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Performance of Four Near Zero Energy Homes: Lessons Learned

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ABSTRACT

While the idea of a zero or near zero energy home is well understood, the actual performance of the structure can be different than expected. High performance homes necessitate increasingly complex envelope, HVAC, water heating, and appliance systems, and successful designs rely on proper function and feedback from those systems to achieve low-energy goals. This paper presents measured data on four near zero energy homes located in Florida that are a part of the U.S. DOE Building America program. The monitored data are compared to both a benchmark model and the prototype computer simulations. By examining the sub-metered energy data, audited miscellaneous electrical loads, and occupancy, the paper seeks to identify the sources of the discrepancies in reaching performance goals. In some cases, attempts were made to improve the performance of the home by changing system components during the monitoring process. Occupancy and lifestyle related issues also are found to strongly influence performance. For example, in two homes with nearly identical HERS Index ratings and technical performance, the actual measured energy consumption varied by a factor of nearly three.

INTRODUCTION

This paper examines the monitored performance of four newly constructed near zero energy homes in Florida. A zero energy home is typically classified as a home that produces as much energy as it uses on an annual basis, with a simulated Home Energy Rating System (HERS) Index (RESNET 2010) ≤ 0 being the primary design goal. A near zero energy home typically incorporates enough renewable energy to offset a significant portion of the annual energy use, and has a HERS Index close to 0. Three of the four homes examined were located in the Central Florida region, while the fourth was located in the northern panhandle region. All were subject to hot-humid climate conditions (IECC Climate Zone 2). The homes were designed and monitored in partnership with the U.S. Department of Energy's (DOE) Building America program. A chief objective of the program is a 40–70% reduction in energy consumption. The reference for this performance metric is defined by the Building America Research Benchmark Definition (BA Benchmark) and is representative of 1990's construction with the minimum requirements of the 1995 Energy Model Code and federal appliance standards of that time frame (Hendron 2010). The EnergyGauge® USA (EGUSA) building energy simulation tool (Parker et al. 1999) developed at the Florida Solar Energy Center uses DOE-2.E as its calculation engine to optimize the design of the homes, calculate the HERS Index, and evaluate performance with respect to the BA Benchmark. The impetus for the monitoring was to identify elements that contributed to the low energy goals and to identify those that came up short relative to expectations.

Pre-construction planning involved evaluation of owner/builder house plans and optimization of building materials and equipment. EGUSA was used to evaluate combinations of building enclosure elements, HVAC equipment, and photovoltaic (PV) systems and simulate system performance. While the construction details were reviewed and selected with low energy use in mind, in some cases site selection and house orientation were selected prior to our involvement and therefore were

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Figure 1 *NZEH #1.*

not optimized. Since cooling represents the largest component of energy use in Florida, the building enclosure design emphasis centered on combating heat gain in a hot, humid climate.

All the houses were instrumented to obtain data on the electrical consumption and generation, interior conditions, and basic weather parameters. Some had additional data points taken on the water heating systems and the HVAC performance characteristics. Data were logged every 10 seconds with average output over 15 minute intervals.

NEAR ZERO ENERGY HOME #1—NZEH #1

Measured Home Energy Performance

This is the first of two low energy homes constructed in the same subdivision in Gainesville, Florida. It is a single-story three bedroom/two bath home with 1,519 square feet of living space occupied by three adults, who work full time and are home at different times. The home has a simulated HERS index of 16 (zero would indicate achievement of a zero energy home design when evaluated on an annual basis) featuring a ground source heat pump (GSHP) with a high expected cooling and heating efficiency (Figure 1).

The enclosure of the house is slab on grade, 2×4 frame construction covered with lightly colored cement board siding over OSB sheathing and R-13 (hr·ft^2·F/Btu) blown cellulose insulation. The roof is white metal shingles (solar absorptance = 0.35) with 2 ft overhangs. The home has a sealed attic with R-30 open cell spray foam insulation. Ceramic tile comprised 80% of the conditioned space flooring to take advantage of passive cooling from the ground as well as the thermal mass of the slab. House fenestration consists of low-e double glazed glass and vinyl frames (U = 0.34, SHGC = 0.28).

Energy consumption is offset by a west-facing 4.2 kilowatt PV system. Domestic water heating is provided by an 80 ft^2, 120 gallon, drain-back solar system. The house also uses all Energy Star® appliances (refrigerator, dishwasher, and clothes washer) and compact fluorescent lighting. Heating and cooling is provided by a two-ton open loop GSHP. The loop exchanges heat with the local aquifer through an injection well.

Measured electrical use data over a nine-month period (April–December 2009) was used to evaluate the home's net energy performance (Figure 2). The PV system was sized to produce 70% of the homes annual electricity needs using TMY3 weather data for Gainesville, Florida as well as the BA benchmark assumptions for occupant effects such as thermostat set points and miscellaneous energy use (Hendron 2010). The overall, average daily energy related performance of the home is given in Table 1.

Gainesville, Florida has 1,810 heating degree days and 2,174 cooling degree days (65°F; NOAA 2007). Simulations forecasted a site savings of 75% and a source savings of 83% relative to the BA Benchmark. Based on the year of monitored data, the homes net energy performance has been close to simulations.

