Toward Simple Affordable Zero Energy Houses

By

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Abstract

In a Mixed Humid Climate is it possible to build an affordable house for a family of four that has an average monthly energy bill of zero? No loss of basic amenities; thermal comfort, moisture/mold/ mildew control, hot water, light, refrigerator, washer, drier, dishwasher, entertainment center. This paper describes the first attempt at a Zero Energy Habitat for Humanities House constructed in 2002. This house was also the first to sell solar energy back to the largest public utility in the United States. A Habitat Family of four took occupancy November 2002. Forty sensors were installed to monitor the energy saving technologies and roof top photovoltaic solar electric generation system that together, form a first attempt at an affordable net zero energy house. The house is 6 times more air tight than similar houses with 2 X 4 wood frame construction that meet the local electric utility rating minimum criteria of 20% better than the Model Energy Code 1993. Other unique features are; supply mechanical ventilation, structural insulated panel walls, roof and floor, reflective metal seam roof, high efficiency windows with low U-Factor and Solar Heat Gain Coefficient, space integrated heat pump water heater, unvented crawl space, heat recovery shower, energy star appliances, compact florescent lighting and 2 kW_p grid-connect solar photovoltaic system. After the first full year of detailed measured performance this all-electric house total average daily energy cost after solar credits was $0.82. Many of the energy saving, features are very cost effective for all houses. The long-term goal of this research project is to build 5 even more energy efficient Habitat test houses in East Tennessee and then make similar house available to other Habitat Affiliates and the broader housing market. It is hoped these proof-of-concept houses will contribute to a regional transformation of housing demand in a region of the country that is in an EPA designated noncompliance air shed and is looking hard for solutions to excessive ozone, smog and particulate concentrations. The vision is toward affordable net zero energy houses.

Introduction

Simple affordable zero energy houses, could they capture the housing market imagination and become a viable option? The concept of producing on site as much renewable energy as used is most intriguing. Just as intriguing as harvesting affordable electric power from the sun in Tennessee. The local electric utilities sell some of the lowest cost electricity in the U.S. The residential rate in the summer of 2003 at this site was $0.063/kWh compared to the national average of $0.08/kWh. The average solar insolation is almost one half that available in parts of Southwestern U.S. With relatively low energy costs and solar insolation how can the transformation of the housing industry from just meeting minimum energy efficiency standards to near net zero energy housing be spawned? In September, 2003 EPA released smog alert data. Tennessee was the third worst state in the nation, next to California and Texas. In the month of June 2003 ozone alerts were announced 25 out of 30 days in the Smoky Mountains the most heavily visited National Park in the United States with more than 8.5 million visitors. The major cause next to transportation emissions, utility coal fired power plants feeding about 1/3 of their generated electricity to buildings. A healthy economy in East Tennessee is dependent on tourism, availability of healthy-reasonably low-cost labor, industry leaders desiring to site new and expanded facilities, and growing number of retirement communities. The process described in this paper is a roadmap for communities to transform their building industry from part of the problem to part of a solution by leading buildings from energy consumers to net energy producers. In the case of Tennessee, air quality concerns have taken center stage. Pollution abatement equipment on coal-fired power plants is a major reason TVA, in 2003, increased residential and small commercial electricity rates by 7.5%. If the air shed cannot safely disperse even low emitting new pollutant point sources, fewer new businesses will be able to site in East Tennessee. The strongest response to electric utility incentives to conserve energy and pay for renewable power has been the territory surrounding the Smokey Mountain National Park. Customers in this region appear to be willing to pay more for electric power generated from renewables because they have made the connection that the path toward a cleaner, healthier environment and economy is by exercising reasonably affordable available options to take personal responsibility toward becoming better Environmental Stewarts..

On June 17, 2002 the Chairman of the largest electric utility in the U. S. announced they would launch an initiative to help develop net zero energy test houses in an area of the country that has not been aggressively encouraging building energy efficiency nor offering some of the attractive subsidies for onsite solar energy production. Details of this announcement are available at; <http://www.tva.com/news/releases/0602netzero.htm>

The United States Department of Energy long term goal is to create technologies and design approaches that enable net-zero energy residences at low incremental cost by 2020. The current initiative is to lead potential new home owners and builders toward houses that will enable the integration of on site power. Specifically, energy savings goals of about 70% from the International Energy Conservation Code and satisfying the remaining energy demand with about 2 kWp, of peak rated output, of solar collectors. The effort must be all inclusive not stopping with space heating, cooling, domestic hot water, lighting, and major appliances like the refrigerator, washer, drier, and dishwasher, but also plug loads and building owner operation.

Descriptions of the test houses

This paper focuses on the first of a series of six near zero energy test houses. This first house is referred to through out this paper as ZEH1. A true net zero energy house is to be built by the end of 2005. Some comparisons will be given to other houses built in this series. They are referred to as ZEH2, ZEH3 and ZEH4. Table 1 shows the features of each of these test houses.

Table 1 ZEH and base house feature comparisons

House designation	ZEH 1	Base Frame houses	ZEH 2	ZEH 3	ZEH 4
Stories	1	1	1	1	2
Gross floor area ft2	1056	1056-1153	1060	1082	1200
Foundation	Unvented crawl	Vented crawl	Mechanically vented crawl	Unvented crawl with	Walk out basement with

