Building a 40% Energy Saving House in the Mixed-Humid Climate

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August 07 DRAFT

Building AMERICA
U.S. Department of Energy
Research Toward Zero Energy Homes

Contents

1. Introduction

1.1 Background

This report describes how to build a small energy efficient affordable house that will achieve 40% whole house energy savings using a commercially available technology package in the mixed-humid climate region. This package of technology and the method of integration have been used in the 5th of a series of near zero energy test houses.

This information includes floor plans, cross sections, and elevations. Technical specifications are provided for site characteristics, house orientation, envelope components (foundation, above-grade walls, windows, and roof), lighting, appliances, and space conditioning systems, including mechanical ventilation, heating, cooling, dehumidification, and water heating. This package also includes, construction cost, measured energy consumption for a one year period and predicted energy consumption for typical occupancy and energy services of an occupied house for a one year period with and without a roof mounted 2.2 kWpeak PV solar system. This report contains lessons learned and advice on key construction and commissioning steps for this zero energy ready home..

The lessons-learned come from experience gained from designing, building, and monitoring five affordable energy-efficient houses through collaboration among Habitat for Humanity Loudon County, the U.S. Department of Energy (DOE), Oak Ridge National Laboratory (ORNL), and the Tennessee Valley Authority (TVA). The houses were designed by ORNL and DOE Building America teams and constructed by Habitat volunteers in Lenoir City, Tennessee. This report mainly focuses on the 1232 ft^2 one-story-ZEH5. This was the fifth in the series of test houses, all in the same development as laid out in Figure 1. For one complete year ZEH5 was monitored while heating and cooling only the upstairs, the basement was left unconditioned and performed as an eight foot high unvented insulated crawlspace. There are no steps between the upstairs and down so that the house would qualify as a single-floor four bedroom Habitat for Humanity home. This is the largest house allowed within the Habitat for Humanity International guidelines.

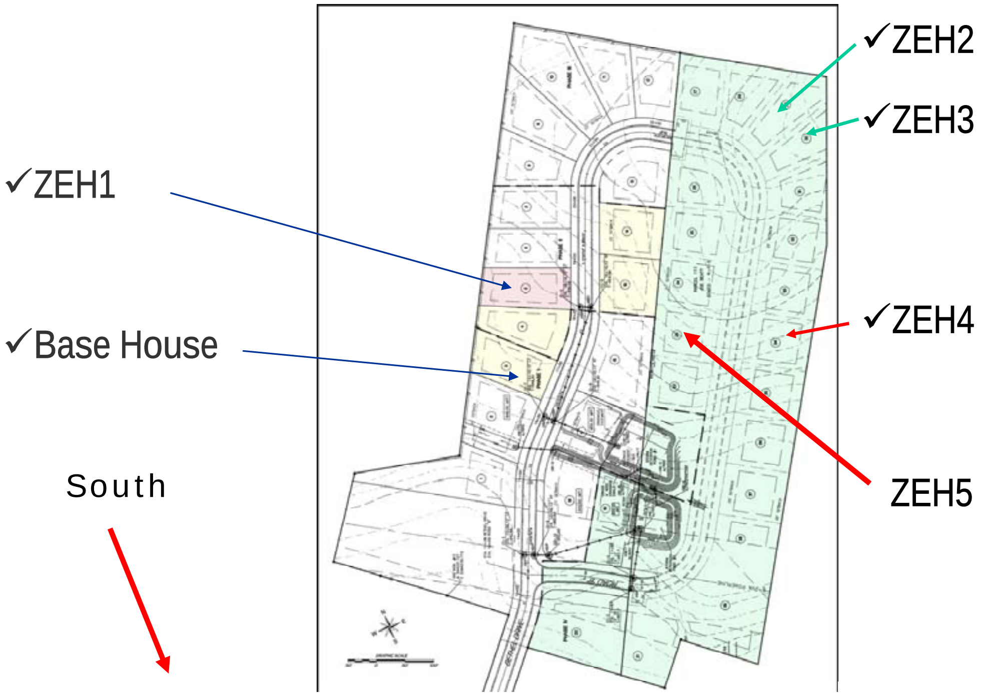


Figure 1. Layout of Development with five ZEHs.

1.2 The 40% energy saving test house

The construction methods, building products, appliances, and equipment that were used, resulted in low energy use in this all-electric, single-family house, approaching “net zero energy.” (A net-zero-energy home is one that produces as much energy as it consumes on an annual basis.) Data collected on the thermal performance of one-story ZEH5 was used to develop the guidelines presented in this report.

ZEH5 was equipped with 94 performance measurements to record electric sub metered usage, temperature and relative humidity (ambient, indoor, and crawl space), hot water usage, heat pump operation, and other data. We have accumulated 15-minute-interval data for one year from January 1, 2006 until December 31, 2006 on ZEH5. The data was analyzed to determine component performance and energy consumption and to validate computer models. This house with assumed typical occupancy and the same 2.2 kWpeak solar PV system as measured on ZEH4 is predicted to have consumed a daily average of off-site energy totaling a cost of $0.66/day. The current hook up charges would add another $0.20/day, totaling $0.86/day.

The construction cost for this house built in 2005 was $122,000, including the cost of the rooftop grid tied 2.2 kWpeak solar PV system. Federal and Electric Utility incentives are included in this cost but the land and development infrastructure is not included. This cost includes the cost of an unfinished but very well insulated, waterproofed and drained 8 ft high unfinished basement. This explains most of the reason that the cost per ft^2 of floor area is higher than the other 4 near zero energy house cost estimates done on a similar basis and shown in Table 8. The cost of materials and value of materials and labor donated were kept track of during the construction of this house. There is some uncertainty in the cost of labor other than that of the plumbing, HVAC, excavation, and foundation subcontractors. The above grade envelope can be assembled quickly with a SIPs technician and crew that have good general carpentry skills. The interior framing is a bit more extensive due to the cathedral ceiling compared to a flat ceiling system under roof trusses. Table 9 shows the cost break down estimate for

ZEH5 with an unfinished basement. The rows with a Phase code shown in the first column in Table 9 are supported by actual invoices.

1.2.1 Technologies

Tables 1 and 2 list building envelope and mechanical features used in the fifth house compared to the other four near-zero-energy houses and a baseline Habitat house used for comparison (Christian 2006c). The base house is measured by Home Energy Rating System (HERS) rating of 84, which indicates about 20% better performance than a typical 2004-05 American house of the same size and layout (RESNET 2002).

Table 1. Envelope technology packages in test houses

House	Baseline House	ZEH 1	ZEH2	ZEH3	ZEH4	ZEH5
Stories	1	1	1	1	2	1
floor ft^2	1056	1056	1060	1082	1200	1232
Foundation	Vented crawl	Unvented crawl	Mechanically vented crawl with insulated walls 2 in polyisocyanurate boards (R-12)	Unvented crawl with insulated walls 2 in polyisocyanurate boards (R-12)	Walk out basement with insulated precast (nominal steady state R-value of (R-16)	Walk out unconditioned basement with exterior insulated block walls (nominal steady state R-value of (R-11)
1st Floor	R-19 fiberglass batts (R-17.9)	6.5 in. SIPS 1#EPS (R-20) Structural splines	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	Concrete Slab, insulated underneath with R-10 XPS and exterior apron of R-10 XPS on south side
Walls	2 x 4 frame with R-11 fiberglass batts, OSB sheathing, (R-10.6)	4.5 in. SIPS 1#EPS (R-15) surface splines, house wrap, vinyl	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	6.5 in SIPS 1#EPS (R-21), structural splines-wood I-beams, house wrap, vinyl
Windows	6-7 windows, U factor 0.538	9 windows 0.34 U-factor, 0.33 SHGC, VT=.55, sill seal pans	8 windows 0.34 U-factor, 0.33 SHGC, VT=.55, sill seal pans	8 windows 0.34 U-factor, 0.33 SHGC, VT=.55, sill seal pans	10 windows, 0.34 U-factor, 0.33 SHGC, VT=.55, sill seal pans	13 windows, 0.34 U-factor, 0.33 SHGC, VT=.55, sill seal pans
Doors	2-doors, one solid insulated, one half view	2-doors, solid insulated, & half view	2-doors, one solid insulated, one half view	2-doors, one solid insulated, one half view	3-doors, one solid, one ½ view insulated, one full view (U=0.33, SHGC=0.27, VT=0.41)	3-doors, one solid, one ½ view insulated, one full view (U=0.33, SHGC=0.27, VT=0.41)
Roof	Attic floor blown fiberglass (R-28.4)	8 in. SIPS 1# EPS (R-28) surface splines	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)	8 in SIPS 1#EPS plus 2 in XPS (R-35), I-joist splines
Roofing	Gray asphalt shingles	Hidden raised metal seam	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	15 in. Brown standing 24GA steel seam, 0.31 reflectivity

Table 2. Equipment technology packages in test houses

House	Base House	ZEH 1	ZEH 2	ZEH 3	ZEH 4	ZEH5
Solar system	None	48-43W amorphous silicon PV modules, 2.06 kWp	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	20-110W polycrystalline 2.2 kWp
Heating and Cooling	Unitary 2 ton HP, SEER 12	1-1/2 ton air-to-air HP, SEER 13.7, 2-speed ECM indoor fan	2-speed compressor 2 ton air-to-air HP, SEER-14, HSPF-7.8, CFM cooling 700, variable-speed ECM indoor fan	2 ton Direct exchange geothermal, R-417a, variable-speed ECM indoor fan, comparable SEER 16.6	2 ton air-to-air HP, SEER 17, variable-speed compressor, ECM indoor and outdoor fan	2 ton water-loop geothermal, R-410A, variable speed ECM indoor fan EER 19.2
Mechanical Ventilation	None	Supply to return side of coil	Supply to return side of coil, CO_2 sensor, bath fan exhaust	Supply to return side of coil, bath fan exhaust	Supply to return side of coil, bath fan exhaust	Supply to return side of coil, bath fan exhaust
Duct location	Crawl space	Inside conditioned space	Inside conditioned space	Inside conditioned space	Inside conditioned space	Inside conditioned space
Water Heater	Electric	Integrated HPWH linked to unvented crawl	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	Solar Water Heater, 40 ft^2 collector area, PV pump, grey water waste heat recovery

Notes for tables 1 and 2: ECM = electronically commuted motor; EF = energy factor; EPS = expanded polystyrene; HP = heat pump; HPWH = heat pump water heater; HSPF = heating seasonal performance factor; OSB = oriented strand board; SEER = seasonal energy efficiency rating; SHGC = solar heat gain coefficient; SIP = structural insulated panel; XPS = extruded polystyrene

ZEH5 has a rooftop solar water heater but the PV grid-tie system with a rating of 2.2 kWp is actually mounted on ZEH4's roof. ZEH4 has the same slope, orientation and very similar and limited tree shading patterns. To be connected to the TVA Green Power Generation Program the houses must be equipped with two electric utility meters, one to track solar PV system generation and a net meter which shows real time whether the house is using more energy than it is producing, or vice versa. The net-meter allows the surplus energy to flow into the utility grid when a house is using less electricity than the PV system produces (usually on sunny summer afternoons). The power consumed by the household and generated by the PV system is metered separately, and the homeowner is credited $0.15 per kWh by the utility for all the solar power produced. The sum of these two meters read once a month represents the actual household energy consumption.

Supply mechanical ventilation is provided in compliance with American Society of Heating, Refrigerating, and Air-Conditioning Engineers Standard 62.2 (ASHRAE 2004). ZEH5 is the first of the five test houses to use a solar hot water heater. An extensive moisture management package is provided in all five test houses.

1.2.2 Cost

Energy cost. The cost-effectiveness of a house like ZEH5 will vary with energy costs, climate, energy-consumption habits, utility, state, and federal incentives, and the cost of the selected technologies. The electricity local rate in 2006 for ZEH5 was $0.07 per kWh, below the national average of around $0.10 per kWh. Energy cost savings would be greater in regions with higher electricity and solar credit rates.

For the last four homes, utility bills averaged less than $1 per day after credit for the sale of solar generated electric power. The ZEH5 had an average daily cost for electricity of 66 cents per day ($0.86/day counting utility hookup charges of $0.20). The Building America Benchmark house for ZEH5 comparison purposes with the same size in the same community would be expected to average $3.36 per day for electricity. Figure 2 shows the energy consumption and solar generation of ZEH1, 2, 3, 4, and 5(one-story) compared to the benchmark house for ZEH5.