Site electricity consumption (not counting the solar contribution) was low, averaging 21.5 kWh/day or 6,192 kWh over the nine month period. By way of comparison, typical

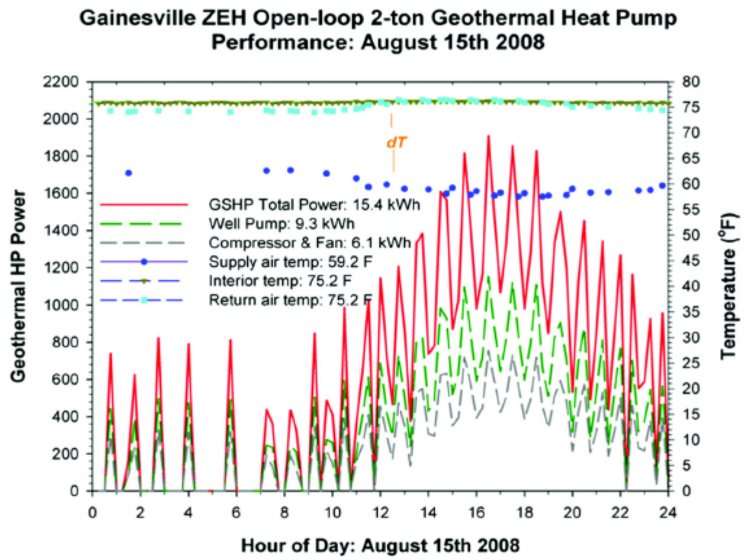

Figure 2 *NZEH #1 ground source heat pump operation.*

Table 1. Nine month (April–December 2009) Monitored Performance Summary of NZEH #1

Site Energy Summary	
	kWh/Day
Total site electricity consumption	21.5
Total AC site PV electricity production	10.8
Net electrical energy production	0.0
Source Energy Summary*	
Total source energy consumption	72.4
Total source energy offset	28.4
Net source energy	44
Total source energy (BA Benchmark, simulated)	159.3
Percent savings relative to Benchmark	72.4%

* The site-to-source energy conversions are U.S. national averages based on the BA Analysis Procedures (Hendron 2004): site-to-source multiplier for electricity = 3.365; site-to-source multiplier for natural gas = 1.092).

electrical usage in North Florida for this same period of time is 44 kWh/day or 16,060 kWh over the entire period (FPL 2008). As shown, the home produced 50% of its ten-month energy requirement from the renewable energy system.

Comparing the estimated 36 kWh/day of source energy consumed by NZEH #1 to the BA Benchmark, which was simulated to consume a daily average source energy of 159.3 kWh/day, shows a 77% savings in daily source energy. The extrapolation to annual results for these calculations is contained in Table 2.

Monthly Energy Summary by End-Use

In addition to overall electric energy use, some end-uses were monitored. These were primarily those that historically comprise the major residential loads: the HVAC and water heating systems. The homeowners were provided with a real-time energy monitoring system in order to give them feedback on immediate consumption.

HVAC System. Air conditioning averaged 414 kWh/month during the summer. While it is better than a typical home in North Florida which uses 800–1,000 kWh/month during the summer (FPL 2008), it was roughly double the use

Table 2. Annual Site/Source Energy Use and Savings for NZEH #1

Characteristic	Site Electricity kWh	Source Electricity kWh
Benchmark Total Energy Use	17,283	58,157
NZEH Prototype (simulation)*	2,003	6,740
NZEH (actual monitored)**	3,085	10,381
NZEH Savings: Simulated	88%	88%
NZEH Savings: Actual	82%	82%

Net of PV production: *5183 kWh simulated; **3107 kWh measured

Table 3. Monthly End Use 2009 (kWh) NZEH #1

Month	4	5	6	7	8	9	10	11	12
Total	345	565	548	631	729	704	539	385	547
GSHP + GSHP Pump	99	273	395	367	433	459	266	27	273
GSHP Pump	56	137	151	170	222	232	137	12	137
Water Heating	15	16	1	0	2	1	8	62	16
Other	232	276	152	265	295	243	265	296	256
Inverter output	444	387	427	389	352	348	248	147	387
PV to grid	341	242	267	226	178	186	127	67	242

of NZEH #2 located across the street which utilizes a high efficiency, conventional air-to-air system. The major source of the discrepancy is the extraordinarily high pump power (1 HP submersible pump) for the open loop ground source heat pump (GSHP) which accounted for between 40–50% of the overall HVAC energy use (Figure 2). Geothermal systems are generally considered to be an efficient means of space conditioning with EER values of 14–17 Btu/Wh range. However, for this particular site, this was not found to be the case. When considering the large pump power in the system's circulation loop, field estimates of EER using measured air side parameters averaged around 6 Btu/Wh. Although the well contractor installed a pump larger than originally specified, a later change in 2009 to a smaller and more efficient variable speed pump did not lead to savings as the system head pressures were higher than calculated. It is noteworthy that geothermal heat pump performance ratings typically do not include pump power.

Water Heating. The household at NZEH #1 was very typical: three occupants. The solar water heating system was sized by the solar installer to virtually eliminate back up water heating. Given the orientation of the house and the hip roof, the system had to be installed on the less advantageous west face of the home, rather than the south face. Based on experience, the installer decided on a pumped system with two 4×10 ft solar collectors feeding a 120 gallon storage tank in a drain back configuration. This system also provides the necessary freeze protection. Simulation of the solar water heating system in EGUSA estimated that such a system would provide a water heating energy reduction of 77% relative to the BA Benchmark, which in this case is modeled to contain four occupants served by a 50 gallon electric tank with EF = 0.86. Monitored data showed that the system saved over 90%. The home used roughly 0.7 kWh/day over the monitoring period including many days with no auxiliary electrical use at all for the solar water heating system. As showing in Table 3, most of the auxiliary electricity use of the solar system comes in the cloudier months of November and December. However, monitoring found that the drain down solar system drew 150 watts when circulated. With seven hours of daily operation the pump energy is approximately 1.0 kWh per day.

Solar Electric Power Production. The PV system consists of 18 200-watt modules with a 3.3 kW inverter. NREL's PVWatts simulation of the 3.6 kWp DC south-facing system using TMY2 weather data from Tallahassee, Florida predicts the system will deliver 4,732 kWh of grid-tied electricity per year with no shading. Similarly, the PV calculator (PVFORM) in the EGUSA software using the Gainesville Florida TMY3 weather data indicated 5183 kWh/year from the PV system (14.2 kWh/day). The actual solar electric energy delivered during the monitored period was 10.8 kWh/day. Although a detailed site shading analysis was not conducted, the PV modules were observed to be partially shaded by a large tree to the home's south, causing a reduction in PV power produced.

