

FLORIDA SOLAR



ENERGY CENTER[®]

CONTRACT REPORT

Preliminary Performance Evaluation of a Near Zero Energy Home in Callaway, Florida

FSEC-CR-1793-09

Final Report

February 2009

Submitted to:

U.S. Department of Energy
Cooperative Agreement DE-FC26-06NT42767

Authors:

Eric Martin
Danny Parker
John Sherwin
Carlos Colon

Florida Solar Energy Center

1679 Clearlake Road, Cocoa, FL 32922-5703 • Phone: 321-638-1000 • Fax: 321-638-1010
www.fsec.ucf.edu



A Research Institute of the University of Central Florida

Preliminary Performance Evaluation of a Near Zero Energy Home in Callaway, Florida

E. Martin, D. Parker, J. Sherwin, and C. Colon
Florida Solar Energy Center
February 2009

Introduction

The U.S. Department of Energy's Building America (BA) program is working to increase the energy efficiency of new and existing homes while increasing comfort, and durability and reducing resource use. As part of this program we pursue opportunities to research highly efficient homes with the goal of understanding what works, what doesn't work, and the most economic ways to reach very high efficiency targets. The program aims to create cost neutral zero energy homes by 2020. In pursuit of this goal, this home and other research homes around the country designed to approach or achieve the zero energy goal are being built and studied.

The performance summary on a near zero energy home (NZEH) presented here was a result of collaboration between the Florida Solar Energy Center (FSEC) and an innovative developer and builder in Callaway, Florida (near Panama City in North Florida) under the auspices of the U.S. DOE sponsored Building America Industrialized Housing Partnership (BAIHP) project. This paper briefly reviews the design and then focuses on the first four months of energy performance of the project home during the second half of 2008.

In general, a zero energy home is designed to produce as much energy as it consumes over the course of a full year. The BA program definition is more specific: A zero energy home is designed to offset as much source energy as it consumes over a typical year (based on TMY data) using BA Benchmark assumptions for typical occupant behavior. To achieve zero energy the home exchanges energy with the utility power grid. It delivers energy to the grid when the photovoltaic (PV) system is producing more energy than is being used in the home and draws from the grid when the PV system is producing less energy than needed in the home.

The particular project here is termed "a Near Zero Energy Home" (NZEH) with the intention that it provide 69% of its annual electrical energy requirement when evaluated over a full year. This project is a case study of reaching near the zero energy goals within a hot humid climate utilizing a modular construction approach to reduce cost and aid in quality control. Note that this is also the first LEED for Homes™ Platinum certified project in Florida.

NZEH Design

The energy analysis of the single story all electric home, shown in Figure 1, was performed using *EGUSA* software (Parker, et. al. 1999) to achieve a building that would have a 69% reduction to annual energy use relative to a Benchmark building in the same climate. This engineering approach was tempered by regular discussions with the developer and builder in Callaway, FL. The 1,371 ft² home specifications are summarized in Table 1.



Figure 1. Stalwart Near Zero Energy Home in Callaway, FL..

Table 1. Summary of Stalwart NZEH Attributes

Square footage	1371 ft ² ; two story construction
Number of bedrooms	3 bedrooms, 2.5 baths
Number of occupants	1 adult
Design heating load	15,000 Btu/hr
Design cooling load	12,000 Btu/hr
Walls	2 x6" walls with batt insulation Nominal R-value = 19 hr ft ² F/Btu
Ceiling/Roof	Galvalume metal standing seam roof (Solar Absorptance= 0.35) Unvented attic with open cell spray foam insulation Roof deck insulation R value = 19 hr ft ² F/Btu
Floor	Vented crawlspace floor with open cell spray foam insulation Crawlspace floor insulation R value = 11 hr ft ² F/Btu
Windows	148 ft ² (10.8% glazing); Low-e, low SHGC U = 0.35 Btu/hr ft ² F, SHGC = 0.25
Miscellaneous Electric load control	None
Occupant Energy Information	None
Water heating	50 gallon electric water heater (EF= 0.91) Desuperheater from geothermal heat pump
Ducts	Very low duct leakage tested Qn=0.011; all ducts in conditioned space between floors
Space heating	Closed-loop geothermal heat pump, COP=3.7, EER=18.3
Space cooling	<i>Florida Heat Pump</i> GT018-1VTC
Lighting	100% Hard wired fluorescent and compact fluorescent throughout the house
Appliances	<i>Energy Star</i> clothes washer, dishwasher and refrigerator. Electric dryer and range.
Solar electric	Nominal 3.6 kW _p DC photovoltaic system (GEPVp-200-MS modules) with 94% efficient GEPVb 3300 inverter; south facing
Infiltration/Ventilation	Tight construction: tested leakage of 3.5 ACH @50 Pa pressure; Low noise, high efficiency bathroom fans on timers, supplemented by 20 cfm of runtime whole house mechanical ventilation and dedicated kitchen ventilation
HERS Index for the house	26 (56 without PV system)
BA Benchmark Savings (source)	69.1% (42.5% without PV system)



Figure 2: Energy Star bathroom exhaust fans are operated on timer switches.



Figure 3: Compact fluorescent lighting is installed throughout the house.

The walls of the home are a single stud wall design using 2x6 on 16" centers and batt insulation (R-19 hr/ft²-F^o/Btu). The roof deck has open cell foam insulation (R-19 hr/ft²-F^o/Btu) creating an unvented attic. The vented crawlspace also has open cell foam insulation under the floor (R-11 hr/ft²-F^o/Btu).



Figure 4. Walls are insulated while the home is still in the factory.



Figure 5. Foam insulation is applied in the attic and in the crawlspace after the home arrives on site.

The two-story home is designed to have a small footprint and to largely reject solar gain in Florida's hot humid climate. Many of the windows are shaded by porches and large overhangs. The windows are double-glazed low-e with vinyl frames a low SHGC of 0.25 and a U-factor of 0.35 Btu·hr·°F ft². A galvalume standing seam metal roof with a solar absorptance only 35% is used to reject heat from the top of the building.