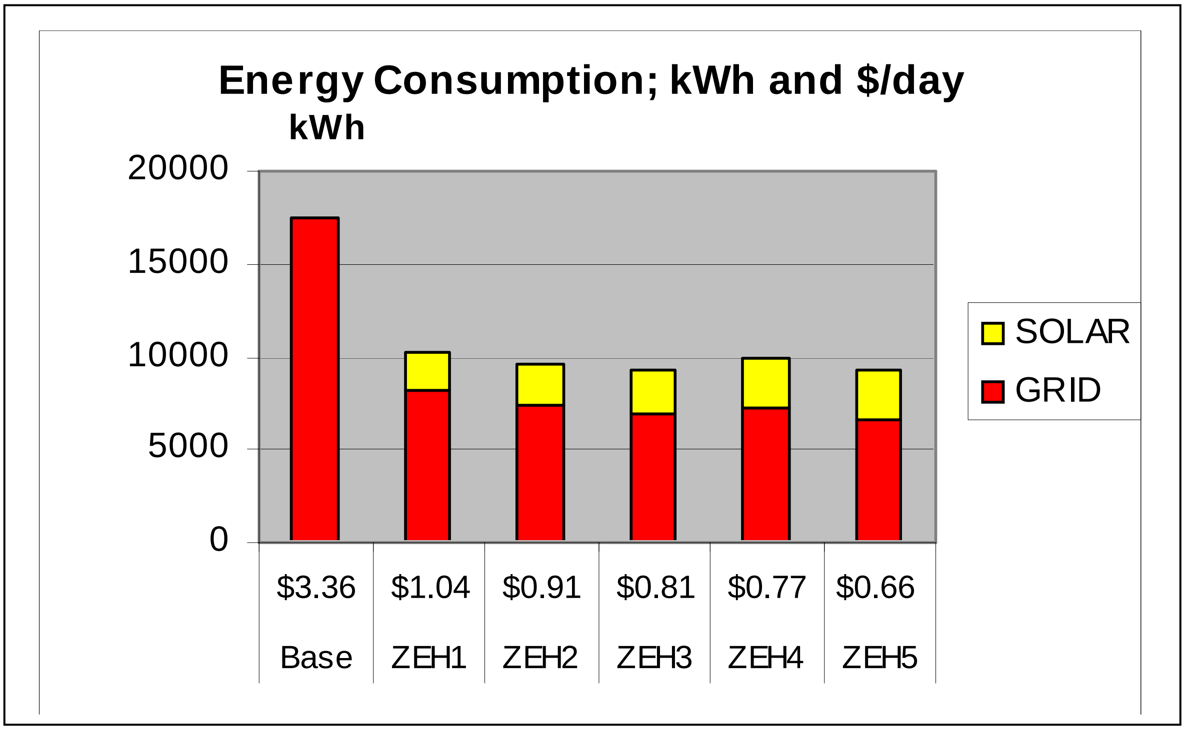


Figure 2. Energy consumption of ZEH's.

The monthly energy consumption values in Table 3 are based upon a combination of hard measurements and modeling. This was necessary since the house was occupied as an office rather than a residence. The actual other loads were 54% higher than those recommended by the BA benchmark occupancy (Building America Benchmark guidelines, Dec. 15, 2006). Measured readings for space heating and cooling were adjusted slightly to account for less heat from the other loads in the house. This raised the heating energy 339 kWhr or 57% and lowered the cooling energy by 285 kWh or 14%, Table 3 other loads come from the procedure outlined in the BA Benchmark modeling procedure.

The hot water loads comes from Energy Gauge modeling of the solar system installed in ZEH5. The house was used through out 2006-2007 to test a variety of different water heating options. The house was equipped with a programmable controlled water usage that varied from 45-100 gallons/day. The solar water heater was tested off and on throughout the year. In June of 2007 the solar water heater was tested for a 23 day period. The house averaged a hot water consumption of 63 gallons/day. The back up electric required 11.0 Wh/gallon of hot water delivered. This was compared to the Energy

Gauge simulation of the same house delivering the same 63 gallons of hot water per day 12.7 Wh/gallon for the month of June. This calibration suggests that the measured performance of the solar water heater is actually slightly better than the model predicts by about 13 percent. Using the June performance to decrease the predicted energy required to back up the solar water heater in ZEH 5, 709 kWh X .875 = 618 kWh, equals 36 Whr/gal or a 76 percent energy savings compared to an electric resistance water heater with an EF of 0.88 using 150 Whr/gallon.

The solar electric energy collected on site amounted to 29% of the total energy consumed. Since there are no actual solar panels installed on ZEH5 at this time, the numbers for solar energy produced were taken from ZEH4 over the same measurement period in 2006, which has a 2.2 kWpeak PV system and roof is oriented in the same direction. If one assumes the solar water heater displaced 76% of the all electric resistance water heater that would add another 1987 kWhr/yr of solar savings. This leads to a solar fraction of 41%.

Table 3. ZEH5 energy use, January 2006-December 2006

Month	Space heat (kWh)	Space cool (kWh)	Solar WH from Energy Gauge	Other from energy gauge	Total electric (kWh)	Solar generated (kWh)	Daily cost
Jan-06	195	0	136	515	846	154	
Feb	237	0	90	465	792	176	
March	118	0	62	515	695	253	
April	0	284	29	499	812	283	
May	0	91	20	515	626	280	
June	0	242	9	499	750	294	
July	0	321	4	515	840	300	
Aug	0	579	10	515	1104	270	
Sept	0	217	21	499	737	229	
Oct	92	0	36	515	643	221	
Nov	91	0	84	499	674	169	
Dec	172	0	117	515	804	110	
Total	905	1734	618	6066	9323	2739	
Annual cost	$63	$121	$43	$425	$653	-$411	
Daily cost				$1.16	$1.79	-$1.13	$0.66

Energy savings compared to the Building America Benchmark

By using the software program Energy Gauge a benchmark model was constructed as a baseline comparison. The benchmark home followed the Building America Definition as described in (Hendron, 2007) to be compared to the ZEH5 one story. When the comparison was completed, ZEH5 required 62% less off-site energy as the Building America prescribed Benchmark House. Without the solar PV system the one-story ZEH5 is a Building America 47% energy saving house. This house has a HERS index of 35 and would qualify for the IRS $2000 builder tax credit. The Benchmark house has a HERS index of 110. Table 4 shows where the improvements in the home were made to lower energy usage. The heating and cooling loads were the two largest reductions, followed by the water heater and the lighting. The only other energy savings reported is from the energy star refrigerator. The plug loads and all the remaining appliance energy usages between the ZEH5 and the Benchmark house are assumed to be the same as called for in the Building America energy savings methodology. The remaining appliance and plug loads represent 62% of the total energy consumption of this all electric house. If you compare this to the smaller total after subtracting the onsite solar PV generation this amounts to 87% of the energy needed from off-site. ORNL is working with several major manufacturers to substantially reduce these loads with no negative impact on expected energy services in American homes.

Table 4. Building America Site Energy Consumption

	Annual Site Energy	
	BA Benchmark	BA Prototype
End Use	(kWh)	(kWh)
Space Heating	5148	1388
Space Cooling	2559	945
DHW	2709	901
Lighting	1155	322
Appliances + Plug	5950	5756
Total Usage	17521	9312
Site Generation	0	2697
Net Energy Use	17521	6615

Tables 5 and 6 show the features used to generate the computer model comparison of ZEH5 and the Benchmark house. Table 7 shows the energy and dollar savings of individual components of ZEH5. The entire package of features saves almost $1000 per year with the PV generation and the $0.15/ solar kWh buyback. For this house to attain a DOE Building America 40% saver status all but the solar PV features are needed. This includes the geothermal heat pump and the solar water heater.

Table 5. Envelope technology packages in test houses

House	Benchmark House	ZEH5
Stories	1	1
floor ft^2	1232	1232
Conditioned volume ft^3	12,689.6	12,689.6
Foundation	Insulated unvented crawl same volume as ZEH5, R-9.46	Walk out unconditioned – unvented crawlspace (basement with no interior steps to conditioned top floor) with exterior insulated block walls (nominal steady state R-value of (R-11) Concrete Slab, insulated underneath with R-10 XPS and exterior apron of R-10 XPS on south side
1st Floor	No insulation in the floor	No insulation in the floor
Walls	2 x 4 frame, Ins R-value 13.16, framing factor of 0.23, sheathing with 0.5 R-value, vinyl siding with solar absorptance of 0.5.	6.5 in SIPS 1#EPS (R-21), structural splines-wood I-beams, framing fraction for north wall= 0.026, east=0.06, south=0.04, west=.02, house wrap, vinyl siding with solar absorptance of 0.5.
Windows	55.45 ft^2 window area on each 4 walls totaling 221.8 ft^2, U-facto and SHGC of 0.58, no overhang	10 windows, 138 ft^2 of total window area, 0.34 U-factor, 0.33 SHGC, VT=.55, sill seal

		pans
Doors	2-doors, one solid insulated, one half view both with U-value of 0.2	2-doors, one solid, one ½ view insulated, both with U-value of 0.2
Roof	Attic floor (R-27.78), framing fraction of 0.11	Cathedral ceiling, 8 in SIPS 1#EPS plus 2 in XPS (R-35), I-joist splines, framing fraction of 0.013
Roofing	0.75 solar absorptance, composition shingles , attic ventilation ration 0.0033 (1 to 300)	15 in. Brown standing 24GA steel seam, 0.31 reflectivity
Infiltration	SLA = 0.00057, ACH(50)= 8.16	SLA=.00012, ACH(50)= 1.65

Table 6. Equipment technology packages in test houses

House	Benchmark House	ZEH5
Heating and Cooling	Unitary 2 ton HP, SEER 10, SHR= 0.75,cooling capacity = 23.3 kBtu/hr, 699 CFM, HSPF=6.8, heating capacity=38.8 Btu/hr,	2 ton water-loop geothermal, R-410A, variable speed ECM indoor fan EER 18.8, cooling capacity 24.7 kBtu/hr, 700 CFM, no desuperheat recovery, COP=4.4,heating capacity 21.7 kBtu/hr
Thermostat settings	76 F in summer, 71 F in winter	76 F in summer, 71 F in winter
Mechanical Ventilation	None	Supply to return side of coil, bath fan exhaust, fixed run time of 33%, supply ventilation rate = 63.7 CFM, exhaust ventilation = 36 CFM
Duct location	Crawl space, R-5, Supply area 332.64 ft^2, Return area 61.6ft^2, duct air leakage=15%	Supply Inside conditioned space, return in crawl, duct air leakage= 9.45%, R-5, Supply area 250 ft^2, Return area 40 ft^2,
Air Handler location	Crawl space	Crawl space
Water Heater	Electric, 50 gal capacity, EF=0.86, usage= 47 gal/day, set temp=120F	Solar Water Heater, 80gal, EF =0.88, set temp = 120F, 40 ft^2 collector area, PV pump, usage= 47 gal/day, set temp=120F
lighting	20% fluorescent, 80% incandescent,1154 kWh/yr	100% fluorescent, 322 kWh/yr
Solar PV system	None	20-110W polycrystalline 2.2 kWp

Notes for tables 1 and 2: ECM = electronically commuted motor; EF = energy factor; EPS = expanded polystyrene; HP = heat pump; HPWH = heat pump water heater; HSPF = heating seasonal performance factor; OSB = oriented strand board; SEER = seasonal energy efficiency rating; SHGC = solar heat gain coefficient; SIP = structural insulated panel; XPS = extruded polystyrene

Table 7. ZEH5 individual technology energy savings using the Building America Benchmark definition.

ZEH5				National Average Energy Cost*		Builder Standard (Local Costs)**			
	Site Energy	Est. Source Energy				Energy Cost		Measure	Package
	(kWh)	(Mbtu)	Savings %	($/yr)	Savings (%)	($/yr)	Savings (%)	Value ($/yr)	($/yr)
BA Benchmark	17521	188.9		$1,752		$1,226			
Benchmark + improved roof R-value & reflectivity	17519	188.9	0%	$1,752	0%	$1,226	0%	$0	$0
Benchmark + improved wall R-value	16969	183.0	3%	$1,697	3%	$1,188	3%	$39	$39
Benchmark +foundation R-value	16959	182.9	3%	$1,696	3%	$1,187	3%	$1	$39
Benchmark + high performance windows & smaller window area	15829	170.7	10%	$1,583	10%	$1,108	10%	$79	$118
Benchmark + lighting	15032	162.1	14%	$1,503	14%	$1,052	14%	$56	$174
Benchmark +energy star fridge	14854	160.2	15%	$1,485	15%	$1,040	15%	$12	$187
Benchmark + tighter envelope, mechanical ventilation, &smaller ducts	13517	145.7	23%	$1,352	23%	$946	23%	$94	$280
Benchmark + geothermal	11154	120.3	36%	$1,115	36%	$781	36%	$165	$446
Benchmark + solar WH	9312	100.4	47%	$931	47%	$652	47%	$129	$575
Site Generation	2697								
Benchmark ++ PV	6615	71.3	62%	$527	70%	$247	80%	$405	$979

*national average = $0.10/kWh
**local residential rate = $0.07/kWh, solar buy back = $0.15/kWh
***assume national average residential rate of $0.10 and utility buy back for solar of $0.15

First Cost. Table 8 shows the costs for all five houses and for a base house of similar size in the same locale. The costs of volunteer labor and donated materials are factored in. The costs of building the five study houses (not including the cost of ZEH5 two-story) ranged from about $93 to $113/ft^2. The base house cost was about $70/ft^2. The fifth house with a walk-out unfinished, unconditioned and insulated basement is \$114/ft^2. This house in 2007 was converted to a conditioned 2632 ft^2 two story and with the estimate of about \$24,139 to finish off the basement dropped the cost to \$62/ft^2. The national average cost of finishing a basement reported in Remodeling Magazine in 2001 reported \$30/ft^2. This converts to \$42K. Using this higher estimate would result in a cost for the larger house of about \$70/ft^2.