			with insulated walls 2 in polyisocyanurate boards (R-12)	insulated walls 2 in polyisocyanurate boards (R-12)	insulated precast (nominal steady state R-value of (R-16)
1st Floor	6.5 in. SIPS 1#EPS (R-20) Structural splines	R-19 fiberglass batts (R-17.9)	R-19 fiber glass batts, ¾ in XPS boards installed on bottom side of 9 ½ in. I-joist (R-24)	R-19 fiber glass batts, ¾ in XPS boards installed on bottom side of 9 ½ in. I-joist (R-24)	Concrete Slab
Walls	4.5 in. SIPS 1#EPS (R-15) surface splines, house wrap, vinyl	2 X 4 frame with R-11 fiberglass batts, OSB sheathing, (R-10.6)	4.5 in. SIPS 2#EPS (R-15.5) structural splines, house wrap, vinyl	6.5 in SIPS 1#EPS (R-21), structural splines, house wrap, vinyl	2nd floor 4.5 in. SIPS polyiso., pentane blown (R-27), surface splines
Windows	9 windows 0.34 U-factor, 0.33 SHSC, sill seal pans	6-7 windows, U factor 0.538	8 windows 0.34 U-factor, 0.33 SHGC, sill seal pans	8 windows 0.34 U-factor, 0.33 SHGC, sill seal pans	10 windows, 0.34 U-factor, 0.33 SHGC, sill seal pans
Doors	2-doors, solid insulated, & half view	2-doors, one solid insulated, one half view	2-doors, one solid insulated, one half view	2-doors, one solid insulated, one half view	2-doors, one solid insulated, one full view
Roof	SIPS 1#EPS (R-28) surface splines	Attic floor blown fiberglass (R-28.4)	6.5 in. SIPS 2#EPS (R-23) structural splines	10 in SIPS 1#EPS (R-35), surface splines	8 in SIPS, polyiso., pentane blown (R-27), surface splines (R-48)
Roofing	Hidden raised metal seam	Gray asphalt shingles	15 in. Green standing 24GA steel seam, 0.17 reflectivity	15 in. Green standing 24GA steel seam, 0.23 reflectivity	Light gray Metal simulated tile, .032 aluminum
Solar system	48-43W amorphous silicon PV modules, 2.06 kWp	none	12-165W multi-crystal silicon PV modules-12.68% eff, 1.98 kWp	12-165W multi-crystal silicon PV modules-12.68% eff, 1.98 kWp	20-110W polycrystalline 2.2 kWp
Heating and	1-1/2 ton air-to-air	Unitary 2 ton HP, SEER 12	Two speed compressor 2	2 ton Direct exchange	2 ton air-to-air HP, SEER 14,

Cooling	HP, SEER 13.7, 2 speed ECM indoor fan		ton air-to-air HP, SEER-14, HSPF-7.8, CFM cooling 700, variable speed ECM indoor fan	geothermal, R-417a, variable speed ECM indoor fan	variable speed compressor, ECM indoor and outdoor fan
Mechanical Ventilation	Supply to return side of coil	none	Supply to return side of coil, CO2 sensor, bath fan exhaust	Supply to return side of coil, bath fan exhaust	Supply to return side of coil, bath fan exhaust
Duct location	Inside conditioned space	Crawl space	Inside conditioned space	Inside conditioned space	Inside conditioned space
Water Heater	Integrated HPWH linked to unvented crawl	electric	Integrated HPWH, linked to crawl which has motorized damper	Desuperheat for hot water, EF .94	HPWH vented to ½ bath which is exhausted for ventilation

The features in the first attempt at a zero energy houses are; Air-tight floor, wall and ceiling SIPS, compact thermal distribution system with all ducts positioned inside the conditioned space, mechanical supply ventilation with sensors and controls monitoring and controlling ventilation to meet ASHRAE 62-2003, 14 SEER - 1.5 ton air source heat pump with ECM two speed indoor circulating fan, integrated heat pump water heater with the refrigerator/AC/dehumidification, compact florescent light bulbs, Energy Star Appliances, high efficient windows with 0.34 U-Factor and 0.33 Solar Heat Gain Coefficient, reflective hidden metal seam roof, grid-connected 2 kWp solar photovoltaic, heat recovery shower, insulated water pipes in the crawl space, and extended roof overhangs. A picture of the first attempt at a near zero Habitat for Humanity House is shown during the SIP roof installation in Figure 1. This was the first house to sell solar energy to the electric grid in Tennessee beginning in May 2003. A picture of the house after construction is shown in Figure 2.

Figure 1 First attempt at a Habitat ZEB June 2002

Figure 2 ZEH1 showing the 48 roof mounted solar modules and south facade

Foundation

The 3 bedroom 1056 ft^2 house sits on an unvented crawl space with a black 6 mil polyethylene ground cover with taped seams and mechanically fastened one foot up the walls and pilasters. The poly is both caulked to the uninsulated concrete block crawl space walls and pilasters with 1 X 4 pressure treated furring strips mechanically fastened using masonry nails. Four crawl space vents were installed near each corner and sealed using 2 inch thick extruded polystyrene XPS. Currently vents are required by most code bodies. The performance of the crawl space in this house would support the argument that they are not needed if the crawl space is properly designed and operated. The floor of the house is 6 inch thick SIPS with two nominal 2 X 6 boards embedded as structural splines on 4 foot centers in the floor. Structural splines cut all the way through the insulating core as shown in Figure 3.

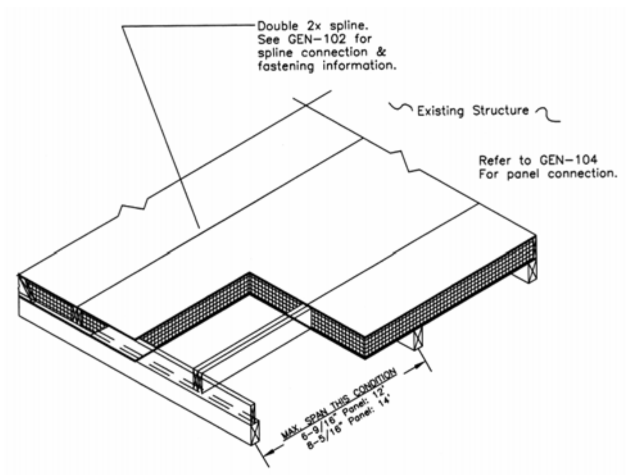

Figure 3 Shows the SIP floor construction

The floor SIPS have 22 mil white aluminum sheets laminated to the bottom surface facing the crawl space as shown in Figure 4.

Figure 4 ZEH Crawl Space with 22 mil white sheet aluminum laminated to the bottom of the SIP floor

This metal laminate provided multiple services. The first, a nonabsorbent surface for those times the bottom of the first floor temperature falls below the crawl space air dew point, generating condensation which would otherwise wet the SIP possibly leading to mold, mildew, odors and eventual OSB decay. Prior to the installation of the ground cover in December 2002 condensation did form on the underside of the floor SIP more heavily near the crawl space wall corners. Once the ground cover was installed no condensation formed. The second service this metal laminate provide was a capillarity break for any moisture that might migrate up from wet soils under the footer and adjacent to the crawlspace walls. A footer drain was installed around the entire structure and run to daylight on the southwest corner of the house. The third service this metal laminate provided was a mechanical termite barrier. However, chemical termite treatment was applied to the soil surrounding the foundation. A fourth service is that the white surface reflects light from the open access hatch and limited light fixtures installed, helping to illuminate the space which because of its 5 and ½ ft height creates useful storage space.