With these shell efficiency features, the peak design heating load for the home is small – about 15,000 Btu/hr. The design cooling load was even lower: 12,000 Btu/hr. These loads were met using an closed-loop ground source heat pump (*Florida Heat Pump GT018*) with rated at 18.3 EER and 16,000 Btu/hr for cooling and 3.7 COP and 10,600 Btu/hr for heating. All mechanical equipment is contained within this thermal envelope. Within the construction, the ducts are located between floors. In addition to the roof deck and crawlspace floor, the floor joist perimeter is also sealed and insulated onsite with open cell spray foam. The air handler is located in an interior utility room, and shares the space with a low-boy water heater. The 0.91 EF electric tank water heater is supplemented with a desuperheater. A 45 pint per day stand alone dehumidifier aids with moisture removal and is located on the second floor inside the return air plenum.



Figure 6. The geothermal unit and water heater share the same mechanical closet.



Figure 7. The stand alone dehumidifier is located in the return air plenum.

Data Acquisition System Design

A data acquisition system was installed to determine if the home met its energy design goal of near zero energy. The system was designed to allow disaggregation of the PV energy production and some end uses. A summary of the data points and the equipment used is given in Table 2.

Data were collected on 15-minute intervals. A dedicated website was created to aggregate daily and monthly averages and sums and to create graphics on the performance of the home for daily troubleshooting (www.infomonitors.com/zep). All electrical end use measurements were in place by August 2008. This report summarizes preliminary data from the project from September – December of 2008. Long term data will be collected on the project over the next year through spring 2010.

Table 2. Measurements and Components of the Data Acquisition System	
Measurements	Component
<i>Electrical energy measurements</i> House total power Geothermal HVAC power Geothermal pump power DHW power DHW pump power	Pulse output watt-hour transducers
<i>Temperatures & humidity</i>	Temperature & RH transmitter
Ambient air temperature & humidity Indoor air temperature Indoor relative humidity Geothermal inlet water temperature Geothermal outlet water temperature DHW loop temperature in and out Return air temperature & humidity Supply air temperature & humidity	Capacitive type hygrometer Type T thermocouples
<i>Water flow</i>	
Geothermal loop flow DHW loop flow	Positive displacement flowmeter
<i>Weather related measurements</i>	
Outdoor temperature and RH Solar radiation - horizontal Solar radiation - plane of collectors	T&RH sensor w/shield Pyranometer Pyranometer
<i>Data Logging Equipment</i>	Campbell data logger
<i>Communications</i>	Thermocouple multiplexer Switch closure multiplexer Telephone modem



Figure 8. FSEC installed chases in the factory to facilitate wiring for the PV and data acquisition system.



Figure 9. A weather station on the roof line records ambient data.

Measured Home Energy Performance

The home is located in Callaway, Florida which is just outside Panama City. Panama City has 1810 heating degree days and 2174 cooling degree days (65°F base; NOAA 2007). Using the *EnergyGauge USA* simulation (Version 2.8), the home received a HERS rating of 26 and a BA Benchmark estimated source energy savings of 69%.

Based on the first four months of data (Sep-Dec 2008), the home's net energy performance has been close to expectations. The PV system was sized to produce 46% of the home's annual electricity needs using TMY2 weather data for Tallahassee, FL and BA Benchmark assumptions for occupant effects such as temperature setpoints and miscellaneous energy use (Hendron, et. al. 2004). The BA Benchmark represents U.S. average occupancy and behavior. Predicted whole house source energy savings was 69%.

The home was occupied by one adult in spring of 2008. The homeowner works during the day as an environmental scientist for the developer. She is very conscious of the impacts of her home's energy use, and adjusts her lifestyle to consume as little as possible. The overall energy related performance of the home is given in Table 3 when averaged on daily basis.

Table 3. Four Month (Sep-Dec 2008) Performance Summary of Callaway NZEH

kWh/Day	
Site Energy Summary	
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)	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).

Site electricity use (not counting the solar contribution) has been exceedingly low, averaging only about 17.2 kWh/day or 2089 kWh over the four month period. This is to be expected, considering the house is occupied by only one person. By way of consumption, the typical September – December electricity use in North Florida for single family houses averages 5411 kWh or about 44 kWh/day (FPL, 2008)

As shown, the home produces 62% of its four month energy requirement from the renewable energy system. While solar electricity produced was supplied to the grid at all times, the overall monthly production was less than the monthly consumption for all monitored months. The monthly site electricity by end use is shown in Figure 10 and Table 5. The average diurnal demand profile over the 24-hour cycle is shown in Figure 11. We also compared the energy use of the NZEH to a typical new 1990's home (the BA Benchmark) which showed a daily average source energy use of 168.3 kWh/day against the 21.9 kWh/day actually measured for the NZEH home. This represents an 87% savings in source energy. The detailed simulation results for this calculation are contained in Table 4.

Detailed Site and Source Energy Savings

We used the *EGUSA Version 2.8* software and monitored energy use to evaluate the source energy savings of the NZEH design. As detailed in Appendix A, the software predicted a 69% site and source energy savings versus the BA Benchmark for the installed measures. To evaluate measured performance, we assumed that the twelve month energy savings would be three times that seen in the Sept - December monitoring period. This preliminary approximation of annual energy use is not truly representative of summertime cooling energy use, and these estimates will be revisited once a full year of data is available.

Table 4. Annual Site and Source Energy Use and Savings

Characteristic	Site Electricity kWh	Source Electricity kWh
Benchmark Total Energy Use	18251	61415
NZEH Prototype (simulation)*	5637	18969
NZEH (actual monitored)**	2367	7965
NZEH Savings: Simulated	69.1%	69.1%
NZEH Savings: Actual	87.0%	87.0%

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

Considering the assumption that approximates annual performance based off the four months of monitored data, the as built and as operated home did even better than predicted by the software. Our evaluation showed that the actual site and source energy savings were 87% – exceeding the predicted performance. While measured HVAC electrical energy was somewhat higher than that simulated (measured = 7.6 kWh/day vs. 4.7 kWh simulated), non-HVAC, non DHW measured electricity use was much lower than simulated: (measured = 6.4 kWh/day vs. 16.4 kWh/day simulated). This is likely due to lower occupancy than that assumed in the simulation and the careful and frugal energy use of the home owner.

The PV system in the NZEH home produces 62% of in house total energy use, although compared to the BA Benchmark home, the very efficient Stalwart NZEH home and systems reduces source energy use by 87%.