NET ZERO ENERGY HOME #2—NZEH #2

Measured Home Energy Performance

This home is located in the same subdivision as NZEH #1 described above. It is a single story, three bedroom/two bath

Figure 3 *NZEH #2.*

house with 1,772 ft^2 of conditioned space and a predicted HERS index of 29 (Figure 3). It shares many of the same construction details with that of its neighbor across the street. A detailed description and analysis is provided in a U.S. DOE contract report (Parker et al. 2009).

The enclosure of this house is slab on grade with 2×4 frame construction. The walls are medium colored (light brown) cement planks over OSB sheathing and R-13 blown cellulose insulation. The roof is comprised of spectrally selective brown metal shingles (solar absorptance = 0.65) and 2 ft overhangs. The attic is vented (1:300) with a radiant barrier applied to the underside of the roof sheathing and R-30 blown in insulation. Flooring is 80% ceramic tile and the windows are low-e, double-glazed, and vinyl framed (U = 0.34, SHGC = 0.28).

Energy consumption is offset by a 3.15 kilowatt PV system. Domestic hot water is provided by an 80 ft^2, 120 gallon, drain back solar system. It uses all Energy Star appliances. Cooling is provided by a 2 ton, SEER 19 straight cool condenser and heating is accomplished via a fully condensing natural gas furnace. The mechanical system and ducting is located within the thermal boundary, below the insulated ceiling. Efficient lighting is used throughout.

This home is occupied by two adults. One works full time and the other is retired. The household is conscientious about energy use and committed to living a low consumption lifestyle. Figure 4 illustrates a typical daily profile.

Measured electrical use data over a one year period (January–December 2009) was used to evaluate the home's net energy performance, and converted to source energy by applying the BA Benchmark site to source multipliers. Comparing the estimated 22 kWh/day of source energy consumed by NZEH #2 to the BA Benchmark, which was simulated to consume a daily source energy of 174 kWh/day, shows an 87% savings in daily source energy. The overall, average daily energy related performance of the home is given in Table 4 below.

Using EGUSA simulation software, this home is modeled to achieve a site savings of 63% and a source savings of 75% over the BA Benchmark. Based on the one year of monitored data, the home's monitored net energy performance exceeded the simulated result. The superior performance results from a very well performing air source cooling system and two adults who live a low-energy use lifestyle. Not counting the solar contribution, site energy consumption was low, averaging 12.2 kWh/day or 4,214 kWh over the one year period. As previously stated, typical electrical usage in North Florida for this same period of time is 44 kWh/day or 16,060 kWh over the entire period (FPL 2008).

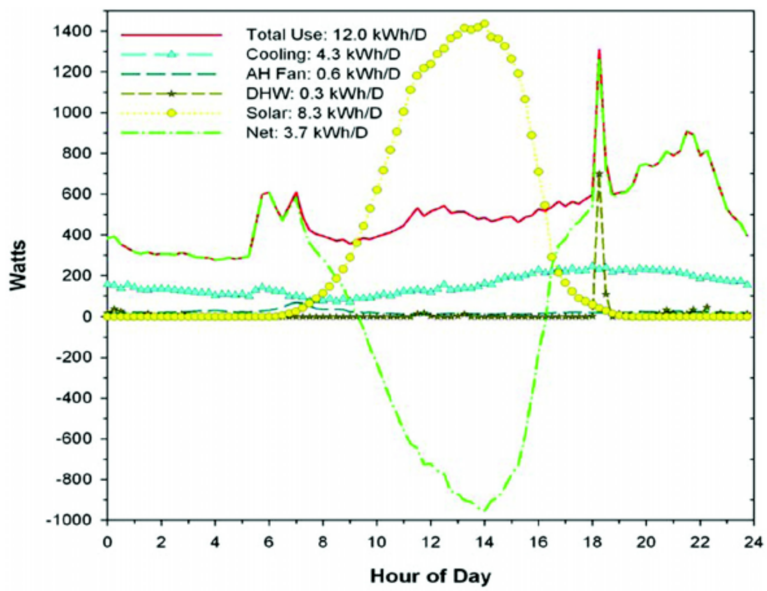

Figure 4 *Typical 24-hour electric demand—NZEH #2*

Table 4. One Year Monitored Performance Summary for NZEH #2

Site Energy Summary	
	kWh/Day
Total site electricity consumption	12.2
Total AC site PV electricity production	8.4
Net electrical energy production	0.0
Total Natural Gas Consumption (therms/day)	0.33
Source Energy Summary*	
Total source energy consumption	50.9
Total source energy offset	28.4
Net source energy	22.5
Total source energy (BA Benchmark, simulated)	173.5
Percent savings relative to Benchmark	87%

* The site to source energy conversions are U.S. national averages based on the BA Analysis Procedures (Hendron et. al. 2004): site-to-source multiplier for electricity = 3.365; site-to-source multiplier for natural gas = 1.02).

The home produced 69% of its yearly electricity requirements from the renewable energy system, and 37% of the total site energy when natural gas is included. The detailed simulation results for this calculation are contained in Table 5.

Monthly Energy Summary by End-Use

In addition to overall electric energy use, some end-uses were monitored. As at the other site, the homeowners were provided with an energy monitoring system in order to give them feedback on consumption.

HVAC System. As expected, space cooling is the largest end use in summer, while natural gas is the largest energy consumer from November until late March. The site used a straight cool condenser for cooling and natural gas for heating. Furnace gas use was not monitored although overall site gas consumption was measured. The air handler and condenser power were monitored individually, so it was possible to quantify cooling energy. The house design and equipment was very successful at reducing cooling loads. Air conditioning averaged 216 kWh/month during the summer months covering

Table 5. Annual Energy Use (Site and Source Savings) NZEH #2

Characteristic	Electricity* kWh	Natural Gas Therms	Site 10^6 Btu	Source 10^6 Btu
Benchmark Total Energy Use	15,769	343	88.088	218.48
NZEH Prototype (simulation)	2,345*	244	32.390	53.56
NZEH (actual monitored)	1,303*	122	16.64	27.41
NZEH Savings: Simulated	84.4%	28.9%	63.2%	75.5%
NZEH Savings: Actual	91.7%	57.4%	81.1%	87.5%

* Net of subtracted PV power produced: 3766 kWh simulated; 2911 kWh measured.