Figure 5 shows average daily temperatures measured in the crawl space for a full year. The space remains above 50 F throughout the entire winter. The coldest ambient temperature experienced in 2003 was zero. Figure 5 also shows the average daily inside air temperature. The crawl space air is in general warmer in the winter and cooler in the summer than the ambient air temperature. This earth coupled space not only leads to minimal winter time floor heat loss but also eliminates the risk of pipes freezing and provides an attractive winter time heat source for the heat pump water heater supply air.

The only wood that had not been treated with preservatives exposed to the crawlspace is the central floor beam running the length of the house. Figure 5 shows the measured crawlspace air relative humidity. In July 03, which experienced above average rainfall, the RH for several days in a row was near 80%. The highest wet bulb temperature observed in July was around 71 F. In Figure 5 the average daily interior temperature is also shown and in July the average inside air temperature was 76 F. This suggests that even if the bottom of the floor reached average inside air temperature it would still be well above the average wet bulb temperature experienced in this crawl space during the worst part of the year. Vented crawlspaces during this time are frequently saturated and experience lengthy periods of 100% RH. Figure 6 shows the hourly average humidity ratio for a warm moist day in July of the crawl space air and the outside air. The humidity ratio in the crawls space remains slightly less than the outside air. No conditioned air is needed in this crawlspace because of the unlikely hood of unwanted condensation and high moisture conditions for generating mold and mildew.

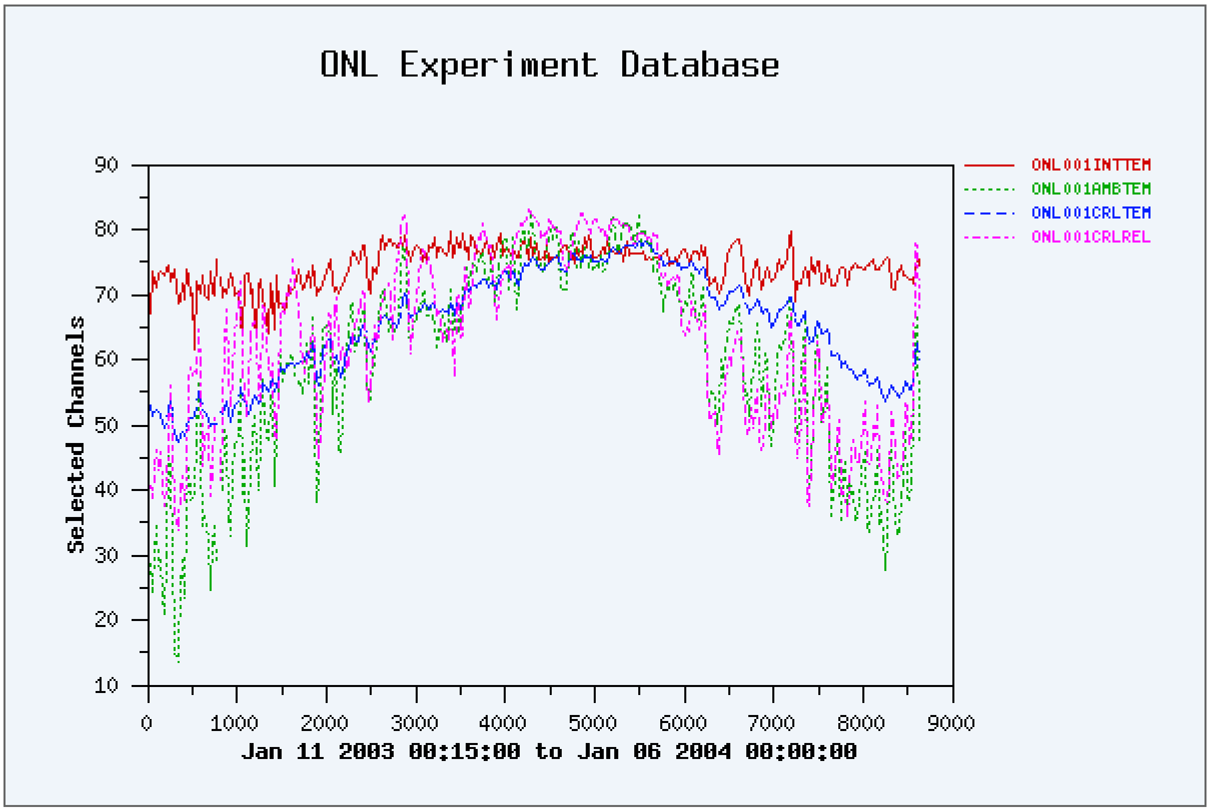

Figure 5 One year's worth of daily average crawl space temperature and relative humidity and inside air temperature measurements, Y axis equals ^{o}F for interior (INTTEM), ambient (AMBTEM), crawl space air (CRLTEM). Y axis equals %RH for crawl space relative humidity (CRLREL)