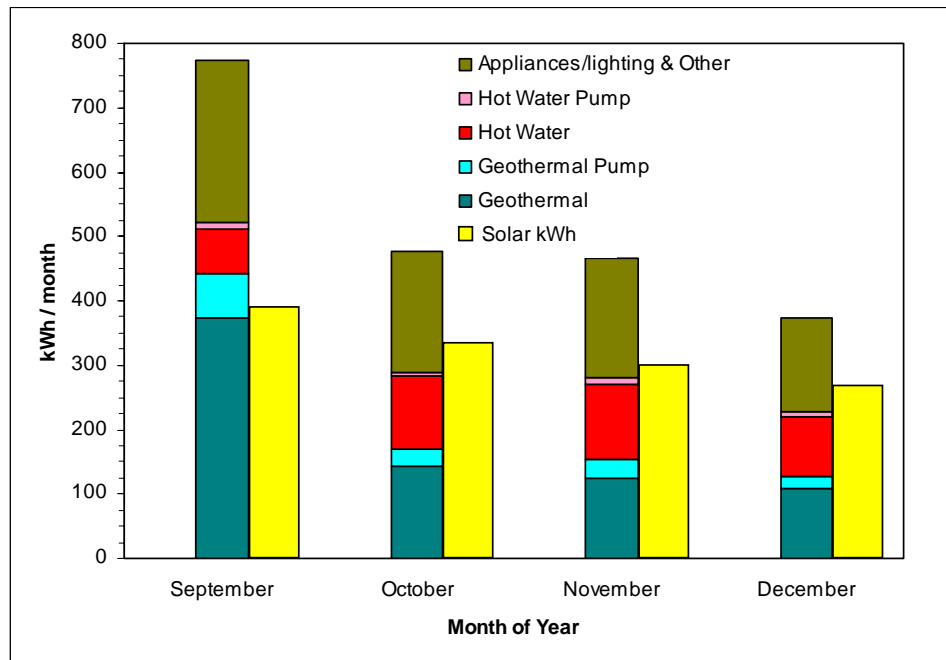


Figure 10. Monthly site electricity consumption by end use.

Table 5. Four Monthly Site Energy Summary 2008
kWh

	Sept.	Oct.	Nov.	Dec.	Average kWh/day
Total House Electrical Demand	773	477	465	374	17.2
Total Geothermal (Geothermal + Geo Pump + HW Pump) kWh	453	175	163	134	7.6
Geothermal kWh	375	144	124	107	6.1
Geothermal Pump kWh	68	25	30	20	1.2
Hot Water kWh	68	115	117	93	3.2
Hot Water Pump kWh	11	6	9	6	0.3
Lighting, Appliances, & Other	251	187	185	147	6.4
PV_{ac} Power Produced	399	333	301	267	10.7

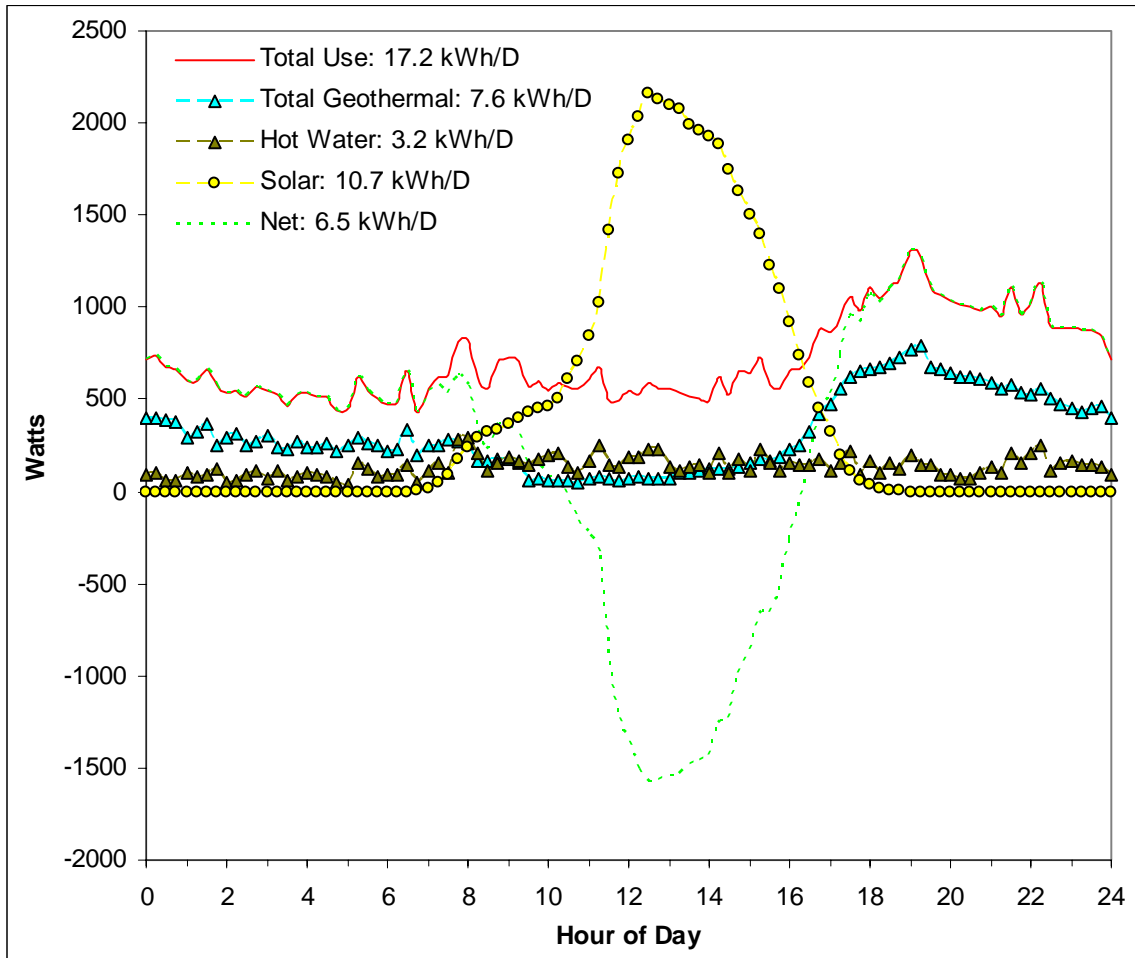


Figure 11. Stalwart NZEH average 24-hour electrical demand, September – December 2008.



Figure 12. Close up of the 3.6 kW PV system.



Figure 13. The inverter is mounted on an exterior wall inside the home's front porch.

