements was not conducted. This calculation assumes that one cubic foot of gas contains 1,000 Btus, a value that was not measured nor confirmed by gas utilities. Outdoor temperatures were also recorded. Gas fireplace operation was not monitored.

Test Houses

Test house selection was based on homeowners volunteering and agreeing to participate in the survey for up to 24 months (IBACOS 2000). The houses have common construction characteristics including:

- An uninsulated slab-on-grade foundation except for one house that had an unvented crawlspace foundation (test house 4).
- Building enclosure with better than average airtightness (0.132 ACHnat to 0.307 ACHnat).
- A mechanical ventilation system integrated with the air distribution system.
- Low emissivity, spectrally selective windows (U=0.32, SHGC=0.37).
- External shading via roof overhangs and/or porch/courtyard roofs.
- Ductwork that is predominately insulated flex duct, sealed for airtightness and is located entirely within conditioned space.
- Solar thermal water heating system consisting of 40-gallon integrated collection storage unit at 35° tilt with gas or electric backup tank. One solar thermal water heating system is integrated with the coil of the space heating system.

Additional characteristics of the test houses are shown in Table 2. Test houses 2 and 5, and houses 7 and 9 have identical floor plans.

Table 2. Test House Characteristics

House Number	Front Orientation, Construction, Building Airtightness	Square Footage	Space Heating System	Space Cooling System	DHW Backup System
1	North facing; Single story, 4"steel-framed walls with 2" EPS sheathing (R-21.2 nominal), full attic (R-42); 0.240 ACHnat	1577 ft²	Gas Furnace, 80% AFUE	Condensing Unit, 12 SEER	Gas, 40 gallon, EF=0.57
2	South facing; Single story, 2"x6"wood-framed walls with 1" EPS sheathing (R-24.9 nominal), full attic (R-42); 0.235 ACHnat	2080 ft²	Electric Heat Pump, 8.0 HSPF	Condensing Unit, 12.1 SEER	Electric, 40 gallon, EF=0.91
3	North facing; Two story, 2"x6"wood-framed walls with 1" EPS sheathing (R-22.9 nominal), full attic (R-38); 0.217 ACHnat	1568 ft²	Electric Heat Pump, 7.6 HSPF	Condensing Unit, 12.1 SEER	Electric, 50 gallon, EF=0.87
4	West facing; Single story, structural insulated panel walls & roof, R-27 (nominal) walls, R-42 (nominal) attic; 0.132 ACHnat	1280 ft²	Gas Hydronic, EF=0.58, indirect coil from Solar DHW	Condensing Unit, 12 SEER	Gas, 50 gallon, EF=0.58
5	South facing; Single story, 2"x6"wood-framed walls with 1" EPS sheathing (R-24.9 nominal), full attic (R-42); 0.224 ACHnat	2080 ft²	Gas Furnace, 80% AFUE	Condensing Unit, 12 SEER	Gas, 40 gallon, EF=0.57
6	Northeast facing; Single story, 4"steel-framed walls with 2" EPS sheathing (R-21.2 nominal), full attic (R-42); 0.234 ACHnat	1859 ft²	Electric Heat Pump, 8.0 HSPF	Condensing Unit, 12.5 SEER	Electric, 40 gallon, EF=0.91
7	South facing; Single story, 2"x6"wood-framed walls with 1" EPS sheathing (R-22.9 nominal), full attic (R-38); 0.281 ACHnat	1227 ft²	Electric Heat Pump, 7.5 HSPF	Condensing Unit, 12 SEER	Electric, 50 gallon, EF=0.87
8	South facing; Single story, Strawbale house with wood-framed roof, R-34 (nominal) walls, R-42 (nominal) attic; 0.307 ACHnat	1870 ft²	Electric Heat Pump, 7.8 HSPF	Condensing Unit, 12.1 SEER	Electric, 40 gallon, EF=0.90
9	North facing, Single story, 2"x6"wood-framed walls with 1" EPS sheathing (R-22.9 nominal), full attic (R-38) 0.281 ACHnat	1227 ft²	Electric Heat Pump, 7.5 HSPF	Condensing Unit, 12 SEER	Electric, 50 gallon, EF=0.86

Heating and Cooling Measured Results

The most complete twelve month period of continuous data for test houses 2 through 7 occurred in the 2001 calendar year. The data period used for test house 1 occurred from February to October 2001 along with January, November and December 2002. In test house 8 the best data set occurred from October to September 2003, and for test house 9 it occurred from June 2002 to May 2003. The discontinuous data sets were either a result of test homes becoming unoccupied or data logger failure.