Table 9 has detailed cost break down for ZEH5. In an attempt to add the cost for a builder to construct this house a 20% builder overhead and profit was added to the estimated total cost. This leads to an over all estimated cost of \$172,000. This represents an estimate of the market sale price for this house with a lot cost of about \$22,200. So if you wanted to ball park the cost of a builder constructing this house on your lot it comes out to about \$150,000. The authors believe this is a reasonable estimate for a very low cost finish out. Upgrading from vinyl to Hardy Board siding, linoleum to tile bath and kitchen flooring, a few more windows and doors could take this construction cost to more than \$200,000.

Table 8. Construction cost of test houses and base house (\$)

	Base 1060 ft^2	ZEH1 1060 ft^2	ZEH2 1060 ft^2	ZEH3 1060 ft^2	ZEH4 1200 ft^2	ZEH5 1232 ft^2	ZEH5 2632 ft^2
House	59,295	78,914	83,953	87,889	85,189	109,788	133,927
Land and infrastructure	14,500	14,500	14,500	14,500	14,500	18,500	18,500
Cost of solar	0	22,388	16,000	16,000	14,935	15,000	15,000
Incentives (Fed+TVA)		-2,800	-2,800	-2,800	-2,800	-2,800	-2,800
Total cost	73,795	113,002	113,153	119,529	111,824	140,488	164,627
\$/ft^2	69.62	106.60	106.75	112.76	93.18	114.03	62.55

Table 9. Detailed construction cost for ZEH5 one story test house (\$)

Phase Code	Phase Description	ZEH5-1story estimate	ZEH5-2story estimate
001	Site Preparation	4,591.01	4,591.01
003	Foundation	13,794.88	13,794.88
004	Termite Pre-Treatment	-	-
005	Framing and Decking	7,708.71	7,708.71
006	Trusses	-	-
007	Roofing Materials	133.06	133.06
008	Roofing Labor	-	-
009	Guttering	325.00	325.00
010	Windows	250.00	250.00
011	Bathtub and Water Heater	720.68	720.68
012	Exterior Doors	303.50	830.50
013	Siding and Scaffolding	1,794.04	1,794.04
014	Plumbing Materials	2,000.00	2,717.39
015	Plumbing Labor	1,700.00	2,606.25
016	Toilets	157.53	157.53
017	HVAC	450.00	450.00
018	Insulation	-	-

019	Sheetrock Materials	1,167.17	167.17
020	Sheetrock Labor	1,871.03	1,871.03
021	Interior Doors	926.69	926.69
022	Paint	286.59	286.59
023	Trim Molding and Casing	-	-
024	Cabinets	2,297.08	2,297.08
026	Closet Maid	-	-
027	Flooring	1,600.00	1,600.00
029	Electrical Materials & Fixtures	1,800.00	2,218.28
030	Electrical Labor	-	-
031	Landscaping	647.38	647.38
032	Driveway	2,260.32	2,260.32
033	Final Grade	1,000.00	385.00
037	Storage Building	900.00	900.00
039	Land & Infrastructure Costs	14,500.00	14,500.00
040	Miscellaneous	300.28	300.28
050	extra excavation for geo loop and labor to install basement floor insulation	715.16	3,215.16
055	Closing Costs	100.00	100.00
	Total Expenditures	64,300.11	67,754.03
	Construction Overhead	5,000.00	5,000.00

Donations:

003	Foundation Labor	467.00	467.00
009	Gutter installation	136.00	136.00
010	Windowsills	-	-
027	Flooring	200.00	200.00
039	Land & Infrastructure Costs	4,000.00	4,000.00
045	Miscellaneous:	-	-
	Labor	6,000.00	10,000.00
	CenterPoint Flood Services	-	-
	Campbell & Associates	-	-
	Southeastern Title	345.00	345.00
	Total Donations	11,148.00	15,148.00
	Total	80,448.11	87,902.03

ORNL donations		
SIPS	17,000.00	17,000.00
Andersen Windows	2900	3830
Andersen Patio door		1000
Englert roof (per Tony august 18,2006, 06 costs)	6950	6950
Solar water heater	2400	2400
solar water heater installation	800	800
DuPont tyvek and window install	1,200.00	1,200.00
HVAC (City Heat and Air), labor	1500	1500
Water furnace equipment & piping	4000	4000

Coil install	1500	1500
aircycler	150	150
Tremco foundation system	7000	7000
Gordon Myers donated time &equipment	1300	1300
Dow XPS	1100	1100
pipe insulation	40	40
PV system	15000	15000
Basement finish out		
interior wall framing		2400
drywall		2000
steps to upstairs		3000
HVAC ducts		655
flooring materials		1600
flooring labor		1000
bathtub		300
more plumbing		800
interior doors		500
more electrical wiring		1300
bathroom cabinets		1200
SUM	$143,288.11	167,427.03
Contingencies of 10% added	$157,616.92	$184,169.73
Builder profit and over head 20%	$189,140.31	$221,003.68
total no contingencies	$171,945.73	
$/ft2 with 10% contingencies and 20% builder profit and overhead	$152.53	$83.97
$/ft2 with no contingencies and 20% builder profit	$138.67	

2. Floor Plans, Cross Sections, and Elevations

2.1 ZEH5 Introduction

Figure 3.   Picture of ZEH5 from the street of the East Elevation.

ZEH5 is a 1232 ft^2 one-story dwelling with a walkout unfinished basement shown in Figure 3. This home's ultimate design intent is to have the basement walk-out completely finished and conditioned. For this report we will only be looking at the top floor. The top floor plan, shown in Figure 4, has four bedrooms, a living-dining room, a kitchen, a laundry room, and 2 baths. The walls and roof are made of 6.5-in. and 8-in. SIP panels respectively. The SIP panels, shown in Figure 5, used on ZEH5 are made of expanded polystyrene insulation sandwiched between two 7/16-in. sheets of oriented strand board (OSB). Another 2 in. of XPS is added on top of the 8 inch thick SIP roof before installing the metal roofing. The XPS is picture framed in on the roof as shown in Figure 6.

Figure 6 Two inches of XPS is laid directly on top of the 8 inch thick SIP roof panels.

The air changes per hour (ACH) at 50 Pascal is 2.5. The HVAC unit is a 2-ton water-loop geothermal with a variable-speed indoor circulating fan. The geothermal ground loop was installed without having to do additional excavation beyond what was needed to construct the foundation and connect the buried utilities. The hot water for ZEH5 comes from the solar water heater, shown in Figure 7 that has a 11 W PV panel powering a 12V DC pump. The two solar water collectors have a total net area of 37 ft^2. The roof is a reflective brown 24 gauge standing seam steel roof with a 4/12 pitch. The PV system assumed is the same as the one installed on ZEH4, which has 20-110W modules and is rated at 2.2 kWp.

Figure 7. Solar Water Heater collectors.

Figure 5. SIP panels for ZEH5 come all numbered to match the panel cut drawings and should be staged on site with the panels stacked in the order they will be installed.

2.2 Floor Plan

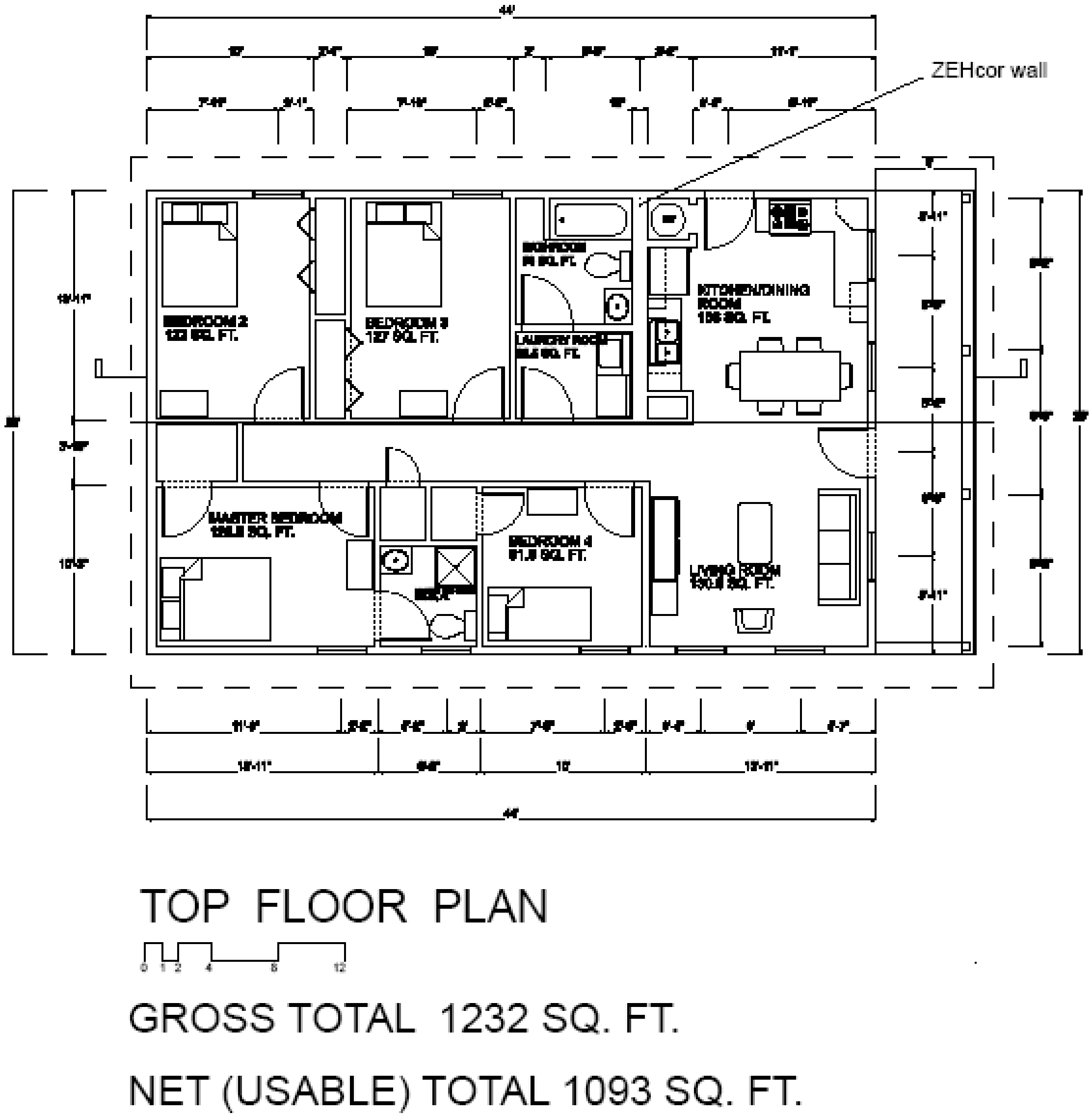
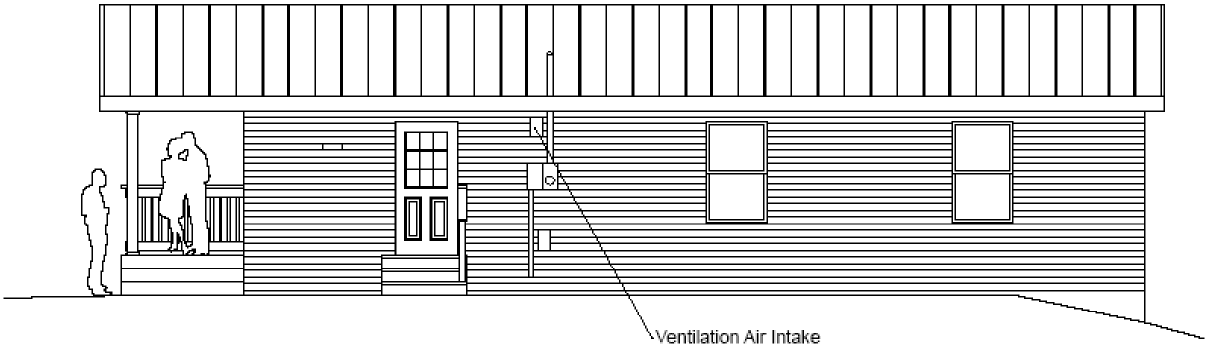


Figure 4. Floor Plan of ZEH5. Notice the location of the 12 inch thick ZEHcor wall. Note none of the interior walls are structural allowing very easy changes to room layout and much more open floor plan and options of 1, 2 or 3 bedrooms.