Monthly Energy Summary by End-Use

As expected, space conditioning is the largest end use. In a NZEH for this climate, the house design and equipment must be seen as extraordinarily successful at reducing space cooling and heating needs. Air conditioning averaged 453 kWh/month in September while a typical home in North Florida uses 800 – 1000 kWh/month during summer months (FPL, 2008). The NZEH value is not extraordinarily low considering 1) the NZEH is smaller than average, 2) the NZEH has lower occupancy than average, and 3) the geothermal system is rated at a relatively high efficiency (18.3 EER). Data collected onsite during the monitoring period provides a rough estimate of actual efficiency at 7.4 EER (Figure 14). While the certified performance rating considers return fluid temperature of 77 F, data from the NZEH shows return fluid temperatures above 90 F. Under these conditions the manufacturer's performance data would estimate the EER closer to 12 Btu/Wh. Also, monitored data for the purposes of estimating operating EER includes the energy use of the geothermal loop pump and the desuperheater loop pump, while the performance rating does not.

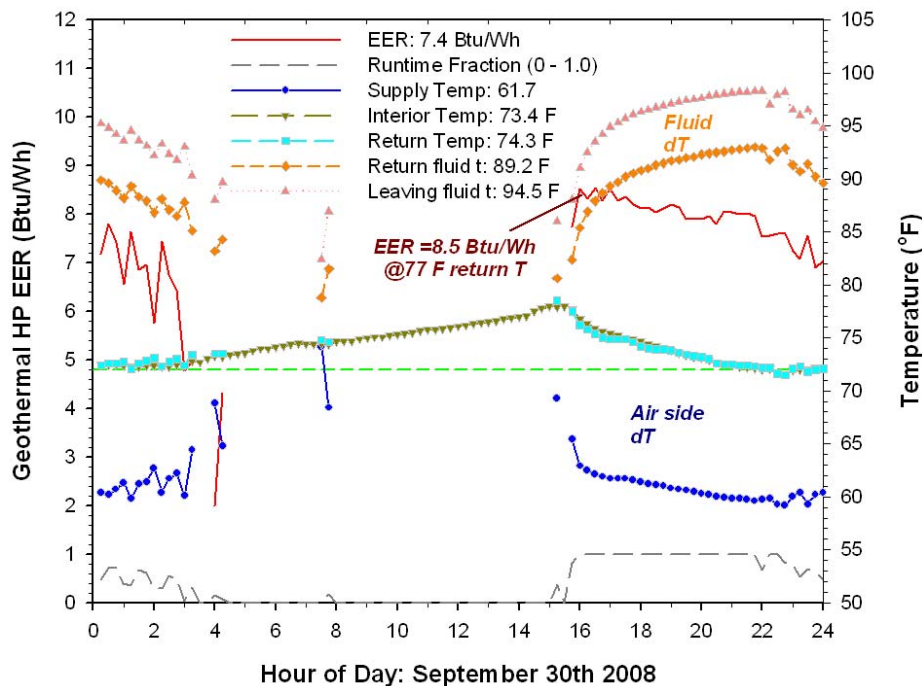


Figure 14. NZEH Geothermal Heat Pump Performance: September 30th 2008 (Tested air flow = 660 cfm).

Although the operating efficiency of the system is much lower than the performance rating, the system produced very comfortable interior conditions during September as shown in Figure 15.

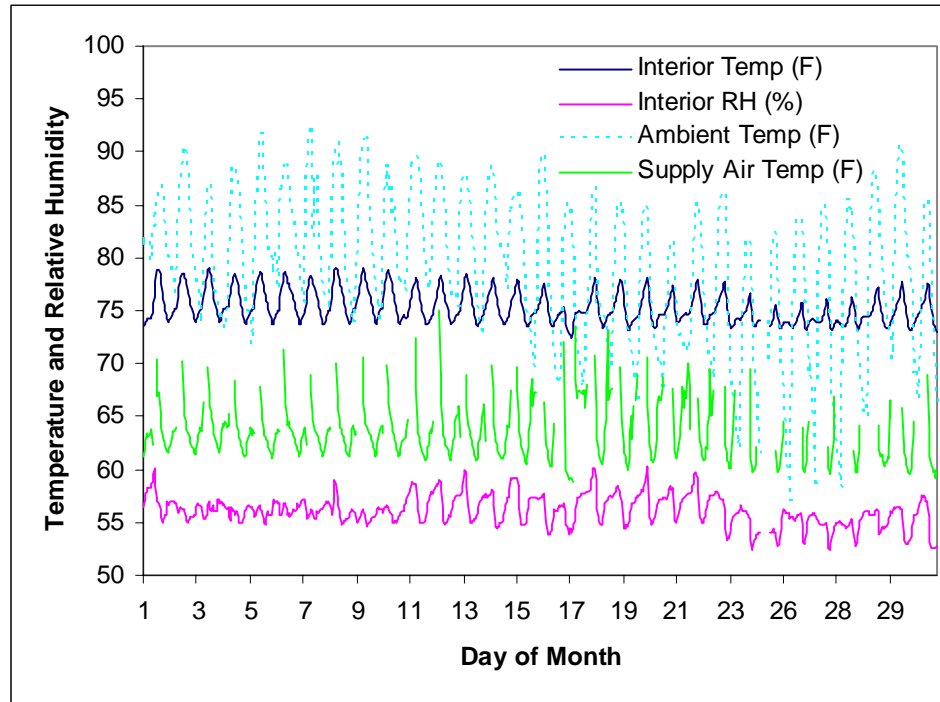


Figure 15. NZEH September home interior comfort conditions (temperature and relative humidity).

Domestic water heating is accomplished by a 0.91EF 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 (depicted in Figures 16 and 17) 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. In Figure 18, one can determine if the geothermal system is in cooling or heating mode through the plotted supply air temperature. During the month of September and the first half of October a gradual increase in hot water tank energy use can be seen corresponding with decreasing hot water pump energy and less run time of the geothermal system. The rest of the monitoring period was heating dominated with little desuperheater operation, although a few minor cooling events can be seen in conjunction with small spikes in hot water pump energy and decreased hot water tank energy use. The relatively large spike in hot water pump energy occurring in the middle of November is unexplained, occurring with geothermal system consuming energy, but delivering no air flow. The gradual decrease in hot water energy during the end of December is also unexplained. Researchers would like to consult with the homeowner to determine occupancy and existence of system malfunctions during these times. Accurate quantification of the heat supplied by the desuperheater coil is difficult for the data appears to show water from the water main surging through the loop during tank refilling. Also, data is not available on hot water draws from the tank. Researchers are considering adding that measurement in the future. This capability may enable researchers to determine if the hybrid system has a net positive effect over the course of a year, or if the effect seen during cooling operation is negated by negative impacts observed in other studies others during heating operation (Bouchelle, 2000).