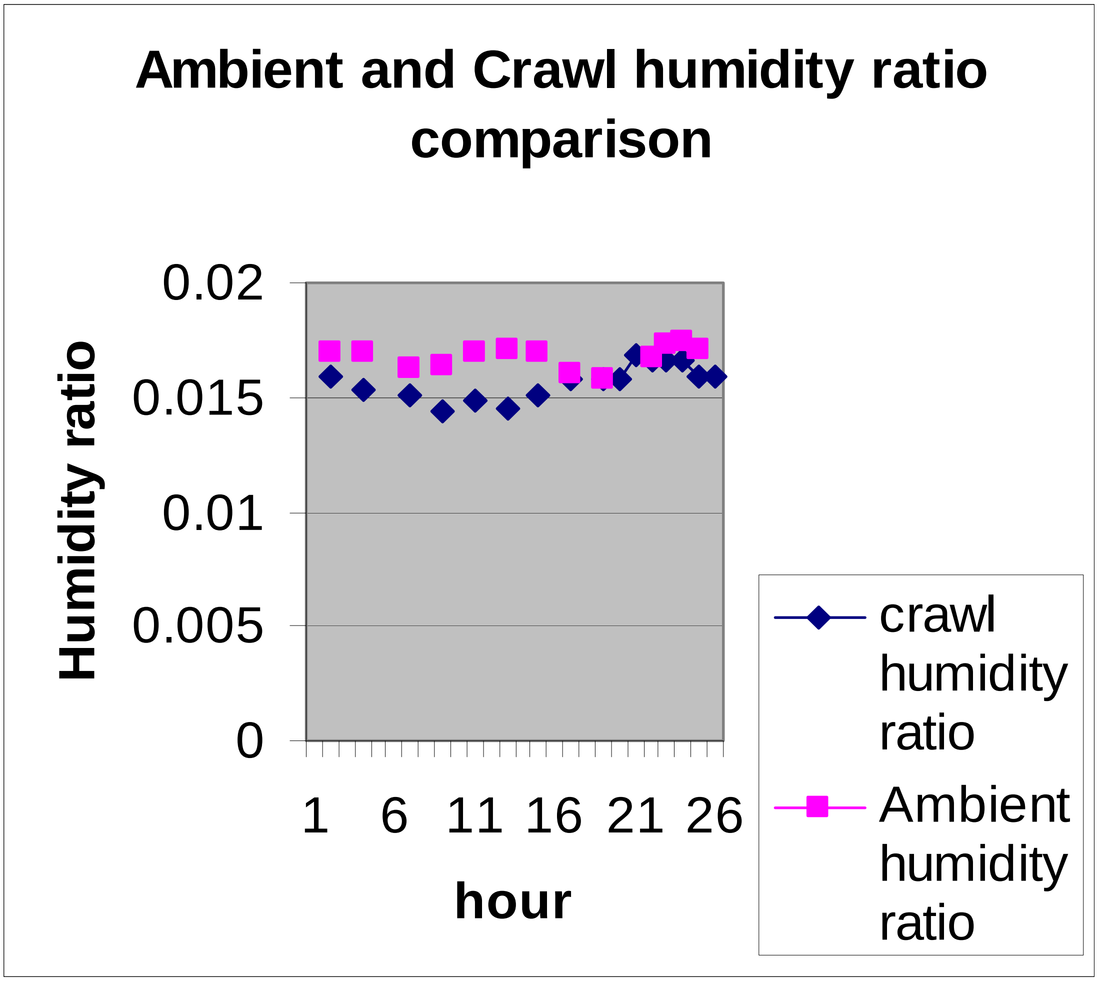

Figure 6 Ambient and crawlspace humidity ratio for July 8, 2003

Envelope

The house floor plan and cross section are shown in Figure 7 and Figure 8. The house walls are standard 4.5 inch thick SIPS with nominal 1 lb/ft^3 density expanded polystyrene sandwiched between two layers of 7/16 in. OSB (Orientated Strand Board). The wall panels were 8 ft high and various lengths on the eave walls and sized to fit the pitched 4/12 gable on the front and back of the house. The panels were fastened together using surface splines that were well sealed using two different types of caulk. Each panel-to-panel connection was sealed at all contact surfaces,