Table 6. Monthly End Use 2009 (kWh) NZEH #2

Month	1	2	3	4	5	6	7	8	9	10	11	12
Total Demand	325	266	282	310	538	455	379	511	430	352	315	411
Cooling	36	32	45	56	122	192	168	225	178	108	43	43
Air Handler	33	29	13	9	12	15	13	16	13	10	10	26
Water Heating	40	7	2	17	8	1	0	1	0	0	14	88
Other	216	199	223	228	397	248	198	269	239	234	248	254
PV output	226	270	300	304	113	270	233	255	250	231	211	134
Net to grid	148	191	210	210	158	165	123	118	129	141	132	63
Gas (therms)	45	20	8	2	3	3	2	2	2	3	13	

June to September (interior conditions 78.3°F and 52% RH). A typical home in North Florida uses 800-1,000 kWh/month during summer months (FPL 2008).

Water Heating. The solar water heating system for this house was exactly the same as NZEH #1 as discussed above. Total back-up resistance electricity use for the entire year was 133 kWh. Simulation predicted 2,900 kWh and 420 kWh for the BA Benchmark and as-built home respectively representing an estimated 85% savings. Monitored data showed that the system saved over 95%. As in NZEH #1 the BA Benchmark is modeled to contain 4 occupants served by a 50 gallon electric tank with EF = 0.86. The monitored data includes only the auxiliary electric energy use of the backup electric resistance elements in the solar hot water tank and not the energy use of the 100-watt differentially-controlled circulation pumps. These data showed that the home used roughly 0.38 kWh/day over the monitoring period.

Solar Electric Power Production. The 3.15 kW system consists of eighteen, 175 watt modules facing west at a 23 degree tilt with a 3 kW inverter. The PV calculator (PVFORM) in the EGUSA software using the Gainesville, Florida TMY3 weather data indicated 3766 kWh/year production from the PV system. A digital shading analysis was conducted at the site. The results of that survey indicated an approximate 14% loss of potential solar power production due to trees on the east and northwest sides of the property boundary. This loss of solar radiation from shading by mature trees on the site could be expected to reduce the annual PV production to about 8.2 kWh/day. The monitored solar electric energy delivered was 8.3 kWh/Day which is essentially identical to the predicted performance given variations in weather. However, the same analysis indicated that PV output could be increased by about 15–20% by using a south facing array which is strongly indicated for future projects.[1]

NEAR ZERO ENERGY HOME #3—NZEH #3

Measured Home Energy Performance

This all electric home is located in the North Florida city of Callaway, near Panama City. This home differs from the others in that it is two-story and is of modular construction. It is a three bedroom/2.5 bath home with 1371 ft^2 of conditioned, living space (Figure 5). The predicted HERS Index is 26. A

1. Both PV simulation software agree that use of the west orientation for the PV system results in about a further 10-15% drop in the annual electric power produced. For instance, *PVWATTS* predicts an annual energy production of 3,418 kWh with the existing west face against 4,052 kWh had the same PV system been facing south. Similarly, *EGUSA* predicts 3,766 kWh with the west face and 4,121 kWh if it were facing south. All things equal, this means that had the PV system been facing south, the PV system would have produced about 76% of total electrical needs and 58% of the annual energy required for the home vs. the 70% and 53%, respectively, now seen. Given the expensive energy of the solar electric system offset, this means that optimal orientation and minimization of PV array shading will provide best performance for ZEH projects when evaluated on an annual basis.

Figure 5 *NZEH #3.*

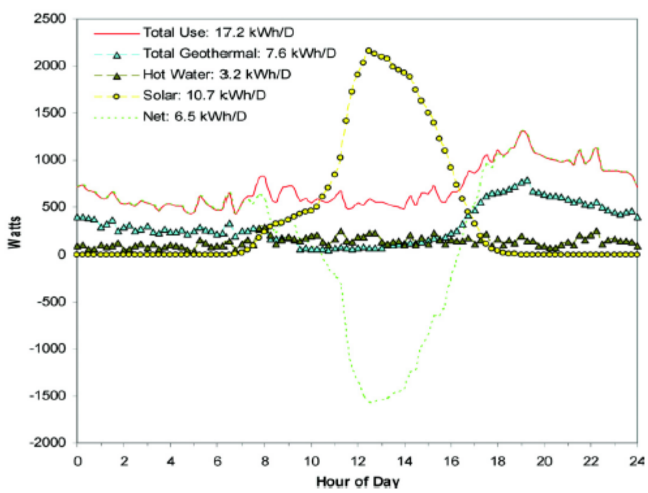

Figure 6 *Typical 24-hour electric demand—NZEH #3.*

detailed report on this project is described by Martin et al. (Martin et al. 2009).

The shell of the house is 2×6 frame construction with cement board siding and R-19 fiberglass batt wall insulation. The attic is sealed and has R-19, open cell foam applied to the roof decking. Placed on raised piers to provide a vented crawl space, the ground is covered with a 6 mil vapor barrier and the underside of the floor decking is sprayed with open cell foam to a value of R-11. The roof is a standing seam galvalum (solar absorptance = 0.35). The windows are low-e, double-glazed, with vinyl frames (U = 0.35, SHGC = 0.25).

The design heating and cooling loads are 15,000 Btu/hr and 12,000 Btu/hr respectively. Both are met by a vertical well, closed loop, ground source heat pump. All mechanical equipment and ducting is within the home's thermal barrier. Domestic water heating is accomplished by an electric tank-type water heater (EF = 0.91) coupled to a desuperheater on the ground source heat pump. On-site power production is a south facing 3.6 kW PV system. Typical daily demand is shown in Figure 6.