The total electrical energy consumption of heating and cooling systems measured in each house and compiled on a monthly basis is shown in Table 3. The number of occupants and the measured average setpoint temperature for heating and cooling months, and the temperature range (delta) between the highest and lowest average monthly temperature in each test house is included for reference. For consistency in conducting and comparing simulations, the setpoint temperature heating months in each house were considered to be December, January, February, March and April. April was chosen as a heating month for the EGUSA simulations since a greater number of days in 2001 received heating over cooling according to monitoring information.

Table 3. Heating and Cooling Electrical Energy Measured Results

House Number		1	2	3	4	5	6	7	8	9
Occupants		1	2	3	3	2	2	3	2	2
Setpoint Temperature	Cooling	76.2°F	76.8°F	79.7°F	77.8°F	77.2°F	77.0°F	74.4°F	76.6°F	77.3°F
	Heating	71.3°F	68.6°F	71.3°F	70.4°F	69.2°F	69.9°F	70.5°F	72.8°F	70.1°F
	Monthly Range	6.8°F	11.8°F	11.9°F	11.0°F	14.2°F	9.0°F	6.3°F	6.7°F	10.3°F
Monthly Heating and Cooling Electrical Energy Use (kWh)	Jan	36(34[1])	299	146	26	21	309	215	184	51
	Feb	43	187	100	18	14	289	172	189(187[1])	66
	Mar	14	60	26	4	2	106(84[1])	40(38[1])	104	76(67[1])
	Apr	24(9[1])	30(26[1])	31(5[1])	9(1[1])	1	45(26[1])	86(25[1])	5	10(4[1])
	May	169	141	225	161	33	199(1[1])	273(1[1])	161	100
	June	477	409	428	319	381	433	461	400	332
	July	511	471	465	377	271	463	452	560	311
	Aug	503	545	469	383	160	516	497	549	296
	Sept	492	439	422	335	254	612	459	406	188
	Oct	86	12	170	19	0	274	198(21[1])	105(2[1])	22(3[1])
	Nov	7	64	57(16[1])	1	0	116(40[1])	39 (21[1])	0	2(11[1])
	Dec	21(8[1])	112	128	14	2	268	167	86	56
Annual Heating and Cooling Electrical Use (kWh)	Total	2383	2768	2667	1667	1141	3629	3059	2750	1521

[1] Heating share of monthly energy use (kWh)

The total natural gas consumption of heating systems (excluding gas fireplaces) calculated in each house and compiled on a monthly basis is shown in Table 4. Cooling systems did not use natural gas.

Table 4. Natural Gas Energy Use Measured Results

House Number		1	2	3	4	5	6	7	8	9
Monthly Natural Gas Energy Use (Ccf)	Jan	50	0	0	23	28	0	0	0	0
	Feb	62	0	0	16	24	0	0	0	0
	Mar	32	0	0	6	6	0	0	0	0
	Apr	13	0	0	1	1	0	0	0	0
	May	0	0	0	0	0	0	0	0	0
	June	0	0	0	0	0	0	0	0	0
	July	0	0	0	0	0	0	0	0	0
	Aug	0	0	0	0	0	0	0	0	0
	Sept	0	0	0	0	0	0	0	0	0
	Oct	0	0	0	0	0	0	0	0	0
	Nov	0	0	0	1	0	0	0	0	0
	Dec	37	0	0	13	3	0	0	0	0
Annual Natural Gas Energy Use (Ccf)	Total	195	0	0	61	62	0	0	0	0

The total site energy consumption of heating and cooling systems (excluding gas fireplaces) measured in each house and compiled on a monthly basis is shown in Table 5. Electrical and natural gas consumption has been converted to kBtus.