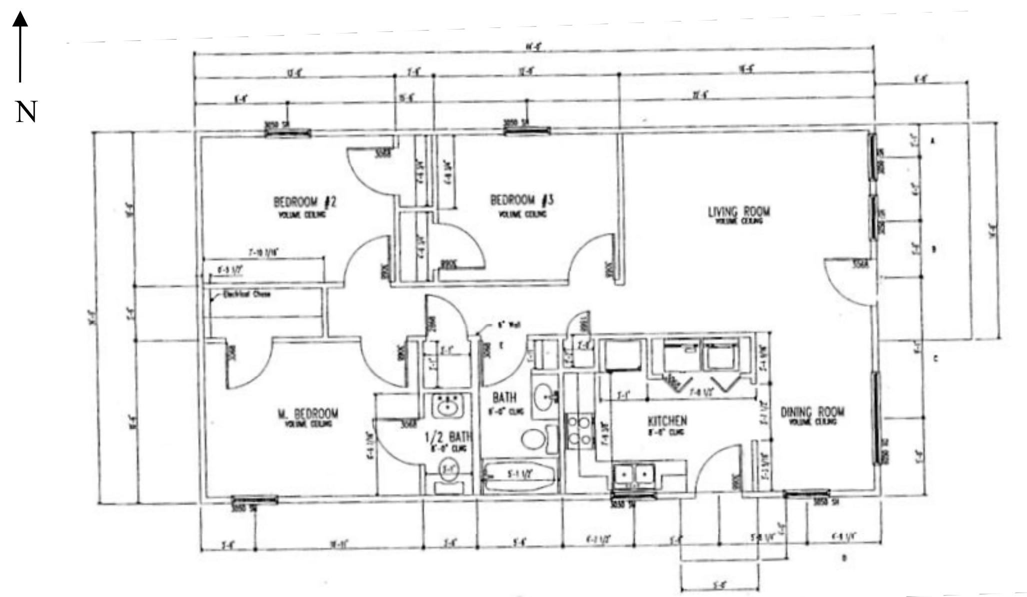

Figure 7 ZEH1 Floor Plan

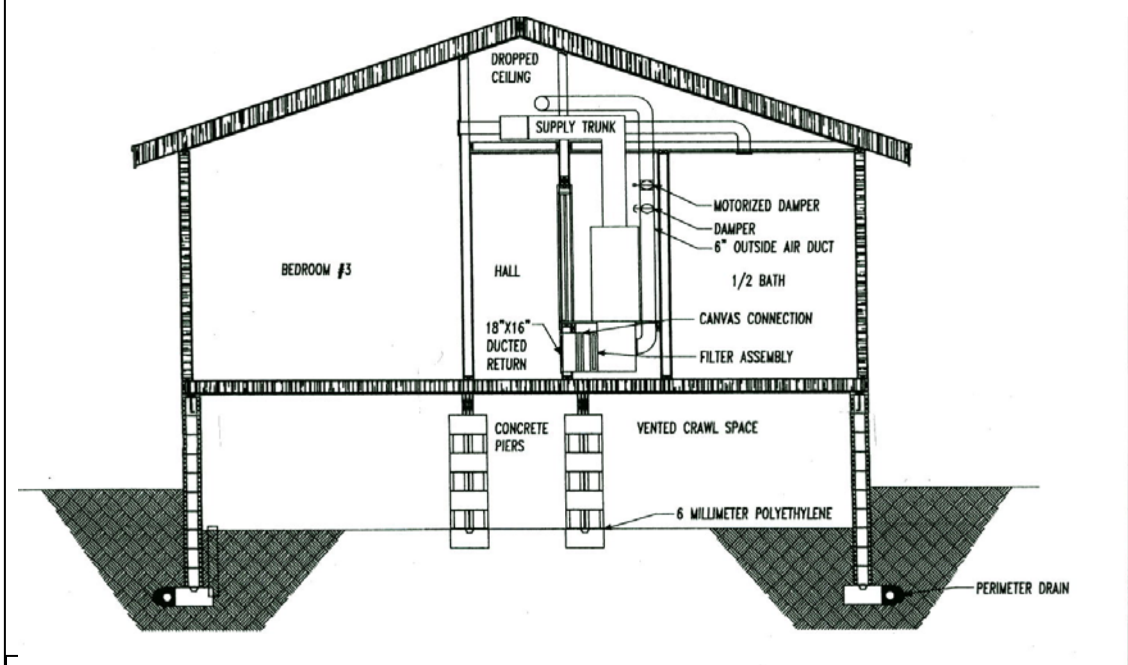

Figure 8 ZEH1 Cross section

spline-to-foam, foam-to-foam and on both surfaces where the OSB skins met. This totaled 5 caulk seals. The cathedral ceiling with a 4/12 pitch consisted of 4 ft wide panels by full length from ridge-to-eave. They were all connected with surface splines. The R-value of this roof system is 28 h·ft²·°F/Btu @75°F. Two of these nominal 8 in thick 4 ft panels were fastened together on the ground and crane lifted to the roof. Two thirds of the roof panels were supported by two full length structural walls that served as partitions between the back two bedroom closets, shown in Figure 7, and hallway walls leading to the open dining living area. The open area was spanned by use of a gluelam ridge beam. The windows were wood vinyl clad doublehungs with National Fenestration Rating Council (NFRC) Labeled U-Factor of 0.34 and Solar Heat Gain Coefficient of 0.36.

Prior to selection of the opaque walls and roofs for this first ZEB test house two 12 ft by 12 ft by 8 ft high test rooms were constructed in the Laboratory. One of these rooms was constructed using 4 inch thick SIP walls with 10 embedded electrical boxes and connecting wires. Several panel-to-panel joints were designed into the walls and sealed using manufacturer recommended splines and caulking procedures for air sealing. The SIP test room had 4.5 inch SIPs and 8 inch flat roof with a R-value of about 30 h·ft²·°F/Btu @75°F. One double hung window and full view 36 in. wide door were installed in accordance with the manufacturer's recommendation for these flanged products. The inside walls and ceiling were dry-walled with one coat of mud. No house wrap was installed on the exterior. A ceiling fan with an electric heater was installed and used to condition the space at 74 F while the Large Scale Climate Simulator outdoor chamber was set at 0° F. The test was run long enough to reach steady state and measure the amount of energy needed to maintain the thermostat setting at mid height in the test room.

The second room with identical inside floor space was constructed and tested in exactly the same manner except with 2 X 6 @16" on center frame walls and flat insulated roof with a layer of R-19 and a perpendicular laid R-11 fiberglass batt insulation with the same window, door, and electrical wiring system. The exterior OSB sheeting was attached with 3/16 space between sheets as recommended by the manufacture's installation guidelines. No house wrap was installed on either test rooms. The walls were insulated by a local insulation crew and instructed to install just like they do in the field. This resulted in the electric wires compressing some of the fiberglass insulation, which is not per manufacturers recommended installation. The batts should be sliced and tucked around the wiring to avoid all compression. The same SIP floor was used in both rooms. Its air-to-air R-value was estimated to be 17.25 h·ft²·°F/Btu. The R-value of both ceilings were ~R-30 h·ft²·°F/Btu.

Figure 9 shows that the 4.5 in. SIP used 10% less energy, at 0 F ambient in the surrounding climate chamber and 74 F inside air temperature, to heat than 2 X 6 wood frame test room. During this test in the Large Scale Climate Simulator there was no intentional control of pressure other than the stack effect caused by the warm air inside the test rooms. The thinner SIP wall thickness results in the consumption of 20% less floor area than the 2 X 6 frame wall takes up.

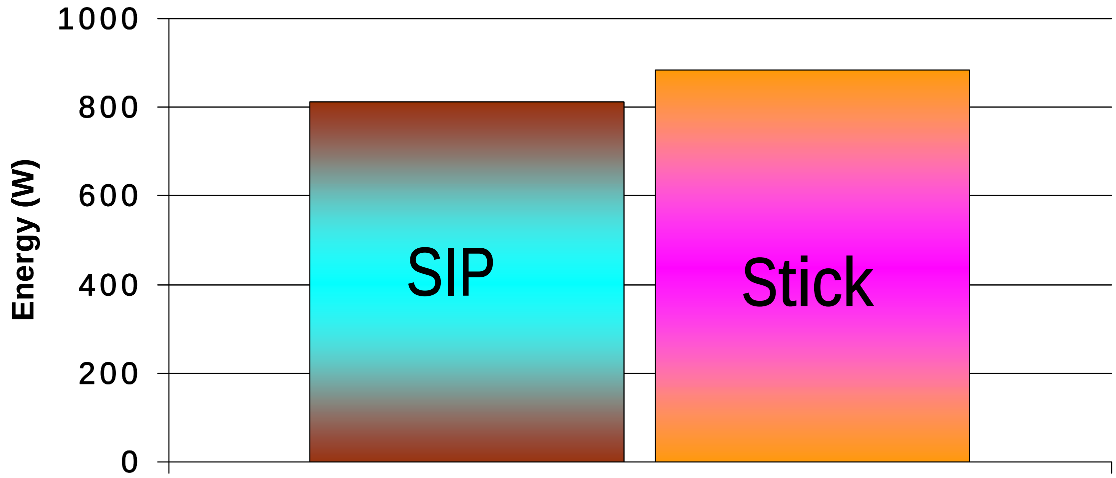

Figure 9 At 0 F the SIP test room used 10 % less energy to heat than the 2 X 6.

The second set of tests, conducted on both test rooms determined air tightness using a blower door. The data for the SIP test room is shown in Figure 10 as the line with the triangles "▲" pointing upward. This is the lowest line shown in Figure 10. The frame test room is displayed as the line in Figure 10 with the triangles "▼" pointing downward. This data is consistent with tightest and the leakiest of 6 nearly identical frame houses all built by the same contactor as the base house, described in Table 1. The two stick built air tightness lines are shown in Figure 10 with "+" and "x" symbols. This provided the confidence that the frame test room was successful in representing field conditions found in the base case stick frame house. At 50 Pascal of pressure across the envelope the SIP test room had an air leakage of 0.078 ft^3/ft^2 of floor area. The identical test room with one double hung window and full view atrium door, 10 electric outlets except the roof and walls were 2 X 6 frame construction had an air leakage value of 1.06 ft^3/ft^2 of floor area. The 2 X 6 frame test room was 14 times leakier than the SIP structure. This impressive air tightness measurement encouraged the selection of a SIP envelope for the first attempt at a net zero energy house.