Measured electrical use data over a four-month period (September–December 2008) was used to evaluate the

Table 7. Four Month (September–December 2008) Monitored Performance Summary for NZEH #3

Site Energy Summary	
	kWh/Day
Total site electricity consumption	17.2
Total AC site PV electricity production	10.7
Net electrical energy production	0.0
Source Energy Summary*	
Total source energy consumption	57.9
Total source energy offset	36.0
Net source energy	21.9
Total source energy (BA Benchmark, simulated)	168.3
Percent savings relative to Benchmark	87%

* The site to source energy conversions are U.S. national averages based on the BA Analysis Procedures (Hendron et. al. 2004): site-to-source multiplier for electricity = 3.365; site-to-source multiplier for natural gas = 1.092).

Table 8. Annual Site and Source Energy Use and Savings NZEH #3

Characteristic	Site Electricity kWh	Source Electricity kWh
Benchmark Total Energy Use	18,251	61,415
NZEH Prototype (simulation)*	5,637	18,969
NZEH (actual monitored)**	2,367	7,965
NZEH Savings: Simulated	69.1%	69.1%
NZEH Savings: Actual	87.0%	87.0%

PV production: *4852 kWh simulated; **3900 kWh measured

home's net energy performance. The PV system was sized to produce 46% of the homes annual electricity needs using TMY2 weather data for Tallahassee, Florida as well as the BA Benchmark assumptions for occupant effects such as thermostat set points and miscellaneous energy use. The overall, average daily energy related performance of the home is given in Table 7.

Callaway, Florida has 1,810 heating degree days and 2,174 cooling degree days (65°F; NOAA 2007). The EGUSA simulation software estimated a source savings of 69% over the BA Benchmark. The home was occupied by one adult during the monitored period. Data beyond December 2008 is not included for occupancy became inconsistently intermittent. Given its relatively low occupancy for the monitored period, the home's performance numbers do not realistically compare well with average numbers for the region. However, this caution and the observed changes in energy use with occupancy at the home does strongly point to the importance of occupancy and lifestyle on consumption.

Site electricity use not counting the solar contribution was low, averaging 17.2 kWh/day or 2,089 kWh over the four month period. By way of comparison, typical electrical usage in North Florida for this same period of time is 44 kWh/day or 5,411 kWh over the entire period (FPL 2008). As shown, the home produces 62% of its four month energy requirement from the renewable energy system. The monthly site electricity by end use is shown in Table 7. Comparing the estimated 21.9 kWh/day of source energy consumed by NZEH #3 to the BA Benchmark, which was simulated to consume a daily source energy of 168.3 kWh/day, shows an 87% savings in daily source energy. As previously stated, differences in occupancy account for a portion of these savings. Detailed simulation and measurement results are shown in Table 8.

Monthly Energy Summary by End-Use

In addition to overall electric energy use, some end-uses were monitored the results are shown in Table 9.

HVAC System. In a NZEH for this climate, the house design and equipment appears successful at reducing space conditioning needs over the occupied time period presented. Air conditioning averaged 453 kWh/month in September while a typical occupied home in North Florida uses 800–1,000 kWh/month during summer months (FPL 2008). However, the NZEH #3 value is not extraordinarily low considering 1) this home is smaller than average, 2) the home has lower occupancy than average, and 3) the geothermal

Table 9. Monthly End Use 2008 (kWh) NZEH #3

Month	9	10	11	12
Total House Electrical Demand	773	477	465	374
Total GSHP (GSHP + GSHP Pump + DHW Pump)	453	175	163	134
GSHP	375	144	124	107
GSHP Pump	68	25	30	20
DHW	68	115	117	93
DHW Pump	11	6	9	6
Lighting, Appliances, & Other	251	187	185	147
PVac Power Produced	399	333	301	267

system is rated at a relatively high efficiency 18.3 EER (Btu/Wh). Data collected onsite during the monitoring period provides a rough estimate of actual efficiency at approximately 7.4 EER. While the certified performance rating considers return fluid temperature of 77°F, data from the home shows return fluid temperatures commonly above 90°F. It is noteworthy that installers in the area indicate that these are very typical return water temperatures for geothermal closed loop, vertical well systems operating in this vicinity. Under these conditions the manufacturer's performance data would estimate the EER closer to 12 Btu/Wh which likely means that higher ground temperatures in Florida are less advantageous for GSHP systems. Also, monitored data for the purposes of estimating operating EER includes the energy use of the geothermal loop pump, while the performance rating does not. This again, points to the importance of site specific GSHP operating parameters that include knowledge of the pumping power requirements as well as the typical return water temperature operating points. Selection of geothermal systems without consideration of these limitations can lead to disappointing performance.

Water Heating. Domestic water heating is accomplished by a 0.91 EF electric tank. The system is supplemented with a heat recovery desuperheater coil utilizing waste heat from the geothermal space conditioning system. This hybrid water heating system enables a pump (~100 W) to circulate water from the tank through the desuperheater coil when water temperature is less than 140°F and the superheated discharge gas temperature is above a certain level, typically obtained during cooling operation.

Solar Electric Power Production. The 3.6 kW system consists of 18 200-watt modules with a 3.3 kW inverter. The PVWatts simulation of the 3.6 kWp DC PV south-facing system using TMY2 weather data from Tallahassee, Florida predicts the system will deliver 4732 kWh of AC electricity per year with no shading. Similarly, the PV calculator (PVFORM) in the EGUSA software using the Tallahassee, Florida TMY2 weather data indicated 4852 kWh/year from the PV system. The predicted PV output for the monitored period from the EGUSA software was 12.0 kWh/day. The actual solar electric energy delivered from September through December was 10.7 kWh/day. Although a detailed site shading analysis was not conducted at this site, the PV modules were observed to be partially shaded by a large tree to the home's south, causing some reduction in PV power produced. Given that fact, performance was close to expectations. Again, it is seen that site shading has can have a significant impact on achieved PV system performance.