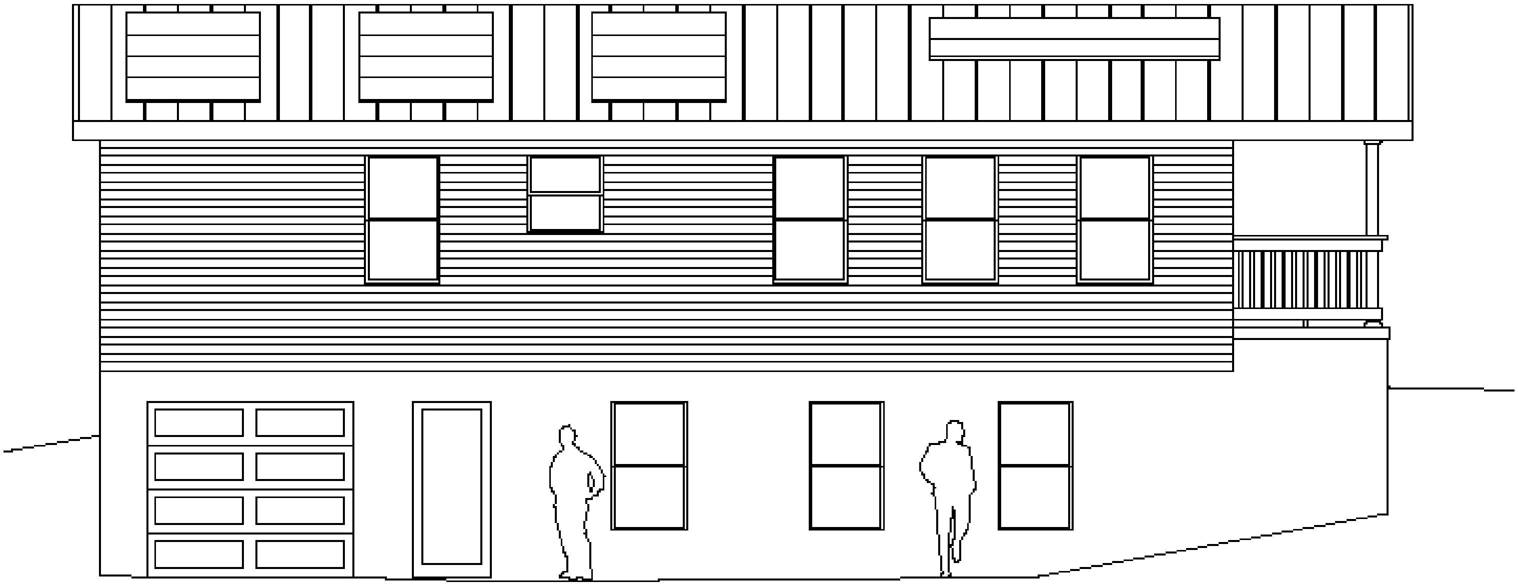
2.3 Elevations

Figures 8 through 11 show the four elevations of ZEH5 which meets the criteria for a simple affordable Habitat for Humanity type house.



NORTH ELEVATION

Figure 8. North Elevation of ZEH5. Notice the electric power feed into the house, ventilation air intake (high), and drier outlet (low) line up with the utility wall located between the kitchen, bathroom, and laundry rooms.



SOUTH ELEVATION

Figure 9. South Elevation of ZEH5. The collector area is to scale. Most of the windows in this house are positioned on the south elevation and provides very pleasant day lit space. The garage door in this house was to accommodate the Habitat Affiliate which used this space for tool and construction material storage during the two year testing period prior to making available to a family. The garage door, patio door and 3 windows in the unconditioned basement are not included in the cost for the 1- story.

EAST ELEVATION

Figure 10. East Elevation of ZEH5. The full length porch on the front is covered with SIPs that are runout from the rest of the house. The space under the front porch is a full 8 ft high and is surrounded with R-10 board insulation on all exterior surfaces including the porch floor. Pouring a concrete porch on top of XPS insulation board requires careful tie-downs to make sure the boards do not float out of place during the pour.

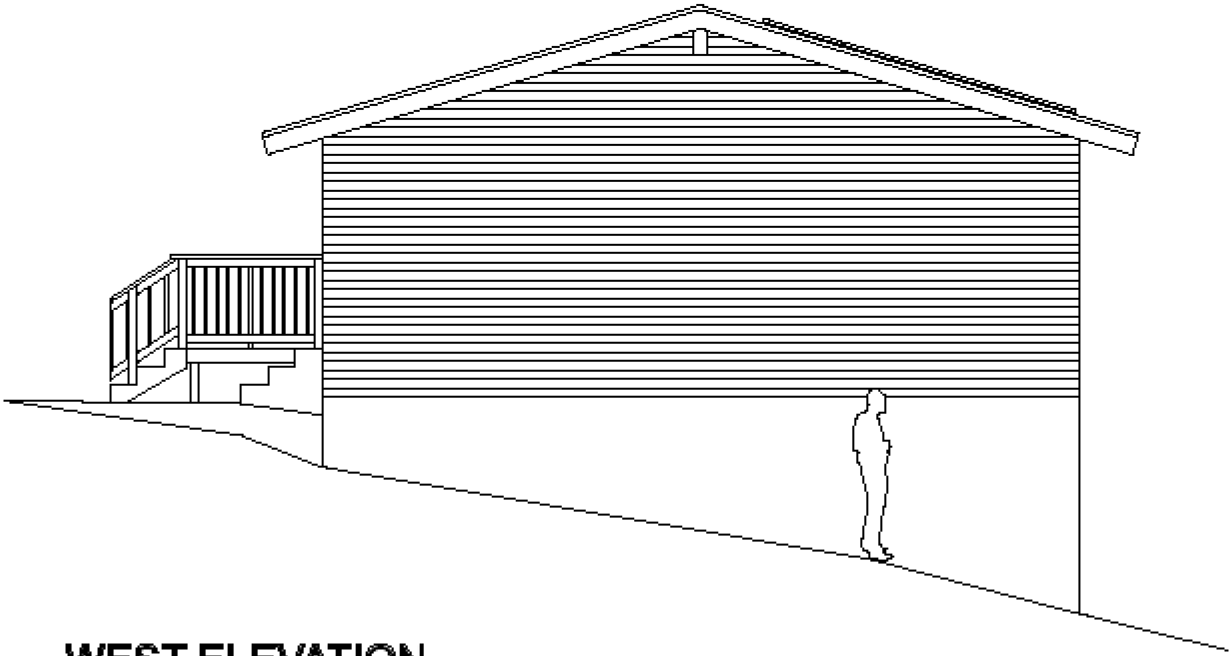


Figure 4. West Elevation of ZEH5. The absents of windows, is due mostly to the limitations placed by Habitat for Humanity in this development on the number of total windows allowed per house. Modeling with as many as four additional 30-50 high performance windows in this house have very minimal impact on peak or annual energy loads.

2.4 Cross sections

Figures 12 and 13 show the cross sections of ZEH5. The 52 foot ridge beam shown in Figure 13 was site assembled with 4-2X12s glued and bolted together to make a full length beam that extended from the outside face of the west wall all the way to the outside edge of the East gable overhang. Raising this beam into place must be done with a well thought out safe lifting plan; include proper rigging, crane and crew. It is recommended that glulam or other type of engineered ridge beam be considered rather than site assembly with dimensional lumber. Of course solid lumber post and beam construction is another option for a more upscale version of this home.

Figure 12. Longitudinal section through ZEH5, location marked on the floor plan in Figure 4.

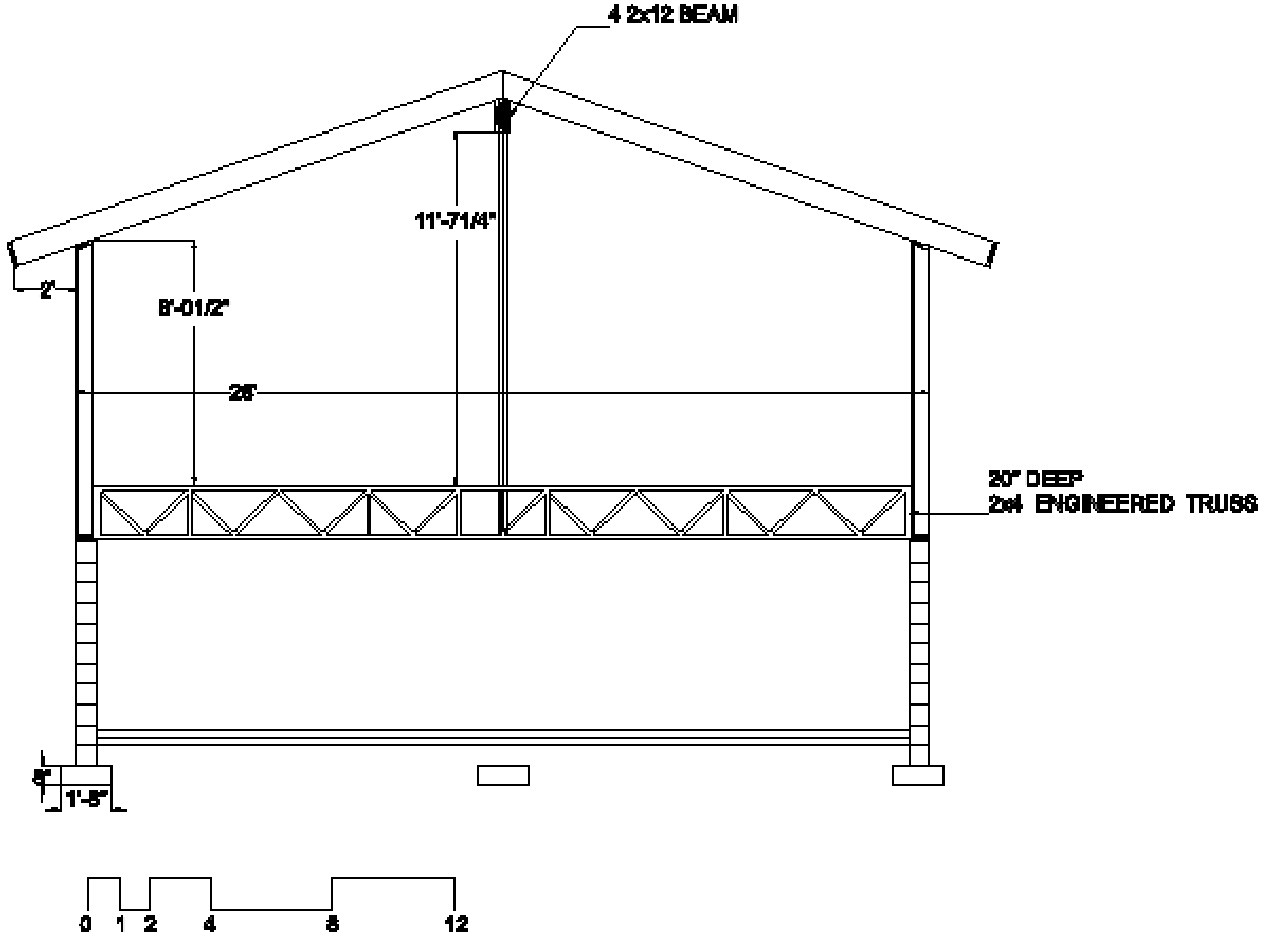


Figure 13. Basic building cross section.

2.5 SIP Cut Drawings

Figures 14-19 are from the SIP manufacture, Premier Building Systems. These drawings start with the digital .dwg files sent to the SIP manufacture from the builder. It is extremely important that the location and size of the window and door rough openings are correctly captured on these panel cut drawings. Structural load points and wire chases should all be clearly marked. The thickness of the wall and ceiling panels as well as the type of splined panel connection is also critical. The floor and foundation interface details need to be clearly illustrated on both the builders original drawings as well as what is drawn on the SIP manufacture's cut drawings.