Table 5. Heating and Cooling Site Energy Measured Results

House Number		1	2	3	4	5	6	7	8	9
Monthly Heating and Cooling Site Energy (kBtus)	Jan	5082	1019	499	2411	2911	1053	733	628	173
	Feb	6348	638	342	1681	2403	987	587	645	226
	Mar	3266	204	88	636	619	364	135	356	259
	Apr	1412	100	104	156	86	152	292	16	34
	May	576	481	768	548	114	674	931	549	341
	June	1628	1397	1460	1090	1301	1479	1574	1365	1135
	July	1745	1606	1585	1285	925	1580	1543	1909	1061
	Aug	1717	1859	1602	1308	547	1761	1696	1873	1008
	Sept	1678	1499	1440	1143	866	2087	1566	1385	641
	Oct	292	42	579	64	0	934	677	359	77
	Nov	54	219	196	102	0	397	135	2	45
	Dec	3819	383	435	1384	291	914	569	295	190
Annual Heating and Cooling Site Energy (kBtus)	Total	27617	9448	9099	11807	10062	12382	10437	9380	5190

The total annual site energy consumption measured for each house and compiled according to major end-use category is shown in Table 6. Electrical and natural gas consumption has been converted to kBtus. The percentage of energy consumption for heating and cooling as a percentage of net annual energy use is shown.

Table 6. Total Site Energy Use Results According to End-Use

House Number	1	2	3	4	5	6	7	8	9
Annual Heating Energy Use (kBtus)	19853	2551	1437	6342	6310	3467	2248	1940	884
Annual Cooling Energy Use (kBtus)	7764	6897	7662	5465	3752	8915	8189	7440	4307
Annual Hot Water Energy Use (kBtus)	6764	4880	5805	9686	20228	4940	3796	1429	1535
Annual Lighting, Appliance & Miscellaneous Electric Loads Energy Use (kBtus)	10867	12246	23825	13896	21084	17684	16864	20530[1]	34292
Total Annual Site Energy Use (kBtus)	45242	26573	38729	35389	51375	35006	31097	31339	40391
Electrical Generation (kWh/kBtus)	0	0	4445/ 15166	0	0	0	0	0	5822/ 19865
Net Annual Site Energy Use (kBtus)	45242	26573	23562	35389	51375	35006	31097	31339	20526
Percentage Heating and Cooling Energy Use of Net Total	61.0%	35.6%	38.6%	33.4%	19.6%	35.4%	33.6%	29.9%	25.3%
[1] Not measured, measurement-based simulation value substituted									

Analysis

Simulation Results

Construction plan information, including all window shading provided by overhangs and/or porch/courtyard roofs, along with duct leakage and building enclosure airtightness test results, and on-site inspection information, was used to build a construction profile for each house. This data was input into EnergyGauge® USA simulation software tool version 2.42 (EGUSA), which uses DOE 2.1-E hourly simulation software.

The first set of simulations, based on measured information, included the average monthly cooling and heating thermostat setpoints for each test house as defined in the Measured Results section. Where accurate information existed, the shading effect of nearby houses was included in this set of simulations.

To facilitate accurate comparison of measurements between test homes, comparison of actual cooling degree day and heating degree day on-site measurements with the values measured on-site was necessary. Annual cooling degree day (65°F base) values from the Climate Prediction Center (National Weather Service) for Tucson, Arizona for the years 2001, 2002 and 2003 yielded conformance within 5% with on-site measurements for all years. Therefore, all simulation cooling data is assumed to be reflective of typical conditions in Tucson, Arizona during the study period. Annual on-site heating degree day (65°F base) measurements for the years 2001, 2002 and 2003 were compared with the 30-year annual average heating degree day value used for Tucson, Arizona by EGUSA. Heating degree day values for 2001 matched within 1%, but monitoring values for 2002 and 2003 were 20% less than the EGUSA value. As a result, measurement-based simulation heating energy consumption values for test houses 8 and 9, which were based on 2002 and 2003 measurements, required normalizing (a reduction of 20%) to facilitate accurate comparisons. The normalized measurement-based simulation results for total site energy consumption due to heating and cooling as compiled on a monthly basis is shown in Table 7.