Figure 16. The desuperheater and hot water tank are adjacent to each other and below the geothermal unit.

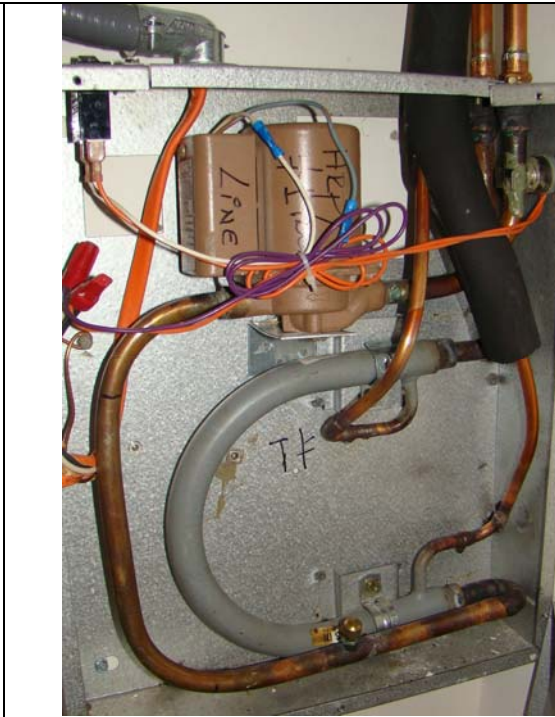


Figure 17. Close up of the desuperheater pump and coil.

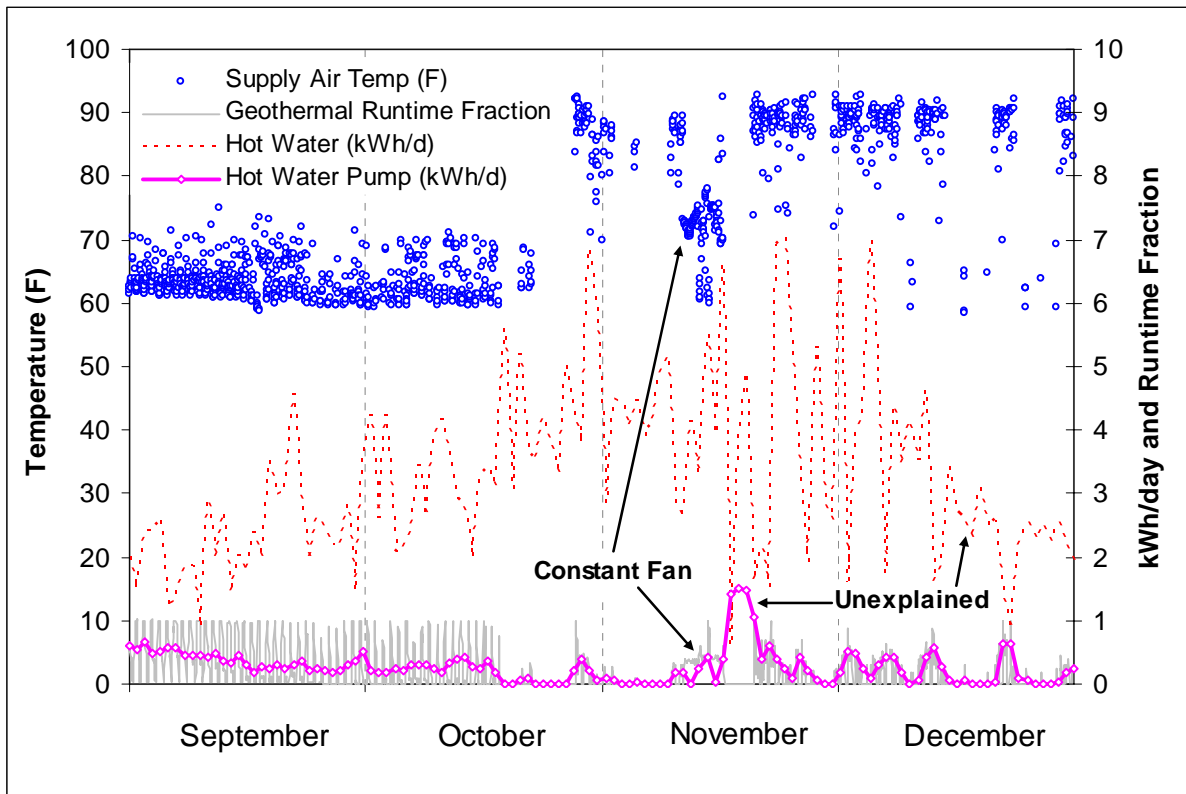


Figure 15. NZEH water heating energy and desuperheater / geothermal operation.

Solar Electric Power Production

The 3.6 kW system consists of 18 *GEPVp-200-MS* modules 200 Watt modules with a 3.3 kW *GEPVb 3300* inverter. A PV performance calculator, *PVWatts*, is available on NREL's Renewable Resource Data Center website (<http://rredc.nrel.gov>). The *PVWatts* simulation of the 3.6 kW_p DC PV south-facing system using TMY2 weather data from Tallahassee, FL predicts the system will deliver 4732 kWh of AC electricity per year with no shading. The *PVWatts* default derate factor of 0.77 was used for this prediction. Similarly, the PV calculator (*PVFORM*) in the *EGUSA* software using the Tallahassee FL TMY2 weather data indicated 4852 kWh/year from the PV system. The predicted PV output for the monitored period from the same 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, the PV modules were observed to be partially shaded by a large tree to the home's south (Figure 19), causing a reduction in PV power produced.



Figure 19. The shadows seen in the photo show the PV modules are partially shaded by a large tree.