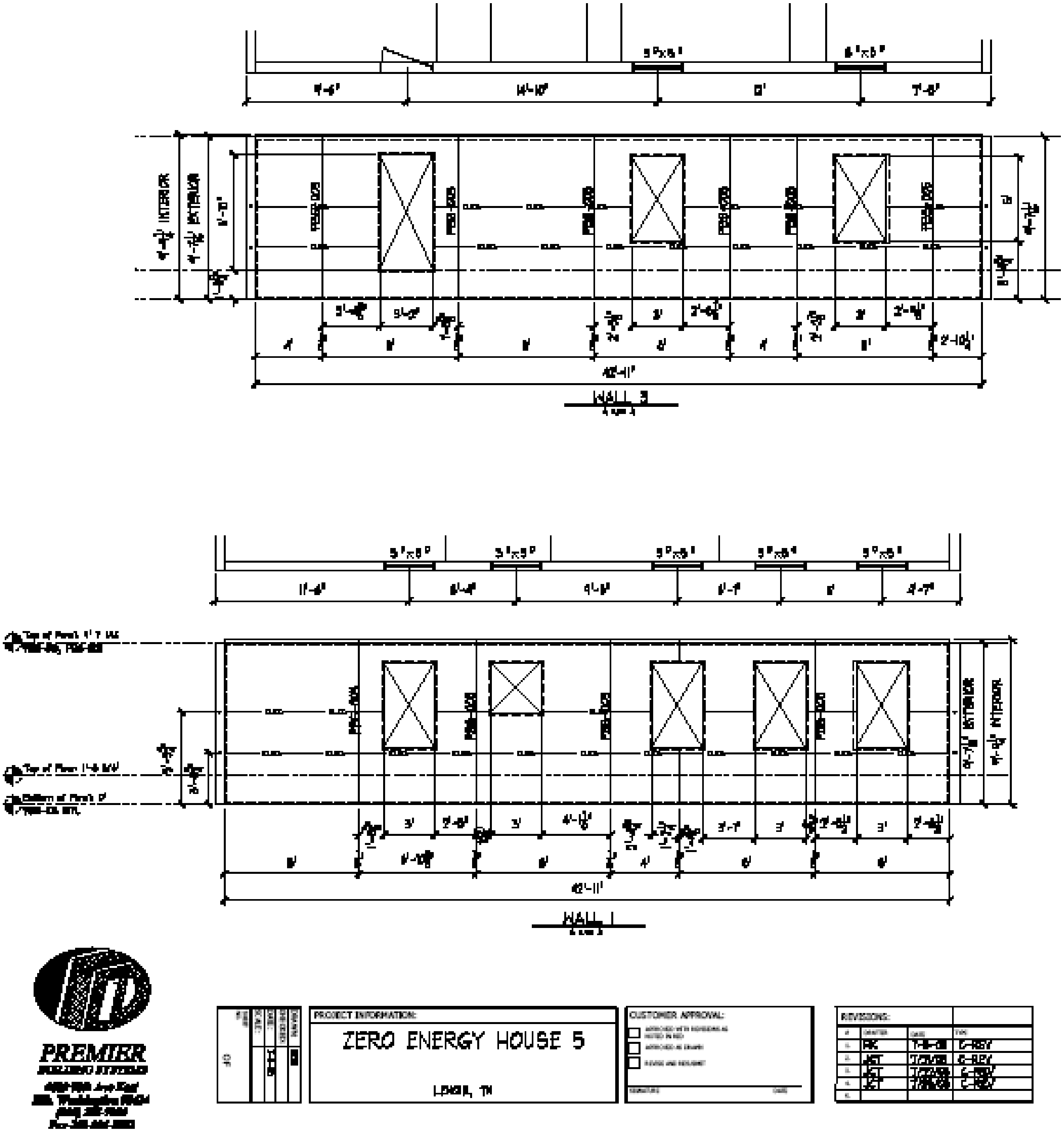


Figure 14. Shows panel layout of the north (labeled wall 3) and south facing (labeled wall 1) walls.

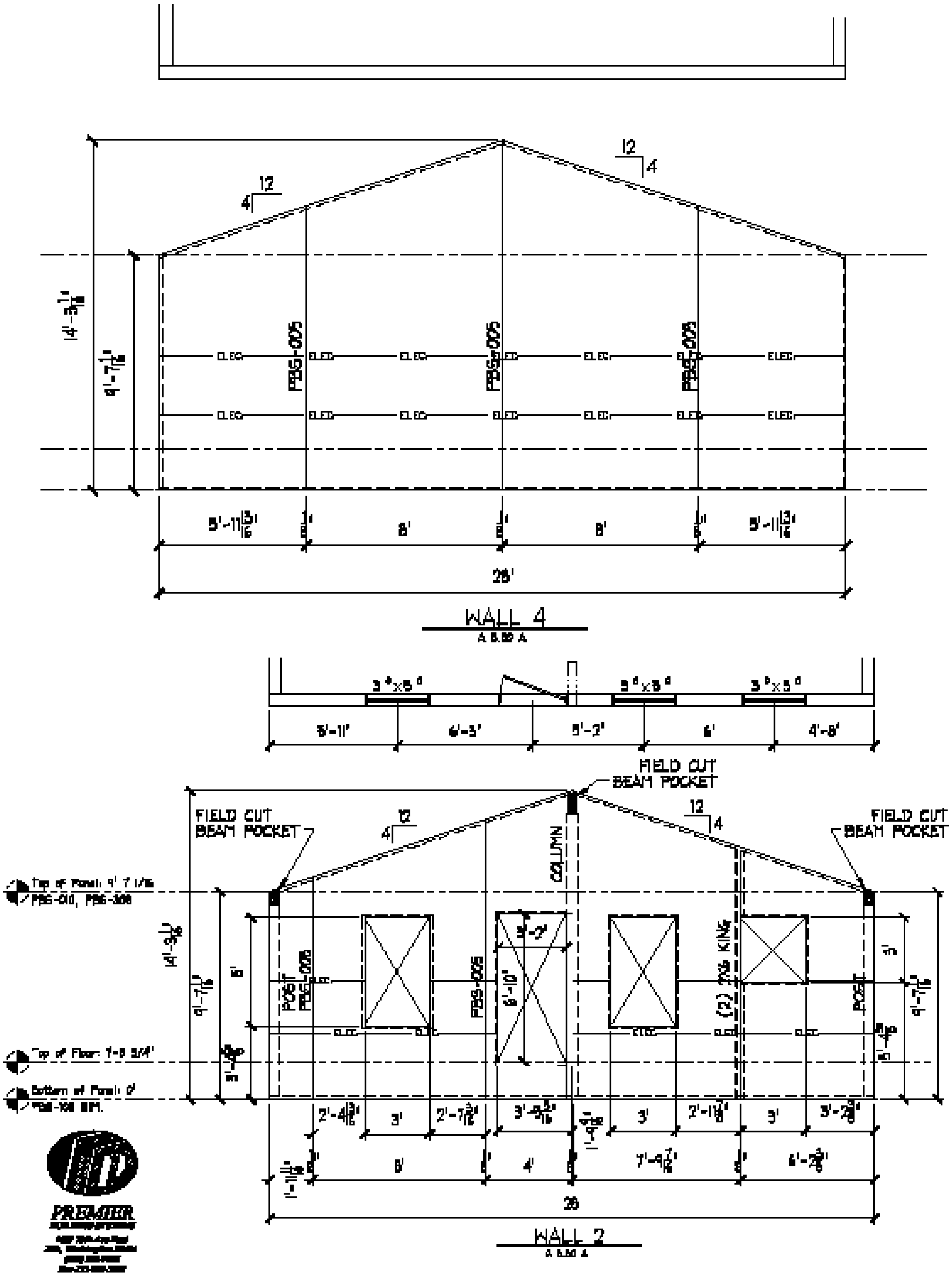


Figure 15. Shows layout of walls 2 (east) and 4 (west). The west wall was modified on the site to contain a column to support the full length ridge beam similar to that shown in the east wall.

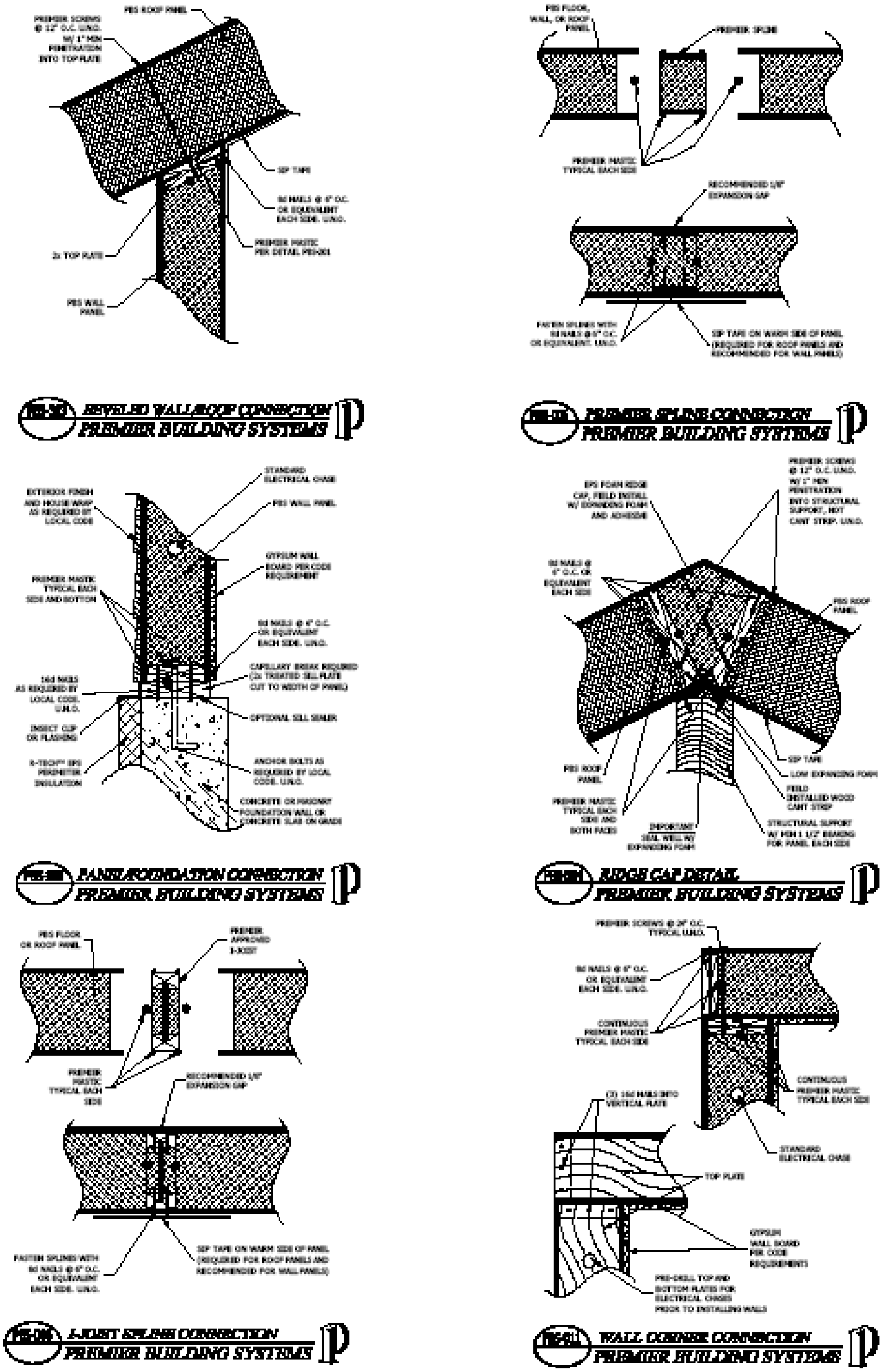


Figure 16. Shows various connection details. The panel foundation detail shown in this figure was not used please see the foundation detail in Figure 27.