Table 7. Measurement-based Simulation Heating and Cooling Site Energy Results

House Number		1	2	3	4	5	6	7	8	9
Monthly Heating and Cooling Site Energy (kBtus)	Jan	2089	775	534	3012	2989	768	713	706	418
	Feb	1110	324	218	1329	2463	338	355	375	190
	Mar	1001	270	188	1125	635	256	334	353	160
	Apr	514	51	116	209	84	222	406	450	123
	May	1051	901	856	488	114	1172	1047	944	781
	June	1744	1686	1372	981	1301	1895	1580	1505	1303
	July	2469	2617	2003	1558	925	2714	2158	2095	1906
	Aug	2387	2515	1918	1431	547	2653	2107	2054	1882
	Sept	1423	1351	1082	674	866	1520	1396	1228	1146
	Oct	396	181	184	24	0	326	604	426	334
	Nov	700	136	133	1043	0	222	334	425	143
	Dec	1615	556	415	2440	295	573	532	565	296
Annual Heating and Cooling Site Energy (kBtus)	Total	16498	11362	9018	14313	10218	12659	11567	11126	8682

A second set of simulations was run to determine if the test homes conform to the SES. The SES conformance simulation followed the procedures outlined in Chapter 4 of the SES, [1] thereby an average heating setpoint temperature of 68ºF, an average cooling setpoint temperature of 78ºF, a set-up/set-back of 5ºF and set-up/set-back duration of 6 hours per day were used. This setpoint temperature range equals 20ºF. In Building America analysis work the setpoint temperature range used is 5°F (Hendron, R. et.al. 2003). The SES conformance simulation results for total site energy consumption due to heating and cooling as compiled on a monthly basis is shown in Table 8.

Table 8. SES Conformance Simulation Heating and Cooling Site Energy Results

House Number		1	2	3	4	5	6	7	8	9
Monthly Heating and Cooling Site Energy (kBtus)	Jan	669	421	261	770	1276	454	371	347	296
	Feb	310	150	78	310	510	167	156	154	118
	Mar	310	96	89	303	307	106	116	136	92
	Apr	230	44	102	107	141	78	38	130	41
	May	901	928	809	522	945	938	614	699	611
	June	1535	1617	1286	974	1651	1591	1047	1208	1051
	July	2252	2441	1849	1523	2496	2356	1576	1802	1602
	Aug	2180	2359	1771	1411	2411	2301	1532	1767	1581
	Sept	1225	1297	1047	688	1307	1271	867	949	928
	Oct	225	188	239	55	184	222	157	229	229
	Nov	261	68	89	231	214	96	58	150	75
	Dec	665	316	247	864	869	341	265	287	210
Annual Heating and Cooling Site Energy (kBtus)	Total	10764	9926	7868	7758	12310	9920	6796	7857	6833

[1] The SES refers to the 1998 International Energy Conservation Code (International Code Council 1998).

Source Energy Values

The SES requirements for determining source energy heating and cooling consumption require multiplying annual site energy usage by the appropriate source energy factor. The total annual source energy heating and cooling for measurements, measurement-based simulation and SES conformance simulation values for each test house are shown and compared in Table 9. Also in Table 9, source energy values for each test house are compared with the SES total annual source energy target and the percentage difference between the measured value and the energy target are noted.

Table 9. Source Heating and Cooling Energy Values

House Number	1	2	3	4	5	6	7	8	9
Total Annual Source Heating and Cooling Energy from Measurements (kBtus)	46839	29288	28206	24424	18913	38383	32356	29079	16090
Total Annual Source Heating and Cooling Energy from Measurement-based Simulation (kBtus)	38147	35222	27956	26460	39945	39241	35857	34492	26913
Total Annual Source Heating and Cooling Energy from SES Simulation (kBtus)	28991	30769	24391	19074	31793	30752	21068	24356	21183
Measurement & Measurement-based Simulation Values Difference	18.5%	-20.3%	0.9%	-8.4%	-95.5%	-2.2%	-10.8%	-18.6%	-67.3%
Source kBtu/ft² (Measurement)	29.7	14.1	18.0	19.1	9.1	20.6	26.4	15.6	13.1
Source kBtu/ft² (Measurement-based Simulation)	24.2	16.9	17.8	20.7	17.8	21.1	29.2	18.4	21.9
Source kBtu/ft² (SES Simulation)	18.4	14.8	15.6	14.9	15.3	16.5	17.2	13.0	17.3
Civano Source Target kBtu/ft²	20.0	19.0	20.0	22.0	19.0	19.0	22.0	19.0	22.0
Measurement Source kBtu/ft² Savings Difference to Target	48.5%	-25.8%	-10.0%	-13.2%	-52.1%	8.4%	20.0%	-17.9%	-40.5%