Conclusions

We have reported on the preliminary performance data on a Near Zero Energy Home (NZEH) built in Callaway, Florida. Featuring a number of very efficient construction methods, appliances and equipment, the 1371 square foot home was anticipated to produce about 46% of its annual electrical energy and required source energy from a 3.6 kW solar electric PV system. Based on four months of monitoring, the home's energy use has been overall very low compared to simulations, mainly as a result of lower occupancy. Total daily electricity use has averaged only 17.2 kWh per day and 6.5 kWh/day when solar energy production is included. This can roughly be compared to about 44 kWh per day for a typical single family home in North Florida for the same four month period. We also compared the home's performance against the Building America Benchmark. The four month usage for the BA Benchmark home indicated a daily source energy use of 168 kWh against the 22 kWh actually measured. This represents a savings of 87% over the BA Benchmark.

Average cooling energy use averaged 7.6 kWh/day, considerably more than simulated. However, performance ratings and simulations of geothermal equipment do not include energy use of pump components. Also, monitored data show that the soil conductivity in the area may not allow for maintenance of ideal ground loop temperatures. Estimation of operating efficiency for the geothermal system using monitored data showed 7.4 EER with an average entering fluid temperature of 89F, while the performance rating of the equipment shows 18.3 EER with an average entering fluid temperature of 77F. However, the occupant reported being very pleased with the even temperature conditions and low energy bills.

Hot water energy use is highly dependent on occupancy, and with only one occupant living in the home during the monitoring period, it was not expected that hot water energy could be correlated with simulations that assume four occupants. Such a correlation is also difficult without measurements of the hot water draws from the tank. However, the data indicate that the desuperheater is somewhat effective at decreasing hot water tank energy use during cooling dominated periods. Additional data collection efforts may be undertaken to quantify the efficacy of this hybrid system.

Although refrigeration, lighting and other minor appliances were not monitored, they were found to average 6.4 kWh/day, making them the second largest collective household end use during the month of September and the largest household end use for the remaining months. The home had very efficient *Energy Star* appliances and fluorescent lighting used throughout (and the owners seemingly committed to maintaining this status) however this area remained the largest energy end use load aside from cooling energy. This serves as another lesson from the project: in very efficient homes, lighting, appliance and miscellaneous loads may comprise the largest use of electricity and likely the most fruitful area for load reduction.

The 3.6 kW solar electric PV system operated close to expectations, considering the observed partial shading of the modules. The system produced an average of 10.7 kWh/day, only slightly less than what is predicted with PV system simulations. However, with the expense of the PV system and installation, optimization of solar access should be achieved in all ZEH projects.

Based on the four months monitoring, we found the PV system to produce about 62% of the electricity used on site and the home could achieve a source energy savings of approximately 87% when compared to the BA Benchmark home when a full year of energy use is approximated from the four months of monitored data. These results exceed simulated PV performance (42%) and simulated Benchmark savings (69%). Monitoring will be continued for another full year to assess long-term performance.

Acknowledgements

The authors would like to thank the many individuals and organizations that supported this project including the homeowner, the builder Stalwart Built Homes with Promised Land Builders, and the manufacturer Nationwide Custom Homes. Calcs-Plus assisted with design of the duct system, performing load calculations, specifying the geothermal system, and commissioning the home. Rodney Dickey conducted on site testing and provided the HERS rating and federal tax credit certification of the home as well as important construction quality assurance. We would also like to thank our sponsors at the U.S. Department of Energy's Building America Program (www.buildingamerica.gov). The research funding was provided by DOE N.E.T.L. through a cooperative agreement DE-FC26-06NT42767.

References

- Bouchelle, M., Parker, D., Anello, M., "Factors Influencing Water Heating Energy Use And Peak Demand In A Large Scale Residential Monitoring Study," Presented at: The Symposium on Improving Building Systems in Hot and Humid Climates, San Antonio, TX, May 15-17, 2000.
- FPL, 2008, "Typical Monthly Total Electric Usage for Single-Family Customer," provided by Craig Muccio, March 2008.
- Hendron, B., et. al. 2004. Building America Performance Analysis Procedures, Revision 1. National Renewable Energy Laboratory, NREL/TP-550-35567.
- NOAA, 2007. Climatology 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.
- Parker, D. et.al., 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.

Appendix A

Evaluation of Project Stage-gate Criteria

Within the Building America process, projects use the Stagegate process to evaluate overall project success, potential for continuation, and refinements to research and development. Within the process are “must meet” and “should meet” criteria. Each of these is examined relative to the Near Zero Energy Home in Callaway, FL. The Stage 2 criteria for prototype homes are examined below.

Must Meet Criteria

Source Energy Savings

We used the *EGUSA Version 2.8* software to evaluate the source energy savings of the NZEH design. As detailed in Appendix B, the software predicted a 69% site and source energy savings versus the BA Benchmark for the installed measures. We assumed that the actual twelve month energy savings would be three times that seen in the September - December monitoring period. This assumption will be refined later as more data is collected in 2009.

Table A1. Annual Site and Source Energy Use and Savings

Characteristic	Site Electricity kWh	Source Electricity kWh
Benchmark Total Energy Use	18251	61415
NZEH Prototype (simulation)*	5637	18969
NZEH (actual monitored)**	2367	7965
NZEH Savings: Simulated	69.1%	69.1%
NZEH Savings: Actual	87.0%	87.0%

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

In reality, the as built and as operated home did even better than predicted by the software. Our evaluation showed that the actual site and source energy savings were 87% – exceeding the predicted expectations. While measured HVAC electrical energy was somewhat higher than that simulated (measured = 7.6 kWh/day vs. 4.7 kWh simulated), non-HVAC, non DHW measured electricity use was much lower than simulated: (measured = 6.4 kWh/day vs. 16.4 kWh/day simulated). This is likely due to lower occupancy than that assumed in the simulation and the careful and frugal energy use of the home owner.

Prescriptive Based Code Approval

The Stalwart NZEH met all prescriptive and performance safety, health and other building code requirements for new homes built within the State of Florida. Modules were manufactured in Arabi, GA, and therefore were determined to comply with many building code related requirements prior to crossing state lines. Local building inspectors were responsible for code compliance of work performed on site. At first, the local building inspector did not agree with the combination of a nearly impermeable peel and stick roofing underlayment with spray foam insulation on the underside of the deck, even though that is what the Florida Building Code calls for when using a shingle roof covering. The Stalwart homes in question utilize a metal roof covering for which code allows use of a permeable or non-permeable underlayment. Once the inspector was shown that the peel and stick underlayment had a very small, non-zero permeability, he accepted the strategy. Another issue that needed attention was the code inspector's

requirement for poor crawlspace venting. His perception was that it was important to keep small animals out of the crawlspace, especially considering the builder used foam for insulation. The issue was eventually resolved through the allowance for a well vented lattice material and insect screening (Figures A1 and A2).