NEAR ZERO ENERGY HOME #4—NZEH #4

Measured Home Energy Performance

This home is located on the west coast of Florida in the city of North Port. It is a single story, 3-bedroom/2-bath house with 1,446 ft^2 of conditioned living space. The construction is slab on grade with concrete block walls. It has a standard vented attic with R-38 ceiling insulation and a radiant barrier adhered to the underside of the roof decking. The roof material is a standard three tab, medium brown shingle. The windows are low-e, double-glazed, with thermally improved metal frames (U = 0.510, SHGC = 0.23). EGUSA calculated a HERS Index of 24 for this home.

Heating and cooling is provided by an 18.4 SEER two-ton heat pump (9.1 HSPF) which features a dual-stage compressor and variable speed air handler. Water heating is provided by a 40 ft^2 differentially controlled circulation solar system. On site electricity generation is provided by a 3.4 kW, dual oriented photovoltaic system which is equally divided area between south and west roof planes. Both sections are tied to a single inverter. Average daily demands for this site are shown in Figure 7. Household occupancy level is high; consisting of a single parent and five school-age teenagers.

Measured electrical use data over a one-year period (August 2008–July 2009) was used to evaluate the home's net energy performance as shown in Table 10.

Tampa, Florida has 560 heating degree days and 3493 cooling degree days (65°F; NOAA 2007). EGUSA simulation estimated a site and source savings of 84% relative to the BA Benchmark. Based on one year of monitored data, the home's net energy performance has fallen short of the prediction. Site electricity use not counting the solar contribution was typical, averaging 39.5 kWh/day or 14,418 kWh over the one year period. By way of comparison, typical electrical usage in Central Florida for this same period of time is 47 kWh/day

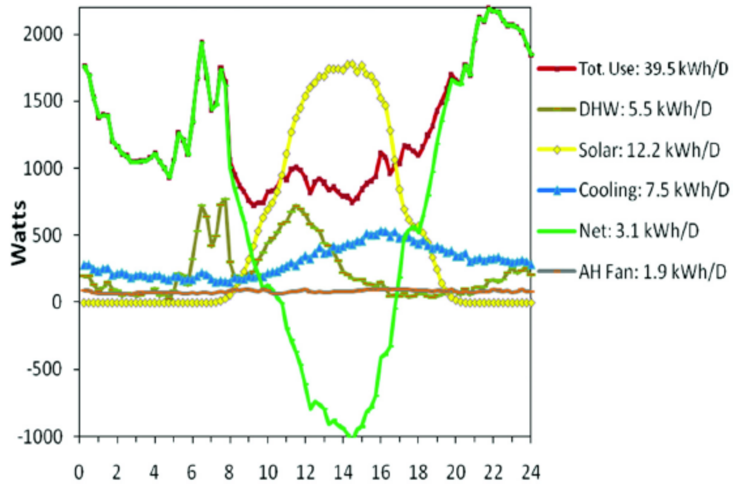

Figure 7 Typical 24-hour electric demand—NZEH #4.

Table 10. One Year Monitored Performance Summary for NZEH #4

Site Energy Summary	
	kWh/Day
Total site electricity consumption	39.5
Total AC site PV electricity production	12.2
Net electrical energy production	3.1
Source Energy Summary*	
Total source energy consumption	132.9
Total source energy offset	41.0
Net source energy	91.8
Total source energy (BA Benchmark, simulated)	177.7
Percent savings relative to Benchmark	48%

* The site to source energy conversions are U.S. national averages based on the BA Analysis Procedures (Hendron, et. al. 2004): site-to-source multiplier for electricity = 3.365; site-to-source multiplier for natural gas = 1.092).

(FPL 2008). However, even with the much higher level of occupancy at this home than typical, it still consumes less electricity than seen in average homes. As shown above, the home produces 31% of its yearly energy requirement from the renewable energy system. Comparing the estimated 102.3 kWh/day of source energy consumed by NZEH #4 to the BA Benchmark, which was simulated to consume a daily source energy of 178 kWh/day, shows a 48% savings in daily source energy (Table 11).

Monthly Energy Summary by End-Use

In addition to overall electric energy use, major end-uses were monitored as shown in Table 12.

HVAC System. The high efficiency 18.4 SEER air conditioner system at NZEH #4 utilizes a dual stage compressor system and variable speed air handler. Since this system represents advanced technology for which there is little data, we used the project's data logger to determine the amount of time the unit operated in low speed and high speed. This was accomplished using the data acquisition power meter on the outdoor compressor unit programmed to determine the operational speed based on manufacturer's published consumption data. (i.e., criteria > 1.38 kWh = high speed). Data indicated that the system operated at low speed 85% of the total running time. This resulted in a 44% reduction in compressor energy. Despite the fact that compressor run time was dominated by the lower speed, indoor conditions averaged 75.7°F with 54.5% relative humidity.

Water Heating. A differential controlled active solar domestic water heater with 40 ft^2 of collector area was utilized to supply hot water to this family of six. The system operated

Table 11. Annual Site and Source Energy Use and Savings NZEH #4

Characteristic	Site Electricity kWh	Source Electricity kWh
Benchmark Total Energy Use	19,281	64,881
NZEH Prototype (simulation)*	3,097	10,421
NZEH (actual monitored)**	11,101	52,306
NZEH Savings: Simulated	83.9%	83.9%
NZEH Savings: Actual	42.4%	42.4%%

Net of PV production: *6423 kWh simulated; **4443 kWh measured.

Table 12. Monthly Energy Summary 2008–2009 (kWh) NZEH #4

Month	8	9	10	11	12	1	2	3	4	5	6	7
Total Demand	1,055	1,040	1,106	787	852	1,024	712	830	801	865	1,005	1,000
Cooling	386	375	268	58	66	98	50	128	175	286	408	442
Air Handler	66	68	57	38	32	80	48	49	43	58	77	88
Water Heating	141	149	231	244	259	294	222	149	124	77	80	32
Other	462	448	550	447	495	551	393	549	459	445	440	438
PV output	347	345	359	331	320	333	351	404	407	432	399	407
Net to grid	0	0	77	128	146	117	169	156	134	115	61	22
Gas (therms)	0	0	0	0	0	0	0	0	0	0	0	0

on an 80 gallon reservoir tank with single 4.5 kW auxiliary heating element. Because the south facing roof surface was utilized for photovoltaic modules, the solar thermal system was installed facing west. The system was able to limit auxiliary energy to 5.5 kWh/day on average. Although this auxiliary energy consumption seems high, it appears to be proportional to the 113 gallons per day of hot water consumption measured at this heavily occupied household with multiple teenagers. The average energy delivered to the home amounts to 12.2 kWh/day. These measured numbers indicate that the system was capable of delivering 55% of the energy from solar, not counting standby loses. Parasitic energy of this system was imposed by the 85-watt circulating pump and 6.5-watt solenoid check valve.