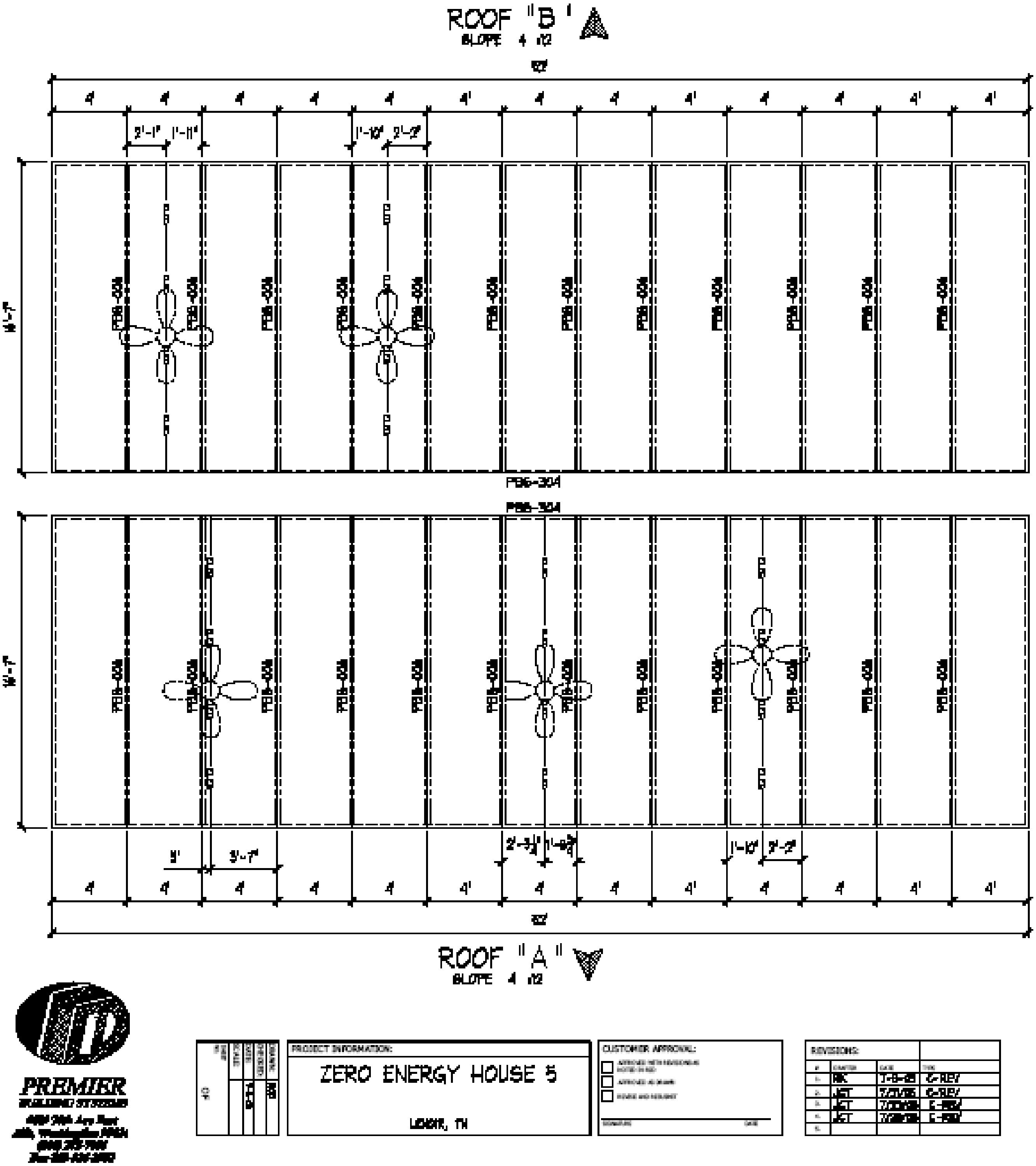
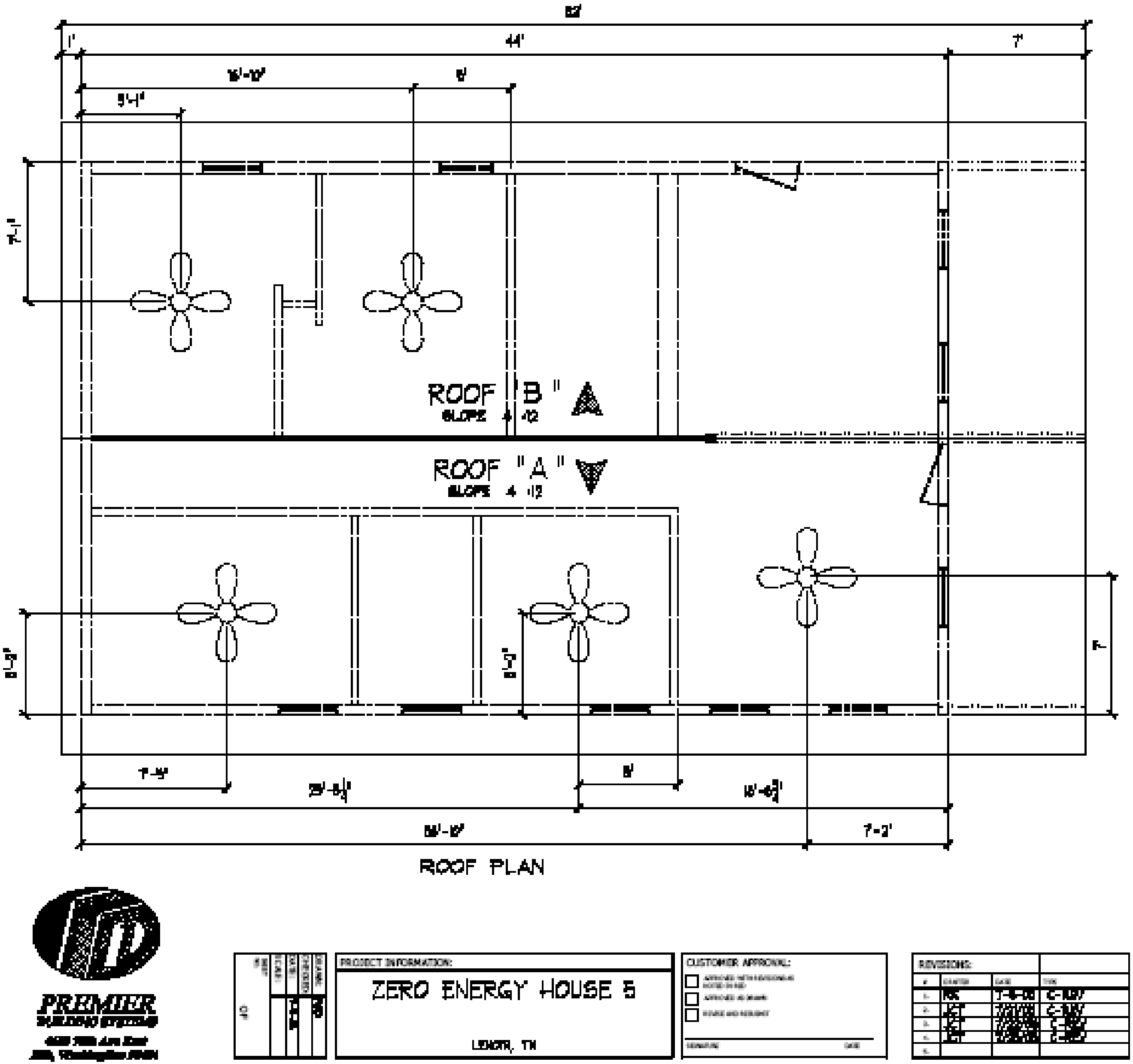


Figure 17. Shows roof panel layout. These panels carry over the front porch.



PREMIER

Figure 18. Shows ceiling fan location and interior wall placement. The positioning of the ceiling fans is important in order to provide structural wood to fasten securely to the ceiling panels. Routing the wire chases to switches and power must also be detailed on these drawings.

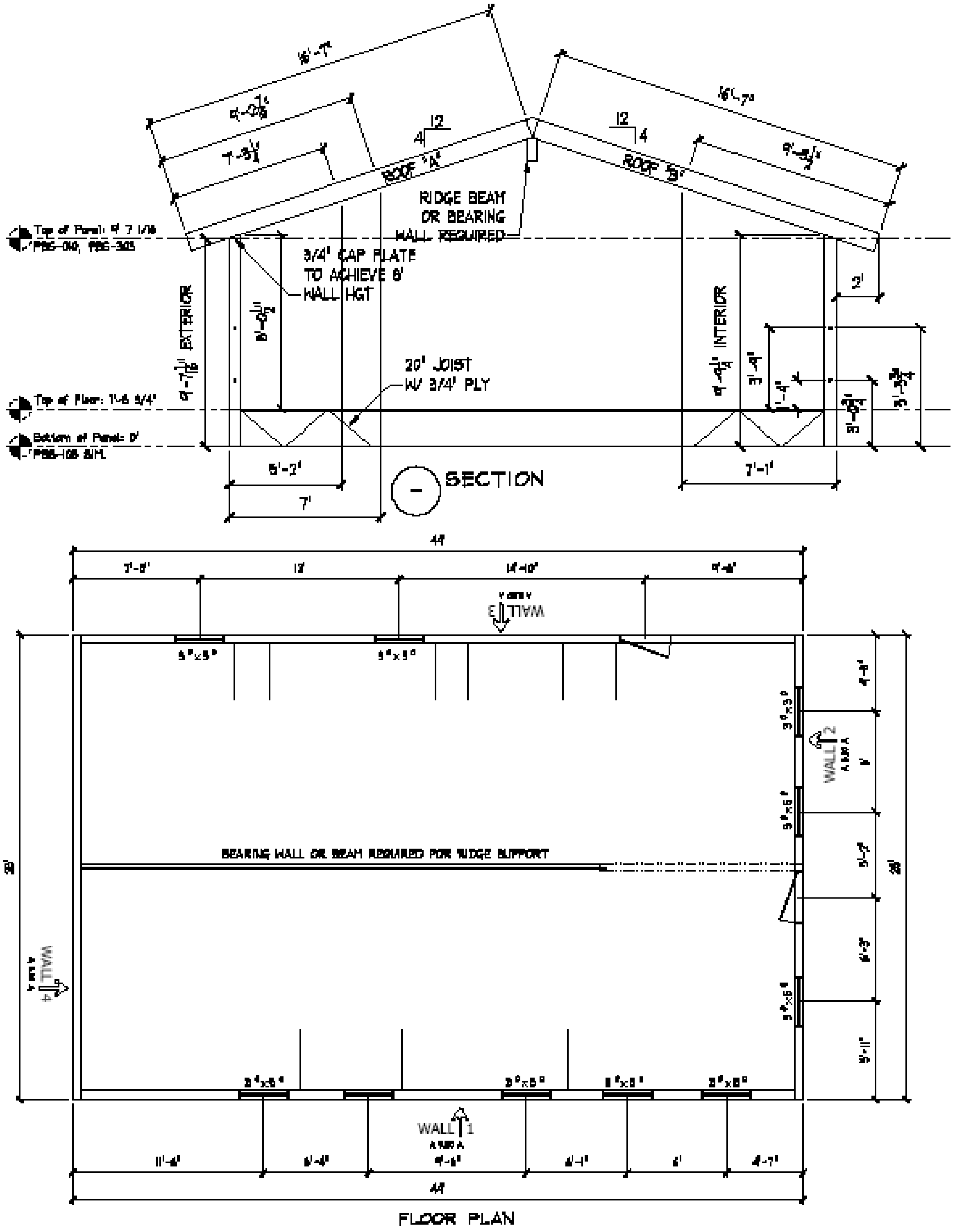


Figure 19. Shows basic section and structure requirements. The extended overhangs are SIPS and this has substantial labor savings compared to site assembled roof extensions.

3. Site Characterization and House Orientation

Selecting a site that encourages an orientation to the south in the mixed-humid climate will make it easier to reach 40% energy savings. This may mean picking lots or sites with views from the house to highlight those that are predominately to the south. Allow for vegetative screens on the west side to minimize the impact of the hot sunny summer afternoons on the cooling load of the building walls. Select the plantings carefully so that you do not cut solar access to the roof collectors. Southern sloped lots are best for capturing maximum daylight year around, winter time passive heating, and ease of shading to minimize unwanted solar heat gain in the summer. Southern sloped lots that allow walk-out basements not only capture more daylight and passive heating but also provide low-cost space and thermal mass, if insulated and ventilated correctly, that contributes to annual energy savings and lower peak space heating and cooling loads. North-sloping lots give off longer shadows.

In planned sustainable communities that ultimately want at least half of the house roof space preserved for photovoltaic (PV) panels and solar hot water and do not want the modules to make a major visual statement from the street or the back yard decks, lots may be laid out with the longer dimension perpendicular to the street. This also allows for high density “streetscaping” in Traditional Neighborhood Developments that continue to gain popularity in 2007. The narrow lot dimension reduces the street paving and utility infrastructure and allows land somewhere else in the development to be preserved. The ZEH5 plan provided in this report fits this growing need.

High performance house development, street and lot layout that is conducive to 40% energy saving houses as initially built should always be sensitive to keeping the longer term capacity to add solar PV and HW. The general solution is to develop conservation communities with the housing in higher density patterns. The smaller lots are more conducive to the ZEH5 shotgun-style house plan detailed in this report. Planned urban developments or conservation developments are allowed in many building zoning ordinances. Thus keeping the same number or more lots and optimizing for the maximum number of solar access lots gets the development off in the right direction for reaching zero peak energy and ultimately zero annual energy. Preserving land gives the whole development the flexibility to include natural noise barriers, maximize solar access, and increase lot value. A general rule of thumb in East Tennessee is that every foot of road, with storm water, sewer and potable water, adds $325-$400 to development cost (Henry, 2007). This does not count excavation which can vary depending on the amount of rock. Infrastructure cost savings can be put into more thoughtful layout of small, deep, long, narrow lots with minimum road and utility distribution expense and maximum solar roof access.

ZEH5 was modeled using Energy Gauge (FSEC 2006) and then rotated in each cardinal direction, north, south, east, and west. The heating and cooling energy for a south orientated ZEH5 are shown in the Table 4. Table 10 shows the impact on heating and cooling energy if the house is orientated in other directions.

Table 10. Heating and cooling loads calculated for ZEH5

	% higher than true south orientation
South	
East	4.7%
West	4%
North	2.5%

4. Envelope Specifications

Table 1 highlights the envelope technologies used in these test houses. The total daily energy costs for these houses ranged from $0.66 to $1.04 per day, compared to $3.36 per day for a benchmark house (ASHRAE 2005, ASHRAE 2006A, ASHRAE 2006B, ACEEE 2006, FEMP 2006).