Quality Control Requirements

As a company, Stalwart Built Homes was begun as a conduit to provide a high performance, affordably built house to consumers. The company aims not to build, but to supply the engineering, designs, tools, and techniques to the industry such that the industry can produce the product at a reasonable cost, and with a reduced learning curve. The principal of the company has years of experience as a builder, and the experience told him that one of the largest barriers to achieving the quality control necessary for high performance was lack of knowledge, training, and capability of trades and subcontractors. Working with modular built products was determined to be one of the keys to success early on. If many of the crucial details required for building science could be accomplished in the factory where it is easier to manage quality control, it could alleviate the need for as much quality control on the site, which has always proven to be difficult and unreliable. Although Stalwart Built Homes engages in training of trades and subcontractors, experience shows that a rapid turnover rate on the crews and a lack of accountability on the part of the workers can often still result in poor quality workmanship. It was also determined that the relative cost of training, quality control, and quality assurance in order to achieve objectives in a site built scenario would result in a much higher priced product than if the majority of quality control and quality assurance could be accomplished in a factory, with tighter controls and highly skilled, long term employees. Together with BAIHP, Stalwart Built Homes developed a set of high performance home specifications and partnered with modular manufacturers to produce the homes. The focus was to accomplish as much of the air, thermal, and moisture barrier/flashing details in the factory.

Although this strategy was mostly effective, a number of elements were still required to be installed or enhanced onsite. Stalwart has specifications for building air leakage, and determined that expanding foam insulation would be a cost effective way to achieve the spec. The modular plants were not set up at the time to accommodate foam in the factory, so it was decided that the walls would be insulated with fiberglass batts and careful air sealing details, and the attic, crawlspace, and floor joist perimeter would need to be insulated onsite. Stalwart has worked closely with a foam insulation installer to achieve the air tightness objectives, but still experienced difficulties with the quality of the fiberglass batt installation and

air sealing of the walls. As a result, certain modular manufacturers have acquired capability to install foam insulation in the plant and will be supplying modules with foamed walls. House wrap is also installed in the factories, serving as both part of the air barrier and as a drainage plane behind the siding. As a result of damage to the wrap during module transport, and as a result of marriage line junctions, Stalwart required a second layer of wrap installed onsite, after modules were brought together, to ensure a continuous drainage plane. This staged approach to installation of air/thermal/moisture barrier did complicate inspection for quality control, for inspections were required both in the factory and onsite. Stalwart Built Homes is currently investigating methods to streamline both installation and inspection. Stalwart Built Homes also partnered with BAIHP and subcontractor Calcs-Plus on HVAC design and specification. Stalwart had determined that neither the modular factories nor the trades and subcontractors had the knowledge required to integrating the performance of the building envelope with the capacity and design of the mechanical system.

Even with much of the critical details accomplished in the factory, and much of the design for onsite components and equipment completed by skilled practitioners, onsite supervision and quality control still proved to be important in order to have components installed as designed. Stalwart built homes worked to improve communication between the subcontractors/trades and the designers to resolve field installation issues together. Final inspections of critical details, along with ratings and performance testing of air flows were also determined to be critical to the overall quality assurance plan.

Should Meet Criteria

Neutral Cost Target

As seen in Table A2, incremental costs of improvements over regional standard practice are presented, along with the amortized annual cost. Incremental and amortized cost of rebates and incentives are also presented. As seen in the table, the total amortized incremental cost to the buyer, not including PV, after rebates and incentives, is \$582.15 per year. Total cost including PV is \$1413.74 per year.

Table A3 presents the simulated source energy savings of the Stalwart NZEH compared to both the BA Benchmark and regional standard practice. Also, using the local utility rate of \$0.13 per kWh, the annual utility bill reduction of the Prototype with respect to the BA Benchmark is show in total, and by end use. Table A4 presents the simulated site energy savings of the Stalwart NZEH compared to both the BA Benchmark and regional standard practice. Again using the local utility rate of \$0.13 per kWh, the annual utility bill reduction of the Prototype with respect to the regional standard practice is shown by end use and in total. When total amortized incremental cost of the Prototype over the regional standard practice, including rebates and incentives, is subtracted from the utility bill reduction the result shows a net positive cash flow of \$38.72 per year when the PV system is excluded from the analysis. When the PV system is included, the result shows a negative cash flow of \$160.58 per year.

Table A2. Incremental and Amortized Cost of Improvements

Measure	Regional Standard Practice	Stalwart NZEH	Incremental Cost	Amortized Annual Cost
<i>Building Enclosure</i>				
Roofing	shingle	5V galvalume	\$ 2,170.00	\$ 173.17
Windows	double pane clear	Energy Star Low-E	\$ 93.92	\$ 7.49
Insulation	fiberglass batts	open cell foam in roof and floor	\$ 1,980.00	\$ 158.00
Air Sealing	standard	open cell foam in floor joist perimeter	\$ 900.00	\$ 71.82
<i>HVAC System</i>				
Heating/Cooling system	air source heat pump - SEER 13 / HSPF 7.7 standard thermostat	geothermal heat pump - EER 18.3 / COP 3.7 Vision Pro thermostat desuperheater	\$ 3,000.00	\$ 239.40
Supplemental Dehumidification	none	stand alone 45 pint/day	\$ 250.00	\$ 19.95
Air Filter	standard	MERV 10	\$ 160.00	\$ 12.77
Fresh Air Ventilation	none	runtime vent system	\$ 150.00	\$ 11.97
Bathroom Exhaust Fans	standard	Energy Star	\$ 300.00	\$ 23.94
<i>Appliances</i>	standard	Energy Star	\$ 281.14	\$ 22.43
<i>Lighting</i>	incandescent	compact fluorescent	\$ 110.00	\$ 8.78
Total Energy Efficiency Investment			\$ 9,395.06	\$ 749.73
<i>Photovoltaic System</i>				
PV system and installation	none	3.6 kW	\$ 29,180.00	\$ 2,328.56
PVC chase for solar PV installation	none	installed	\$ 75.00	\$ 5.99
Total with PV			\$ 38,650.06	\$ 3,084.27
<i>Ratings, Rebates and Incentives</i>				
HERS rating and Tax Credit certification	none	received	\$ 500.00	\$ 39.90
Federal New Home Tax Credit	none	received	\$ (2,000.00)	\$ (159.60)
State of Florida PV rebate	none	received	\$ (14,400.00)	\$ (1,149.12)
Federal PV Tax Credit	none	applying	\$ (4,434.00)	\$ (353.83)
Gulf Power Geothermal Rebate	none	received	\$ (600.00)	\$ (47.88)
Total Incremental Cost to Buyer w/o PV			\$ 7,295.06	\$ 582.15
Total Incremental Cost to Buyer w/ PV			\$ 17,716.06	\$ 1,413.74