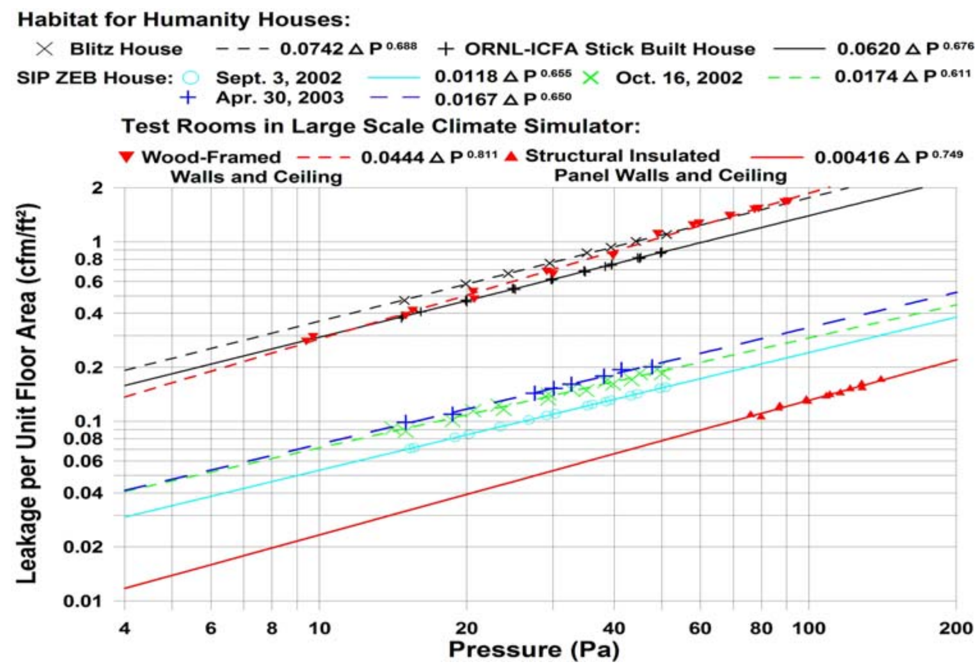

Figure 10 Air tightness of SIP structures compared to stick

Since the SIP test room did not have all the typical penetrations found in real house envelopes that so frequently compromise air tightness the first test of ZEH1 was a blower door analysis. Tests were run prior to installation of the drywall, after the house was ready to be moved into and 6 months after occupancy. The panel sealing prior to installing the drywall was an easy time to plug any significant unwanted leaks. The most significant was found in the front part of the house were the roof ridge beam met the front gable. The other leakage points were around the electrical outlets. Both sets of leaks were sealed and the blower door tests run. The line with the "o" shows the ZEH1 whole house leakage prior to drywall. The ZEH1 leakage per unit of floor area measured out at 0.15 cfm/ft2 at 50 Pascal. This can be compared to the wood frame base house of 0.87. The base wood frame house was 6 times leakier than ZEH1.

Mechanical, Electrical and Plumbing

<u>Domestic Water Heating</u>

This house is equipped with a domestic heat pump water heater. The "drop-in" air source heat pump water heater has the compressor and evaporator coil on top of the 50 gallon tank. The condenser coil is wrapped around the outside of the metal tank. Typically these units are installed in the conditioned space, in an unconditioned basement or unconditioned garage. In general, the warmer the air source surrounding the heat pump water heater the better the unit's thermal performance. A garage in southern Florida works well because the garage air is usually warm year around. Another good location is in an unconditioned basement that needs dehumidification. Occasionally the units are installed in utility closets in conditioned space. This can cause the closet air to become cold. This is not always a bad thing. For example a wine cellar or in the case of the Habitat for Humanities field office a convenient place to store semi cold drinks for hard working volunteers. However, when the conditioned air is used to heat the hot water during the winter this heat may need to be made up by the space conditioning system.

To take advantage of the added cooling and dehumidification available from the HPWH and avoid taking valued heat from conditioned space, the heat pump water heater in this house is connected to the air space behind the refrigerator, which is laid out intentionally in the floor plan to be located next to the utility closet housing the heat pump water heater. When the home owner has the house thermostat set for cooling, motorized dampers are energized to allow the heat pump water heater fans to pull air from behind the refrigerator to extract heat for domestic hot water. This air stream is cooled, dehumidified and directed back into the kitchen to help condition the house. When the thermostat is in the off or heating mode the ducts connecting the heat pump water heater to the kitchen are closed and ducts are opened up to pull in earth tempered crawl space air and reject unwanted cool air to the outside. Since the crawl space vents are sealed as well as the crawl space floor the crawl space will go under a slight negative pressure when the HPWH fans are sucking from the crawl space. The crawl space attic access is not weather stripped and this crack allows some make up air into the crawl. As shown in Figure 5, the crawl space air temperature remains between 50 and 65 F through out the heating season. Not quite as high as Figure 5 shows the conditioned space air temperature but, during the winter the heat pump water heater does not remove desirable heat from the inside space. The air stream from the crawl space after passing through the heat pump water heater evaporator coil is even cooler and directed outside by the water heater fans. The heat pump water heater fans were measured to blow 200 cfm through an unconstrained evaporator coil. When ducts are connected the additional static pressure reduces this air flow.

The continuous water heating usage measurements found that the occupants used 72% of the DHW for showers and baths. The average daily usage was 40 gal/day, which is 43% less than found in the national HPWH field study by Tomlinson and Murphy, ORNL 2003. The measured daily energy consumption is 3.8 kWhr, which is 28% less than found in national HPWH field study. The average heat pump water heater COP was 1.62. The monthly values ranged from a low of about 1.5 in the coldest winter months to almost 2 in the warmest summer months (1.52–1.88 from Aug 03 to Feb 1). The National heat pump water heater study found an average COP of 2.0 (Tomlinson and Murphy ORNL 2003). This is with units installed in various locations with varying amounts of daily hot water usage. It is recognized that with lower hot water usage like is found in this house the standby loses are a higher percentage of energy usage and this results in lower COPs. Because the heat pump water heater and refrigerator were located on inside walls of the kitchen, rather long duct runs were required to vent to the outside and into the middle of the kitchen ceiling. These flex ducts were found to generate excessive static pressure, restricting air movement away from the heat pump water heater closet. It is believed that the optimized coupling with refrigerator, crawl space, space cooling and dehumidification was not attained in this house. If a heat pump water heater could reach a COP of 2.0 this house could have saved another 337 kWh/year ($0.06/day). ZEGH2 has a second generation hook up which consists of the refrigerator and the heat pump water heater located adjacent to the outside wall and has all hard ducts to and from the unit to minimize static pressure and restricted air flow. The COPs in this unit from December 2003 until April 2004 averaged almost 2. During the swing seasons and summer the COPs have averaged 2.2.