4.1 Foundation; Crawl Space (Basement)

Figure 20 shows an exterior insulated foundation similar to that used in ZEH5. ZEH5 actually used a standard 10 inch 2-hollow core block wall with the floor truss resting on top of the wall rather than 12 inch and hung floor trusses as shown. However the rest of the detail is correct.

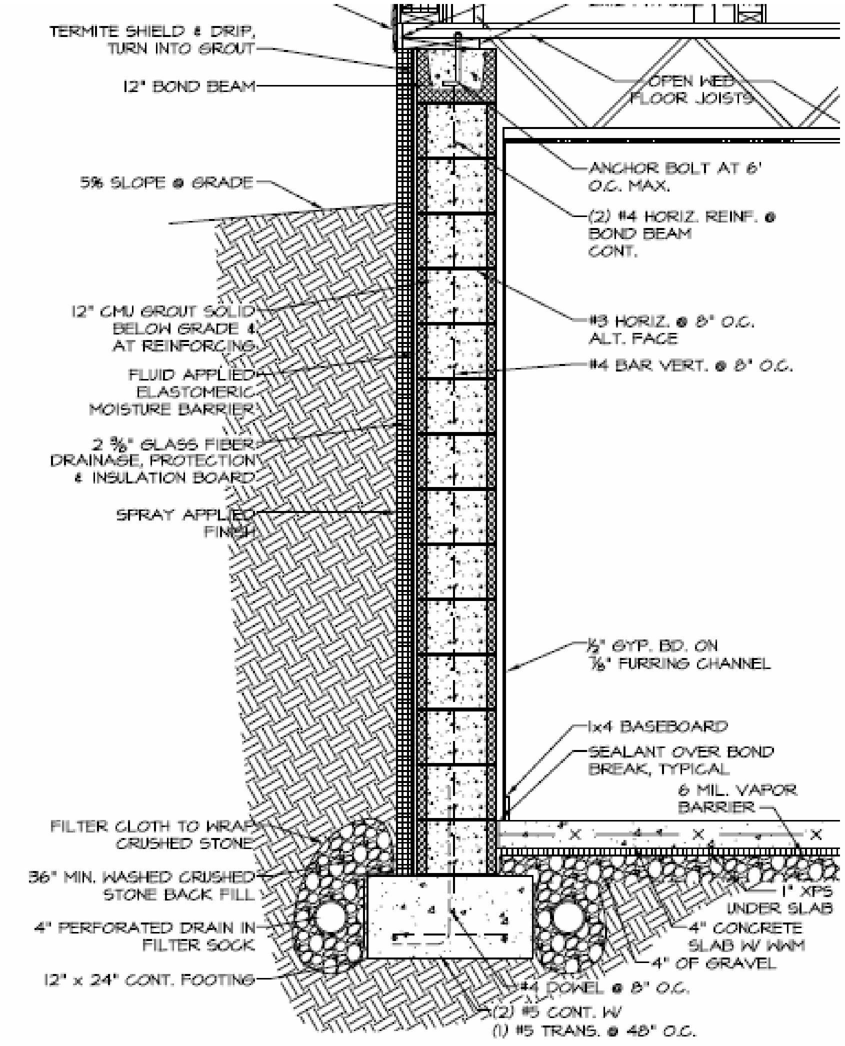


Figure 20 ZEH5 Foundation detail

The waterproofing, insulation and above grade finish system is Tremco's www.guaranteedDryBasements.com . The waterproofing is a water based polymer/asphalt spray applied membrane as shown in Figure 21. It is applied 60 mils thick when wet directly to the outside of the masonry wall, which will be below grade, after the mortar is dry and all loose aggregate and sharp protrusions have been removed. The water vapor permeance is reported by Tremco at 0.08 perms for 40-mil dry coating using the ASTM E-96 dry-cup method.

Figure 21 Waterproofing

Two and 3/8 inch thick fiberglass drainage board, with a density of 6 lb/ft^3 is placed over the waterproofing as it cures as shown in Figure 22. The area of the basement wall that is exposed above grade was covered with 9 lb/ft^3 fiberglass board with the same 2 3/8 inch thickness used below grade. The higher density was necessary to provide a firmer substrate in which to apply the Tremco elastomeric-emulsion based coating. This insulated board is mechanically fastened to the wall and has mesh-reinforcing on the outside surface. The lower density board was measured at ORNL according to ASTM C518 to be 10.0 hft^2 ^{o}F/Btu. The higher density board was measured at 10.2 hft^2 ^{o}F/Btu.

Figure 22. Installation of four by eight foot fiberglass boards sized to cover the waterproofing

The exposed fiberglass above grade is covered with Tremco's "Horizon Foundation Finishing System". Mesh strips are fastened over seams as well as the mechanical fastener indentations. A "fill" material is used to cover these locations to make the insulation a uniform surface for spray applied elastomeric coating. The preparation around inset windows shown in Figure 23, to place the window inside the drainage plane and still avoid thermal shorts, can be rather labor intensive. When ever possible the fasteners should be located slightly below grade when only small above grade wall heights are needed between grade level and the top plate. For larger areas the mechanical fastener indentations will need to be filled and leveled to avoid telegraphing through to the final surface.

Figure 23 Detailing around inset windows to avoid thermal shorts and minimize water penetrations is very important

The final step is the spray applied paint. Figure 24 shows this coating being sprayed on to the fiberglass board. If the paint is applied during high humidity periods as common in the hot humid climate and mixed humid climate avoid touching the surface for at least 24 hours. According to the manufacture, the 40 mil coating has a water vapor permeance of 6 perms as measured using ASTM E96.

Figure 24. The above grade portion of the foundation wall receiving final spray covering.

The foundation system is complete once the footer drains are run to daylight. Figure 25 shows footer drains on both the inside and outside the first course of basement block wall. These perforated drains were connected to a 4 inch plastic pipe with no holes and run to daylight on the southwest corner of the house. The foundation system in ZEH5 has had no leaks of any kind up to the time of this writing.

Figure 25. Footer drains run to daylight on both sides of the wall below the basement floor.

4.2 Walls—SIPs

We chose SIPs because of the whole wall hot box thermal performance and test room air-tightness tests performed at the ORNL Buildings Technology Center Laboratory test facilities. A SIP wall had the highest whole-wall R-value of 18 systems reported in (Christian, JE, Kosny J, "Thermal Performance and Wall Ratings "ASHRAE Journal March 1996). The whole-wall R-value we reported for a conventional 6-in. SIP was 21.6 hft^2/Btu. SIP houses when designed correctly have few thermal shorts and our first-hand experience with five test houses built in 2002–2005 demonstrated they are easy to consistently air seal. Blower door tests before and after drywall installation in all these houses showed that the final anticipated air tightness was the same as that measured before drywall. This makes it simple to seal the most likely source of overlooked leaks, which tend to be through the base plate of interior walls where most of the utilities come from the crawl space and attic into the conditioned space. We suggest specifying the peel-and-stick tape manufactured by Ashland Chemical (http://www.ashchem.com/ascc/) at panel to panel seams. The ridge and wall roof interface as well as all roof and wall seams at the corners and straight panel-to-panel connections are carefully taped as shown in Figure 26.

Figure 26. Peel-and-stick panel tape provides added insurance that panel seams will remain airtight.

SIP manufacturers that provided precut kits for these five near-ZEHs are found at the following web sites;

- Pacemaker Plastics, http://www.pacemakerbuildingsystems.com/ (ZEH1)
- FisherSIPS, http://www.fischersips.com/ (ZEH2)
- Insulspan, http://www.insulspan.com/ (ZEH3)
- Winter Panel, http://www.winterpanel.com/ (ZEH4)
- Premier Building Systems, http://www.premier-industries.com/ (ZEH5)

When working with SIPS the ten most important considerations according to Todd Helton, Habitat for Humanity Loudon County Affiliate Construction Supervisor and Certified Union Carpenter Trainer on ZEH2, ZEH3, ZEH4, and ZEH5, are the following.

Number 1; Trained personnel

Either train yourself or have trained personnel involved in the project at as early a stage as possible. The affordable zero energy house project at ORNL has spawned three educational programs;

1. The United Brotherhood of Carpenters of North America has prepared certified training for Union Carpenters. Todd Helton, the construction supervisor on ZEH5 helped develop this training and offers this course at the local Union Hall 50 located next to ORNL in East TN.

2. Cleveland State Community College in Cleveland, TN now has a two year program inspired by this research. The program is lead by Allan M. Gentry, Cleveland State Community College Technology Department. The school has approved curriculum for a one year Zero Energy Housing Certificate that focuses on 6 courses (17 credit hours). This curriculum is offered with flexible scheduling options to accommodate working adults. Distance and on-line learning options are coming in the future.

3. Four- and five-year collage programs are also becoming available that formally teach the building science behind the design and construction of zero-energy buildings with an experiential community outreach project consisting of the design, construction, and monitoring of an affordable ZEH. A good example is the University of Tennessee, Department of Architecture, where a Zero-Energy Building Series is now a formal module within the Environmental Management Controls Course (Arch 342). This module includes zero-energy house design, envelope systems including heat, air, and moisture management, whole-building energy performance simulation tools, HVAC sizing, and energy monitoring and analysis. The students review the five ZEH case studies and than design their own near zero energy house. This course was modified for Engineering Students at the University of Wisconsin Spring term 2007. The designs presented in a one hour, open to the community, lecture and one 3 hour workshop were the starting point for a 3 credit course. The community seminar gathered a number of practicing architects, builders, engineers and interested ZEH buyers to serve as a resource base in which the students could draw upon as they worked through their main class project. The project was a set of detailed design drawings and specifications for an affordable house as close to zero as practical for the local UW student Habitat for Humanity affiliate chapter to construct.

Number 2; Protect the panels

Avoid damaged panels — they take more time to install. Coordinate with SIP manufacturer to ship panels loaded to minimize handling of panels on site. Panel protection begins with on-site staging by stacking high, dry, and flat. It is generally the contractor’s responsibility to unload the truck when the SIPS arrive. Be prepared to stage the panels in a logical manner, first up is at the top of the pile closest to the foundation.

Number 3; The right equipment

This list includes a boom truck and proper rigging for lifting the ridge beam and SIP ceiling panels. An all terrain fork lift will also come in handy. For the occasional panel adjustment, foam hot wires and panel (beam) cutter should be on site. Beam cutting attachments are available to fit worm-drive circular and electric chain saws. If the foundation layout is not square you may have to cut one or more of the panels. Foam scoops are usually supplied as part of your SIPS package. The BBQ starter type foam scoops have a radius in the corners of about ½ in. and do not square the corners so you have to make another pass down each side with the iron turned 90 degrees to square the corners. On all five of the test houses the SIP manufacturer provided the caulk, one provided a power caulker. ZEH5 has 930 ft of panel seams. The wall/floor and wall/roof each require 4 beads of caulk totaling 1792 linear feet of caulk. The wall/wall and roof/roof seams each take 6 beads of caulk totaling 3492 feet of caulk. The ridge detail requires 8 beads of caulk totaling 416 feet. This totals 5092 ft of caulk. That is going from goal line to goal line on a football field 17 times. Get a power caulker.

Number 4; Foundation accuracy

There is less room in SIP construction than in stick construction for lack of plumb, level and square. The top of the foundation needs to have provisions for a termite shield and capillarity break. This can be an aluminum flashing traversing the top of the foundation from inside to outside the wall surfaces. It is also important that the outside skin of the SIP be fully supported to avoid creep and loss of structural integrity. Double-check to make sure you have the right dimensions for the footer, foundation wall, and floor on the design drawings, and follow up with measured confirmation of plumb, level, and square of the footer, foundation wall, and floor during construction. The foundation for ZEH5 was not as square as desired the end result is a 4 inch SIP wall section needed to be fabricated on site and added to the North wall.

Figure 27 shows the foundation/floor/SIP wall detail used on ZEH5. The floor truss length can not be changed once on site. The outside facing of the SIP must have continuous structural support the full length of the bottom edge. It would be best to leave a small gap between the SIP wall and the end of the floor trusses than to hang the SIP face over the edge of the top plate. Engineered floor joist and dimensional lumber floor joist can be cut on site and would be more forgiving of larger tolerances. The concrete subcontractor needs to understand that a SIP foundation must be closer to square, plumb and level than the industry accepted standard.