Solar Electric Power Production. Solar electric power production was supplied by nineteen 190-watt power modules. As noted earlier, due to the limited south exposure area and hip roof design at this house, the array was equally divided into south and west orientations. The 3.4 kWh photovoltaic system was capable generating 12.2 kWh/day on average, as measured at the inverter output.

DISCUSSION / LESSONS LEARNED

Low or near zero energy homes require efficient thermal enclosures, efficient mechanical systems, and a form of site energy generation. Using the HERS Index as a reference, where national average minimum code homes built to the 2006 International Energy Conservation Code (IECC) score 100 and a zero energy home scores a 0, it is relatively easy to build homes that consume 30–40% less energy than a standard home in the hot humid climate zone. Often, the next level of achievement would be to include a solar thermal water heating system which would result in a 50–60% improvement. The final measure for a true low energy use home requires some form of renewable energy generation, typically photovoltaics (PV). This last improvement would produce a house that uses 80-100% less energy than a standard home. All of the homes studied were designed to operate in this range. Each home presented individual challenges that resulted in deviation from expected results leading to a discussion of lessons learned as summarized below. One recurring lesson from the projects is that small changes matter, and the overall success of the project will depend on the cumulative integrity of individual parts. Lack of attention to details and compromise will lead to shortfalls in expected performance. Each component must be integrated into the system, and the system must be engineered to perform with the end result in mind.

Construction

The four homes discussed in this study represent the three major forms of residential construction in Florida: site-built wood frame, site-built concrete block, and manufactured or modular housing. Relatively standard construction techniques were utilized throughout. The largest opportunity for improvement would be for site built wood frame homes. In these cases, it was observed during the construction process that there was excess framing and utilizing advanced framing techniques would have improved the thermal envelope, reduced materials, and limited waste.

Modular homes are built in a factory and assembled on site. NZEH #3 was a two-story home that consisted of 4 modules, two mated side-by-side with two more placed on top those. The overall construction of the modules was quite good. However there were some issues when all four were assembled on site, resulting in air leakage in the cavity between the first and second floors, and portions of the duct system located therein. There were also some issues between the factory and the mechanical contractor coordinating installation of the ground source HVAC system and components.

Photovoltaics

All the homes had grid-tied PV systems, although the overall monthly production was less than the monthly consumption for all monitored months. Given the very large expense of the PV systems (typically $7000/kW and easily the most expensive element in the entire project), there are good reasons to maximize its performance.

By far, the biggest issue facing the performance of the PV systems in this study was shading and orientation. In the two cases with west facing orientation, it was already expected that power production would be lower by about 15–20% over a true south orientation. Although the timing of the power production may be more beneficial for the utilities, we conclude from our evaluation that optimizing the south facing orientation and even tilt may be beneficial for homeowners.

In most cases, it was recognized that shading would be a factor early in the construction process. It was also believed that the existing shading issues would be addressed by the removal of trees. However, the shading problems were not resolved due to conflicts with city ordinance policies on tree removal, in one case, and a developer in the other. This circumstance dictates that not only should a high priority be placed on orientation and shading analysis, but that if shading is a factor, measures to minimize it prior to construction are recommended. When there are some questions, a digital site shading survey should be performed. Current technologies that might be considered include multiple string arrangements, multiple inverters, or micro inverters. More conventional approaches would be optimal PV array arrangement and tree trimming where necessary.

Solar Thermal Water Heating Systems

Three out of the four houses had solar hot water systems. All of these systems performed well and provided the majority of the daily hot water needs. The systems were installed without any knowledge of actual occupancy and relative water consumption. Although this resulted in low backup energy requirements (particularly in summer) low use can result in an oversized system and un-used capacity. For a production home with no knowledge of the eventual occupants, this seems unavoidable. However, variations in performance are to be expected with occupancy. One house with two retired adults showed almost no auxiliary water heating while another with a family of six showed 113 gallons of hot water used daily. In the context of minimizing energy requirements for a low energy home, consideration should be given to the pumping energy use of the system. The drain down systems installed at NZEH #1 and #2 were installed with a 125-watt pump that used nearly 1 kWh per day. Since these systems had short piping runs, perhaps a smaller or variable speed pump would suffice and perhaps save 300 watt hours or more per day.

HVAC Systems

Two out of the four houses had ground source heat pump systems. One was an open loop system that exchanged heat with the aquifer (NZEH #1) and the other was a closed loop system using a vertical well (NZEH #3). The systems were specified for the homes based on the high performance ratings published by the manufacturer. As installed, these systems did not meet expectations. In both cases, the deviations from the performance ratings were attributed to the heat exchange loops. The open loop system for NZEH #1 required very significant pump power (>1 kW) to draw the water out of the ground from a depth of 118 ft, move it through the heat exchanger and then inject it back into the aquifer. When factored into the overall energy use, the total system EER was around 6 Btu/Wh—considerably worse than conventional available air source equipment. An attempt was made to improve the performance by changing out the pump to a slightly smaller, more efficient pump. Selection of the pump and calculation of head pressure was done in negotiation with engineers at Oak Ridge National Laboratories. However, this resulted in only a marginal improvement in performance. Variations in the water table necessitated a minimum pump size to ensure adequate flow to the geothermal unit and the head pressure appears to have been higher than that calculated by the project engineers. Also, designers must be aware that listed performance ratings for such equipment do not include pump power and thus direct comparisons cannot be made with air source equipment.