Conditioned Space Thermal Comfort

The conditioned space average hourly temperature and relative humidity for one complete year are shown in Figure 11. The temperature on average is kept around 75 F. The occasional spikes in RH are due to window openings and 24/7 mechanical ventilation. The home owners generally were not home during the summer day time periods and even though the RH would tend to drift above 60% on some hot summer days the owners had no thermal comfort complaints. Because of the airtight envelope, well shaded low solar heat gain windows, and continuous mechanical ventilation the thermostat would occasionally not call for sensible cooling until after the RH rose above what would be considered acceptable in some situations. The HVAC systems in ZEH2 and ZEH3 addressed this by changing the thermostat control logic and in one case two speed compressor and in the other a lower evaporator temperature of the direct exchange geothermal system.

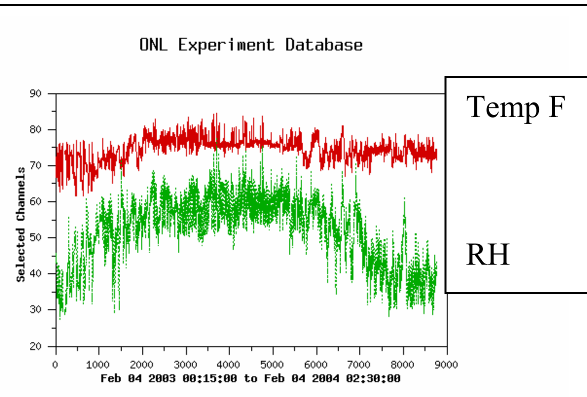

Figure 11 Interior temperature and RH for complete year

Total electric energy usage and cost

The ZEH1 all electric house from March 1, 2003 until February 29, 2004 used 10,216 kWhr as shown by Table 2. The heat pump and ventilation fan power required 2759 kWhr or 27% of the total energy. The heat pump water heater used 1549 or 15% of the total. The rest of the energy loads in the building required 5907 kWh or 58% of the total. Prior to construction of this house the HERS was calculated to be 90.2, which converts to a 50% better than the IECC. The electric rates in this area during the monitoring period were \$0.63/kWh. The house is the first house to sell green power back to the largest electric utility in the country. The contractual arrangement is that the utility will pay the homeowner \$0.15/kWh for all the solar power produced by the 2kWp PV system for 10 years whether they use it or not. During this monitoring period the solar system generated 2006 kWh. Officially this started on May 14, 2003. This house would have been given an annual credit of \$300 if initiated at the beginning of the monitoring period. The net energy cost to the homeowner results in an annual expense of \$343, average monthly of \$28.58 and daily of \$0.94. In the winter of 2002-03 the homeowners used a bit less energy than the winter of 2003-04. If the reporting period was from when they moved in on November 15, 2002 until November 15, 2003 this daily cost figure would have been \$0.82/day.

The ZEH1 house has a gross conditioned floor area of 24 ft X 44 ft or 1056 ft^2. During this same period a near by 20 year old two story house with 3032 ft^2, gas heat, SEER 13 AC experienced $2853/yr or $7.82/day. The HVAC in this house was just replaced in 2002. On a cost per square foot of floor area per year basis this is $0.94 compared to the near net zero house of $0.32. The ZEH1 requires 66% less energy expense. Over a 30 year period this house would save the home owner more than $20,000 compared to the option of moving into an older house with new HVAC equipment.

Figure 12 shows ZEH1 used 40% less total energy than the base house described in Table 1. The local electric utility inspected and certified this house as a HERS 84 Stick home (already 20% better than IECC) in the same neighborhood.

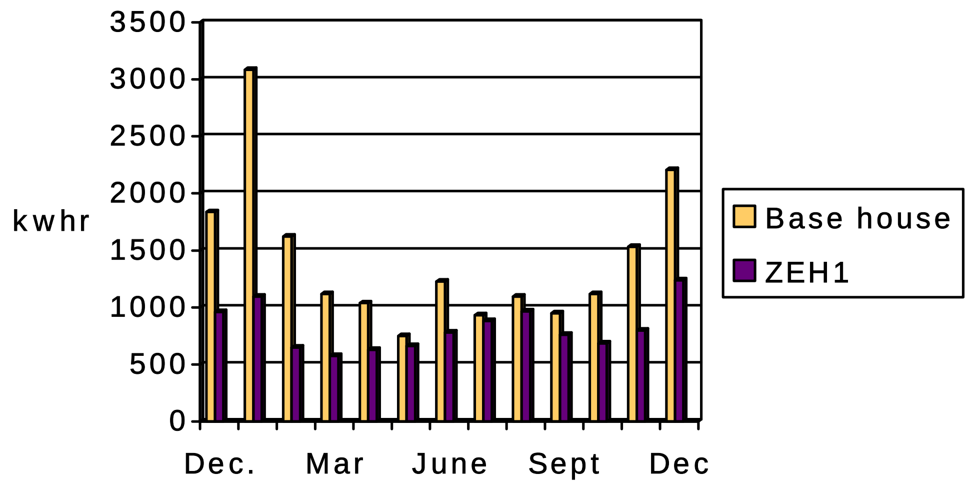

Figure 12 Monthly energy bills from base house show a 40% higher annual energy cost than ZEH1, from Nov. 2003-Dec.2004.

Closer look at Energy Use

Table 2 shows the monthly measured electric energy flows for ZEH1. The first four columns labeled, space heat, space cool, hot water plus other, equal the values shown in the column labeled total electric. The annual energy cost for space heating totals about $100, space cooling $74, domestic hot water $98, the other electric uses in this all electric house cost $372. The total cost is calculated by subtracting the solar credit which is based on the electric utilities rate of $0.15/kWhr or $301 from the total used which came to $644/yr.