Observations

Source Energy Comparison with SES

Referring to Table 9, annual heating and cooling source energy resulting from measurement information found that the SES annual source energy targets was achieved in six of the nine test homes, a 66% success rate. Measurement-based simulation results determined that the same six houses meet the target level. SES conformance simulation results disagreed with this conclusion by determining that all houses meet the energy target. In all but one case measurement-based simulation results were greater or considered equal (less than 1% difference), than the results determined by monitoring. Of the three test houses that did not meet the SES annual heating and cooling source energy target they all had average monthly setpoint temperature ranges of 9.0°F or less and exceeded the target level by a minimum of 8.4%. In these three cases, measurements and measurement-based simulation values were close to each other (within 18.5%) suggesting the houses are performing as predicted.

House by House Results

Test house 1 had the highest monitored annual heating and cooling source energy and therefore failed to meet the energy target. Heating and cooling energy use comprises 61% of all energy use, a percentage greatly exceeding similar values in other homes. This house had one of the lowest average monthly setpoint temperature ranges (6.8°F) indicating that its homeowners preferred a fairly narrow temperature comfort range compared to most of the other test houses. Measurement-based simulation results for different orientations indicate that the most energy efficient direction for the front of the house to face would be south, although this offered only 1.6% annual heating and cooling source energy savings. In this orientation more windows would face south (all receiving some shading) and fewer would face west resulting in reduced heating energy use (6.6%) and minute cooling energy savings. Although the other two gas heated homes (houses 5 and 6) had modestly lower average heating setpoint temperatures (by 2.1°F and 1.4°F respectively), monitoring information on house 1 indicated that gas consumption for heating was more than three times higher. Simulating the lower average heating setpoint temperature (69.2°F) on house 1 resulted in 33.3% less gas consumption for heating. In addition, the monitored gas consumption for heating also greatly exceeded the simulation estimate (19484 kBtu compared with 6532 kBtu). The reasons for the remaining discrepancy in heating energy use could follow from an on-site examination of the efficiency of the space heating and air distribution systems. This house had the lowest lighting, appliance and miscellaneous electric energy use of all homes.

Test house 2, the largest test home, equal in size to that of house 5, easily met the SES heating and cooling source energy target according to measurements. The average heating season setpoint temperature was the lowest of all houses at 68.6°F.

Test house 3 displayed excellent agreement (within 0.9%) between measurements and measurement-based simulation total heating and cooling source energy values and comfortably met the energy target value. Contributing to meeting the target was the highest average cooling season setpoint temperature at 79.7°F, the second lowest level of building airtightness (0.217 ACHnat) and a two story configuration (thereby gaining an advantage by having less exposed surface area than if the house was all slab-on-grade). Measurement-based simulation results predicted that this house would use the least amount of annual heating and cooling source energy of all homes.

Test house 4 had the lowest measured building airtightness, the second highest cooling season setpoint temperature at 77.8°F and it easily met the annual heating and cooling source energy target. Its solar water heating system was integrated with the hydronic space heating system by an indirect coil in the DHW tank. The contribution of this system to the heating load could not be simulated in EGUSA and therefore it was modeled as only providing hot water for domestic purposes. Therefore, the measurement-based simulation heating source energy value should be lower than currently estimated.

Test house 5 met the annual heating and cooling source energy target by the widest margin. This house was monitored as using the least amount of cooling energy, about a third of the amount the measurement-based simulation estimated. This house had the highest monthly temperature swing of 14.2°F, which likely reflects a homeowner that very actively tries to save energy by varying the thermostat setpoint temperature and/or is absent from the home for extended periods. In August, the cooling season setpoint temperature was 81.4°F, the highest one-month average cooling season value. The most cooling energy was used in the month of June, compared to July in all other homes. In addition, the homeowner admitted the use of a gas fireplace to provide heating leading to low furnace gas usage for space heating in March, April, October, November and December.