Table A3. Neutral Cost Analysis for the Stalwart NZEH Using Source Energy Savings

Description	Annual Source Energy			Estimated Source Energy Savings				Annual Utility Bill Reduction
	BA Bench	Regional Standard Practice	Prototype House	Percent of End Use		Percent of Total		Prototype WRT Benchmark
	Mbtu/y	Mbtu/y	Mbtu/y	vs. BA Bench	vs. Standard	vs. BA Bench	vs. Standard	
Space Heating	35.3	24.8	5.4	85%	78%	14%	11%	\$1,138.89
Space Cooling	57.0	35.6	14.1	75%	60%	21%	12%	\$1,634.06
DHW	33.3	30.9	26.4	21%	15%	3%	3%	\$262.82
Lighting	20.9	20.9	10.5	50%	50%	5%	6%	\$396.14
Appl. & MEL	58.3	58.3	58.3	0%	0%	0%	0%	\$0.00
Ceiling Fan	4.1	4.1	4.1	0%	0%	0%	0%	\$0.72
OA Vent Fan	0.3	0.3	1.2	-300%	-300%	0%	0%	-\$34.28
Total Usage	209.2	174.9	120.0	43%	31%	43%	31%	\$3,398.35
Site Generation	0	0	-55.7			27%	32%	\$2,121.61
Net Energy Use	209.2	174.9	64.3	69%	63%	69%	63%	\$5,519.96

Table A4. Neutral Cost Analysis for the Stalwart NZEH Using Site Energy Savings

Description	Annual Site Energy			Estimated Site Energy Savings				Annual Utility Bill Reduction
	BA Bench	Regional Standard Practice	Prototype House	Percent of End Use		Percent of Total		Prototype WRT Standard
	Mbtu/y	Mbtu/y	Mbtu/y	vs. BA Bench	vs. Standard	vs. BA Bench	vs. Standard	
Space Heating	10.5	7.3	1.6	85%	78%	14%	11%	\$217.11
Space Cooling	16.9	10.6	4.2	75%	60%	20%	12%	\$243.78
DHW	9.9	9.2	7.8	21%	15%	3%	3%	\$53.33
Lighting	6.2	6.2	3.1	50%	50%	5%	6%	\$118.08
Appl. & MEL	17.3	17.3	17.3	0%	0%	0%	0%	\$0.00
Ceiling Fan	1.3	1.3	1.3	0%	0%	0%	0%	\$0.00
OA Vent Fan	0.1	0.1	0.4	-300%	-300%	0%	0%	-\$11.43
Total Usage	62.2	52.0	35.7	43%	31%	43%	31%	\$620.87
Site Generation	0	0	-16.6			27%	32%	\$632.29
Net Energy Use	62.2	52.0	19.1	69%	63%	69%	63%	\$1,253.16
Added Annual Mortgage Cost w/o Site Generation								\$749.73
Annual Mortgage Reduction from Incentives and Rebates w/o Site Generation								-\$167.58
Net Annual Cash Flow to Consumer w/o Site Generation								\$38.72
Added Annual Mortgage Cost w/ Site Generation								\$3,084.27
Annual Mortgage Reduction from Incentives and Rebates w/ Site Generation								-\$1,670.53
Net Annual Cash Flow to Consumer w/ Site Generation								-\$160.58

Quality Control Integration

All of the quality control issues mentioned in the *Quality Control Requirements* section above that were known to likely be a quality control issues were included construction documents and scopes of work that the modular factories and site-based subcontractors worked from. Also, such issues were discussed in builder/subcontractor training activities. HVAC system design and commissioning activities were listed in the BAIHP scope of work for the project. As failures were identified based off of ignoring or misunderstanding construction documents/scopes of work, corrections and additional training was

provided where necessary. For a time, Stalwart Built Homes held stake in the development that the Stalwart NZEH is located in, and therefore had some leverage in ensuring corrections were made and specifications were ultimately achieved. The process of designing, constructing, and commissioning the NZEH prototype has influenced future Stalwart Built Homes in this development and elsewhere in the southeastern US.

Gaps Analysis /Lessons Learned

- In certain situations, the modular construction process can be leveraged to achieve tighter quality control in a high performance home. Stalwart Built Homes experimented with allowing builders to construct the designs entirely onsite, since some builders insisted that they could achieve the same performance for a reduced cost. In the end, due to marginal site supervision and untrained trades, performance suffered and cost to correct the performance was greater than modular construction methods.
- Even the modular construction/pre-design process requires that site installed components be carefully inspected and commissioned in order to achieve desired performance.
- Coordinating inspection and commissioning of a hybrid factory/site built home is complicated, and can possibly be streamlined with more education and certification of factory employees.
- A detailed plan for communication between the onsite workforce and the builders, specifiers, and designers needs to be implemented to resolve unexpected issues that arise in the field as a team.
- The perception on the part of buyers that a factory built home will provide less quality and less performance can be overcome with proper buyer education.
- Building inspectors unfamiliar with high performance construction techniques can initially prove to be a barrier to implementation, but can be educated.
- In order to keep the selling price of the home at a level affordable for most buyers, Stalwart Built Homes worked closely with factories and trades to keep construction costs down, the developer to acquire land that would keep development / land costs down, and with state and county housing agencies to acquire lending incentives and assistance. In addition, rebates and incentives available from utility, state, and federal agencies on equipment and performance add to the project's cost effectiveness. One principal issue however is how quickly the buyer can receive all of these incentives.
- Actual operating efficiencies of geothermal HVAC systems are highly dependent on ancillary components such as pumps as well as ground loop temperatures and soil conductivity. An estimate of the Stalwart NZEH Geothermal system operating efficiency showed 7.4 EER compared to a performance rating of 18.3 EER.
- Although the desuperheater heat recovery unit did appear to reduce the hot water energy use somewhat, equipment manufacturers claim substantially better performance than what was observed during the monitoring period.