Table 2 Energy breakdown and costs

Month	Space Heat (kWh)	Space Cool (kWh)	Hot Water (kWh)	Other (kWh)	Total electric (kWh)	Solar AC generated* (kWh)	Solar sold back (kWh)

March 03	127		124	325	575	167	91
April	64		146	419	629	195	100
May		94	109	460	663	188	90
June		204	87	490	781	213	88
July		314	74	494	882	209	79
August		359	70	536	966	219	76
Sept		187	82	491	760	195	95
October	34	17	117	518	686	159	77
November	141		138	518	797	121	45
December	401		187	650	1238	115	15
January	473		219	540	1232	120	23
February 04	344		196	466	1006	104	25
TOTAL	1584	1175	1549	5907	10216	2006	804
% total used	15.5%	11.5%	15%	58%		20%	
Cost ($)	-100	-74	-98	-372	-644	301	

***Alternating Current**

Table 2 also shows the 2kW peak rated solar PV system monthly generation in the column labeled "Solar AC generated". During this period the total annual generation came to 20% of the total energy used. The last column shows the solar power which was generated on site but at the time it was available was not used in the house and therefore sent to the electric grid. The estimated cost of the ZEH1 solar system was $22,388, as shown in Table 3. The total installed solar system cost with the same capacity installed in ZEH2 and ZEH3 was $16,000. Solar systems first cost will have to continue to drop. For ZEH1 to have met the net zero energy goal of producing on site what is consumed the solar system capacity would have to have been 10 kWp. The cost of the energy saving features in this house will also have to come down as suggested by the numbers shown in Table 3 for the first three attempts at net zero and the base house.

It is also interesting to note that 40% of the solar power was not used by the house because at the time the solar was being produced exceeded the current house energy demand. This excess power for the most part is available during hot summer afternoon hours when utility electric grids welcome not only the reduction in load but the surplus power to help meet peak cooling demands. The PV system on this house on average reduced summer peak loads by 40% in the three summer months June-August.

Construction cost

These houses were all constructed by the Habitat for Humanity Loudon County Affiliate. Most of the construction labor draws from volunteers. Frequently a church or a civic group will commit to doing a house. This generally entails providing labor and in most cases a financial commitment. This particular affiliate has a paid staff consisting of an Executive Director that is also a CPA and keeps the financial records, a logistics expert that schedules all material deliveries and volunteers, and a Construction Supervisor. Critical subcontractors are hired for plumbing, HVAC, foundation installation and site work, concrete pavement, and drywall installation. Volunteer hours are kept track of by a sign in and sign out book. The value assigned to each volunteer hour is $5.50. This is about half of average prevailing rates but because of skill level and the social element of this activity it is the Habitat's perception the assigned hourly rate is in the "ball park" of market value. Table 3 shows a spread sheet for construction cost of ZEH 1, ZEH 2, ZEH 3 and the average base house used in this paper to compare energy costs. Because the ZEHs are test buildings some of the materials were donated or were funded by other sources than Habitat. The estimated value of all the costs is reflected in the totals shown in Table 3. Because of the research aspects of these test houses the costs are much higher than production units. The general agreement with the Habitat Affiliate is that the test houses will cost them no more than their current "conventional construction" costs which they are held to by various grants and overarching requirements set forth by Habitat International.

Table 3 Construction cost of three ZEHs and the base frame house

	Base House	ZEH 1	ZEH 2	ZEH 3
house	59,295	78,914	83,953	87,889
Land and infrastructure	14,500	14,500	14,500	14,500
Cost of solar	0	22,388	16,000	16,000
Total cost	73,795	115,802	115,953	122,329

Lessons learned

Table 2 shows that the more than 75% of the heating energy for an air to air heat pump is consumed in the three coldest months December, January and February. ZEH 2 and 3 research houses used better envelopes, and better heat pumps. ZEH3, shown in Figure 13 used a direct exchange geothermal system for January and February 2004 demanded 19% less total house energy and produced 12 % more solar power than the first house. This house is shown in Figure 7. The orientation of this house is a bit better and has a 6/12 pitched roof compared to 4/12. The biggest energy savings is believed to come from the geothermal heat exchange with surrounding earth temperatures of 50 F compared to the much colder ambient air, particularly at night which the air source heat pump must extract heat. A few of the additional features of this second generation of affordable zero energy house are: 6 inch SIP wall, 10 in. roof, forest green cool pigmented roof (reflectivity of .23 instead of .17), 2 ton direct exchange geothermal heat pump with SEER of 16, desuperheater for DHW, more airtight than the first near ZEB with an ACH_4= 0.03 compared to 0.04. The local electric utility auditors rated this house with a HERS = 93.9. This represents a house almost 70% more efficient than IECC. In general just meeting code would lead to a HERS rating of 80. Each point above 80 represents 5% energy savings beyond just meeting code. So a 94 has 14 points above 80 or 14 X 5% will equal 70%. It also meets the long term energy savings goal of the DOE Building America Program. The cost goal has not been met in this first prototype.

Figure 13 ZEH3 has a smaller size collector field and much thicker fascia than ZEH1 shown in figure 2.

Conclusions

This paper reports on the first of six attempts at an affordable zero energy houses in the Mixed Humid Climate of Tennessee. ZEH1 had a rated HERS of 90. It used about 40% less energy than the base house with electric utility certified performance of HERS 84. The total cost to build ZEH1 including the market value for all the donated time and materials came to $116K. This included the estimated $14.5K for the infrastructure and lot. The actual cost to the Habitat Affiliate not counting donated ZEH materials was about the same as the base house they are currently building in the same development. The total energy costs are coming in under $1/day. The annual heating cost of this first attempt at an all electric zero energy houses using the local electricity rate of $0.063/kWh measured at under $100/year, cooling under $75, and domestic hot water under $100.

The solar PV system generated about 2000 kWhr over first full year. This amounted to 20% of total energy load and 74% of HVAC load. The lowest average total energy cost less the solar credits came to $0.82/day. This was the first local electric utility's Green Power Switch Generation Partner. With the electric utility green power offering $0.15/kWh and the energy saving features this house experienced an annual energy cost savings of 65%. ZEH2 and 3 **had b**een occupied for only two months at the time this paper was written. The use of geothermal heat pump in the winter time was making a substantial step closer to net zero. However it did add first cost as shown by Table 3. Additional cost reductions in the envelope and geothermal heat pump are ongoing at the time of this writing. However, it is apparent that the plug loads will have to be addressed to realistically address the opening question of this paper. With plug loads at 60% of the total energy demand on the first house this is an important issue. The homeowners have all expressed an interest beyond your typical habitat family on how much energy they are using. With real time feedback and reliable automated shut off controls an obvious critical technology on the path to attaining zero energy at zero net cash flow over the life of the building.