In test house 6 the difference between measurement data and measurement-based simulation annual heating and cooling source energy values was within 2.2%, suggesting that the house performed as predicted. In this case the house exceeded the SES the energy target value by 8.4% likely because of its relatively low (for the community) monthly setpoint swing (6.4°F). Modeling indicates that if the front of house faced southeast instead of northeast these windows would be shaded by porches and a modest energy savings of 1.1% would have resulted. If the savings resulting from the orientation change could be applied to the monitoring results the house would still not have met the energy target.

Test house 7 failed to meet the annual heating and cooling source energy target. It had the lowest average cooling setpoint temperature (74.4°F) and the lowest average monthly setpoint range (6.3°F) of all test houses. This indicates that these homeowners has the narrowest temperature comfort range (69.6°F to 75.9°F) although this range is wider than the 5°F setpoint range used in Building America analysis work. Simulating the same average setpoint temperatures (higher cooling, lower heating) as the house with the same floor plan (test house 9) resulted in the house not meeting the target by 2.7% instead of 20.0%. This house is already oriented in its most energy efficient front facing direction with south facing windows well shaded by a porch.

Test house 8, the straw bale house met the annual heating and cooling source energy target based in both measurement and measurement-based simulation results. The house had the exterior wall system with the best (nominal) thermal performance (U=0.029) but the highest building airtightness value (0.307 ACHnat). The average monthly setpoint temperature range (6.7°F) in this house was among the lowest of the test homes and it had the highest monthly heating season setpoint temperature at 70.7°F. The house was monitored as having the lowest energy usage in April (16 kBtus) and used very little energy in November (2 kBtus). The straw bale wall assembly together with the home's other energy efficiency attributes appears to have resulted in a comfortable (with low temperature swings) and energy efficient enclosure.

Test house 9 was monitored as using the least annual amount of heating and cooling energy and consequently easily met the source energy target. The house uses half the energy as monitored in the same home plan that has its front facing south (test house 7) with windows shaded. The discrepancy during the cooling season appears to be due to the higher August setpoint temperature in house 9, which was 79.5°F versus 74.7°F for house 7. Heating season measurement-based simulation results were normalized to match heating season conditions during the monitoring period and this led to the simulation result meeting the energy target. Shoulder season (months of March, April, October,and November) monitored energy use stands out as the lowest of any test house.

Conclusions

The SES annual source heating and cooling energy target was met in six of the nine test homes based on measurement (and measurement-based simulation) information. The homes that did not meet the energy target each had average monthly setpoint temperature ranges of 9.0°F or less, although none of the homeowners set their setpoint ranges as low as required by Building America simulation procedures (5°F). SES conformance simulation results disagreed with monitoring (and measurement-based simulation) results by concluding that all houses meet the energy target.

Measurement-based simulation predictions, using EGUSA, to determine conformance with the energy target concurred with the monitoring assessment in all nine test house cases. Normalizing of simulated energy use values using measured outdoor temperature data is necessary for accurate predictions and comparisons. Energy use simulations were within 18.6% of measurement results (indicating decent calibration) in six of nine test house cases. Except for one case, measurement-based simulations were found to use more (or an equal amount) of energy than predicted by than their monitoring counterparts. The use of simulation software to model according to monthly (or daily) average setpoint temperatures, rather than heating or cooling season values, should result in more accurate predictions thereby giving greater confidence for larger scale energy performance verifications.

Acknowledgements

The authors acknowledge the support of the U.S. Department of Energy, Building America Program, which provided funding for this work. Technical guidance and support from Paul Norton, Craig Christensen, Jay Burch, Bob Hendron and Ed Hancock of NREL, Greg Barker of Mountain Energy Partnership, and Paul Reeves of The Partnership for Resource Conservation was greatly appreciated. The authors would also like to thank the homeowners of Civano who so graciously volunteered for this study.

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