The geothermal system at NZEH #3 did not meet performance expectations as well. However, in this case it was because of high temperatures in the loop. The loop of the 200-ft vertical well was closed so the water movement could be accomplished by a 1/6 hp pump whose power was 385 watts. High return temperatures (90°F) in the loop degraded the performance significantly. A Field measurement of EER for the system was about 7 Btu/Wh—much poorer than a typical air source heat pump. As with NZEH #1, an attempt was made to improve the performance. The pump was changed out to more energy efficient model rated at 1/12 hp and 175 watts. It was hoped that this would not only reduce system energy consumption, but also slow the flow down within the loop to improve the heat exchange with the ground. This measure only marginally improved performance. With the pump and flow optimized, it is believed that the issue lies with installation of the loop. The fact remains that higher ground temperatures found in Florida will exact large limitations on the cooling performance of such systems. Similarly, higher ground temperatures in warmer climates may naturally lead to lower than expected performance.

Given the poor performance of the geothermal systems at the two sites, it is suggested that when considering this technology, careful consideration be made in regards to the heat transfer characteristics of the ground/water loop. This includes the design, installation (grouting, etc.), and the pumping requirements. Since the published system performance data does not reflect pump power, it is vital to consider this load when evaluating comparative performance claims.

The straight cool air conditioning system at NZEH #2 performed quite well. It maintained consistent conditions of temperature and humidity at a low power cost. However, during periods where cooling was not required it was observed that the condensing unit routinely consumed about 55 watts. It was learned that this power draw was from a crankcase heater. A crankcase heater is a resistive heating element attached to the compressor that prevents refrigerant migration in cold weather. The heater on this unit was activated when the outdoor air reached 55°F. Since this unit is used for cooling only, operation of the heater during non cooling periods is an unnecessary energy use. Considering that Gainesville, Florida averages 2,231 hours per year with outdoor temperatures below 60°F, it is estimated that 128 kWh/year would be saved if crankcase heater use could be avoided during periods when the cooling system will not be needed. This represents a significant energy savings opportunity that is not captured.

In general, we found that high efficiency air source systems in Florida showed better performance in our case studies than the evaluated geothermal systems.

Appliances and Miscellaneous Electrical Loads

Appliance loads, which were not separately measured in the monitoring scheme, include fans, clothes washers, clothes dryers, refrigerators, computers, and other plug loads. Lighting is another large energy end use not separately measured in our study homes. Together, these miscellaneous electrical loads (MELs) are comprised not only of loads while devices are operational, but also the low level electricity use consumed by a given device when turned off. MELs now comprise about 28% of the total energy consumed in a residence (Parker et al. 2010). Consumer electronics comprise a large share of MELs, although lighting can be very large as well. Some devices are routinely left on during periods of non use (such as ceiling fans) while others such as televisions, computers, and DVRs also contain electronics that require power in the off mode to retain settings and perform other functions. Also, lifestyle influences a number of these end uses. For instance, high consumption households often may leave many ceiling fans on much of the time, along with several televisions and computers.

Electrical end-use audits were performed at both NZEH #1 and NZEH #2. It was found that these homes contained 100-300 watts of plug loads. As discussed earlier, both homes had access to a whole house feedback system that provides real-time, electric energy consumption to the occupants. Since both homeowners were genuinely interested in curtailing energy use, they were able to use the monitoring system to reduce their miscellaneous consumption to half of what might be expected in a standard home. Other studies have already demonstrated the value of such information can be useful in homes, particularly with motivated users looking to cut consumption (Parker et al. 2008). As evidence, one of the sites discovered that a son's home computer and television was left on 24-hours a day using 3.1 kWh—a load that was substantially reduced using an ordinary power strip.

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REFERENCES

FPL. 2008. "Typical Monthly Consumer Electric Use by DCA Climate Zone," provided by Craig Muccio, Florida Power and Light Company, Miami, FL.

Hendron, R., R. Anderson, R. Judkoff, C. Christensen, M. Eastment, P. Norton, and P. Reeves. 2004. Building America Performance Analysis Procedures, Revision 1. National Renewable Energy Laboratory, NREL/TP-550-35567.

Hendron, R. "Building America Research Benchmark Definition." NREL Technical Report TP-550-47246, January 2010.

NOAA. 2007. Climatography of the United States No. 81, Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days, 1971-2000, National Climatic Data Center, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Martin, E., D. Parker, J. Sherwin, and C. Colon. 2009. "Preliminary Performance Evaluation of a Near Zero Energy Home in Callaway, Florida," Florida Solar Energy Center, FSEC-CR-1793-09, February.

Parker, D., P. Broman, J. Grant, L. Gu, M. Anello, R. Vieira, and H. Henderson. 1999. "EnergyGauge® USA: A Residential Building Energy Simulation Design Tool", Proceedings of Building Simulation '99, International Building Performance Simulation Association, Organizing Committee for the 6th International IBPSA Conference, Department of Architecture Texas A&M University, TX.

Parker, D., D. Hoak, and J. Cummings. 2008. "Pilot Evaluation of Energy Savings from Residential Energy Demand Feedback Devices," Florida Solar Energy Center, FSEC-CR-1742-08, January.

Parker, D., J. Sherwin, D. Hoak, S. Chandra, and E. Martin. 2009. "Preliminary Performance Evaluation of a Near Zero Energy Home in Gainesville, Florida," FSEC-CR-1792-09, Florida Solar Energy Center, Cocoa, FL, February.

Parker, D., P. Fairey, and R. Hendron. 2010. Updated Miscellaneous Electricity Loads and Appliance Energy Usage Profiles for Use in Home Energy Ratings, the Building America Benchmark Procedures and Related Calculations. FSEC-CR-1837-10, Florida Solar Energy Center, Cocoa, FL, January.

Residential Energy Services Network (RESNET). "2006 Mortgage Industry National Home Energy Rating Systems," Residential Energy Services Network, Oceanside, CA, 10 March 2010.