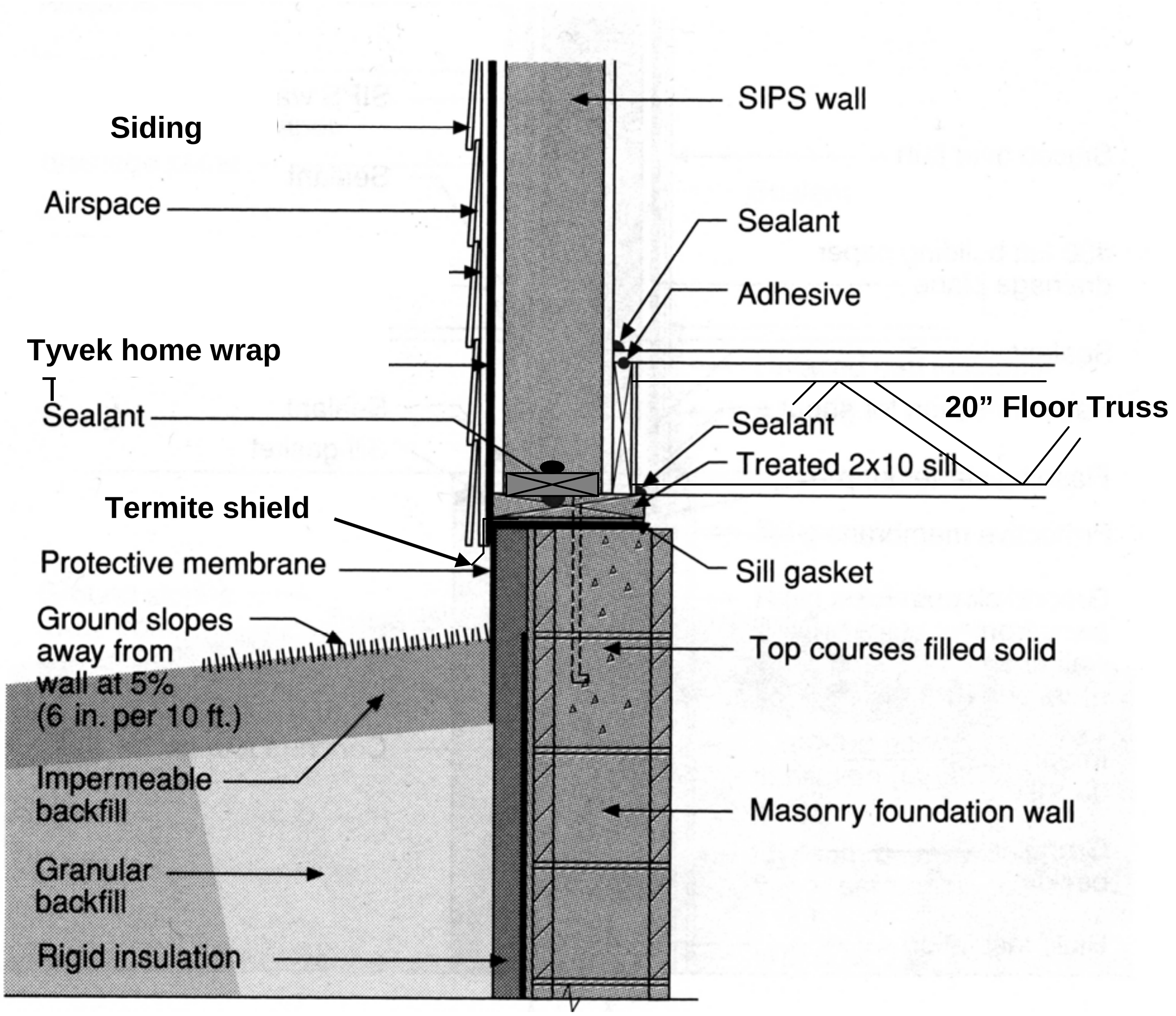


Figure 27 ZEH5 Foundation/floor/SIP wall detail

Number 5; Drain plane

> "*Water damage is the worst thing that could happen.*"
> — Todd Helton, Union Carpenter

The above grade wall drainage plane in the ZEH's is attained by wrapping the house with DuPont Tyvek (www.tyvek.com) and making sure the window/SIP interface is correct. This includes providing pans that drain only to the outside under each window and door as shown in Figure 28. The drainage plane must be continued at the base of the first floor by providing flashing that directs any wind driven rain water away from the wall at the wall/foundation junction.

With a SIP roof it is also recommended that a roof drainage plane be provided. Figure 29 shows the drainage plain between the #30 felt paper and the raised metal seam roof. This gap not only provides moisture control, it also provides a cavity in

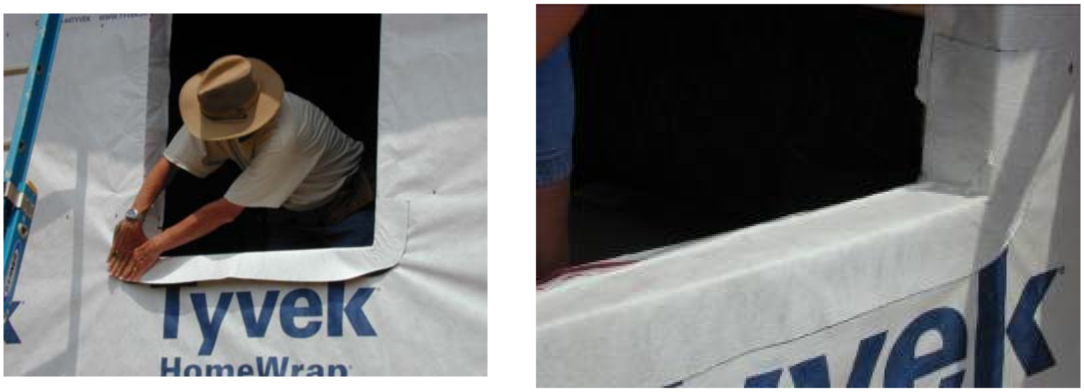


Figure 28. Panned window opening.

which natural convection will help keep the hot summer heat from penetrating into the conditioned space and will contribute to the cooling of the underside of the solar modules. The panel clip fastened to the SIP holds the metal roof about ¼ to 3/8 inch off the #30 felt, providing a continuous drainage area.

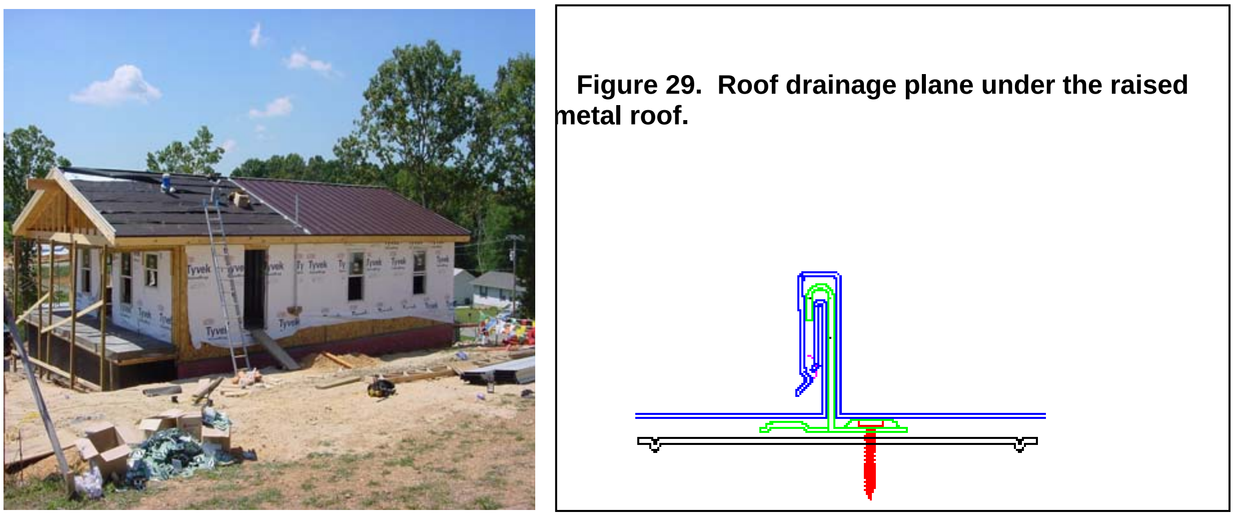


Figure 29. Roof drainage plane under the raised metal roof.

Number 6; Know connection details — minimizing air leakage is a primary goal.

Electrical wiring placement should be designed to stay as much as possible within interior walls. Electric chases are cut in the SIP foam prior to shipping, and when the panels are installed you must provide 1–1/2-in.-diameter access holes in plating, structural splines, and the precast foundation to align with electrical wire chases in the panels. The wall-foundation detail selected in Figure 27 was in part done to make it easier for the electrical subcontractor to run wires from the basement up into the exterior walls. From the basement the electrician can easily measure the location of each vertical wire chase. All electrical wires are pulled after cutting out the outlet box locations and prior to setting electric boxes. The boxes are threaded onto the wires and set in the SIP. Apply low expanding foam sealant around the box and in the chase once all the wires are pulled to block this potential air leakage path.

When you position ceiling fans and other heavy lighting fixtures be sure the locations are clearly dimensioned on the drawings sent to the SIP manufacturer so they can provide added structural support and electric chases in the SIP ceiling panels. This was done for all the ceiling fans in ZEH5 as shown in Figure 17 and 18 panel drawings. With a little planning the desired location of these fixtures can be aligned with the panel splines and additional solid wood factory inserted in the panels. Along the ridge beam is also a good location to include a wire chase.

The ridge detail is important to assure air-tightness throughout the life of the structure. Manufacturers have different favorite details. The five test ZEH's each have a different ridge detail. Established SIP manufacturers have been aware of the importance of ridge detailing for a long time. ZEH5 was taped with the peel-and-stick tape applied to the inside surface of all seams. If at the time the panels were installed heavy rain occurred, or the quality of the panel seam caulking and sealing is in anyway suspect, tape it!

Another common leakage point we find is were the exterior door dead bolts have been drilled into the door fames. Careful application of low expansion foam filling the space between the door frame and the rough opening will seal this up.

If your blower door test, run before installation of the drywall on the wall and SIP ceiling, indicates air leakage, tape it! The series of electrical chases and the panel seams create a three-dimensional matrix of potential passages for air to leak into and out of the SIP envelope. Experience with blower door studies prior to installation of the drywall on SIP wall and ceiling systems suggests that you should never detect any air leakage at any panel seams. We always find some leakage at electrical outlets. At 50 Pascal suction, you very quickly can get a feel for what is "typical" and what is "excessive" by simply running your hand over every outlet. Those that are high can easily be sealed at the outlet box. At this point in the construction the wires have been pulled and it is relatively easy to seal the outside of the electrical box while mounted in the SIP.

ZEH5 was blower door tested numerous times and was found to have a natural air change of 0.08. The only taping prior to conducting the test was the six inch fresh air supply. However when the mechanical damper is closed we found no detectable difference in the whole house air tightness measurements. The mechanical ventilation motorized damper is installed to open when the HVAC unit power is shut off, so be sure to shut the HVAC system off and tape the fresh air inlet during the blower door test.

Number 7; Check panel drawing accuracy

Roof panel span tables are available from the SIP manufacturer. Be sure to check that the roof panels are not exceeding the maximum allowable spans between load points provided in the span tables. The span tables for the SIP roof in ZEH5 can be found at < http://www.premier-industries.com/pbs/Page.aspx?hid=320>. The spline detail is shown in Figure 16, PBS-005 I-Joist Spline Connection. The thickness of the roof panel was 8 ½ in. Table 4 on the Premier Building Systems web site for determining roof transverse loads shows that for a 14 foot span from ridge to eave and this delivers a design load of 70 lb/ft2 for an L/240 deflection. In general the entire exterior wall needs to be supported all the way to the foundation. The ridge beam generally has several intermittent load points that also must transfer the design load all the way to the ground. Understanding where these load points are located is important to maintain not only the needed structural support within the conditioned space but also to maintain chase ways for HVAC, plumbing, and electrical distribution.

Avoid designs that call for ganged windows, not only because they are harder to install since they are heavy and awkward to handle. They also require more solid wood headers in the SIP panels in place of insulating foam, which has a much higher R-value. The floor plan for ZEH5, Figure 4, shows all windows are separated by at least 2 ft.

Number 8; Attaching solar modules to SIPs

The recommended roofing to cover a SIP roof structure is raised metal seam, as shown in Figure 30 (www.atas.com/dutchseam , http://www.englertinc.com/roofing-panels.aspx?Page=7) with reflectance of at least 0.3 in the mixed-humid climate. This is attainable by metal roofs in almost any color. The ZEH5 has an Englert S2000 Series with a brown color and a reflectance of 0.31. This high reflectance for what appears to be a dark roof is due to the use of infrared-reflective pigments in the coating that selectively reflect most of the heat from the sun that comes in the infrared portion of the electromagnetic spectrum. The ZEH5 metal roof panels were sized and bent on site. Some effort was required to design the exact location of the raised seams so as not to interfere with the roof penetrations for the solar water heater pipes that needed to fall directly over an interior wall chase leading to the solar water tank in the basement utility room.

Figure 30. Infrared selective coating was used on the brown raised metal roof to cover ZEH5.

The standing seams on the roof allow for attachment of the solar water heater collectors and photovoltaic modules without any roof penetrations. This is advantageous because fewer roof membrane penetrations mean less water leak risk. By using a S-5 clipping mechanism (www.unirac.com/s5.htm) shown in Figure 31, the solar modules can be installed on the roof with no penetrations.

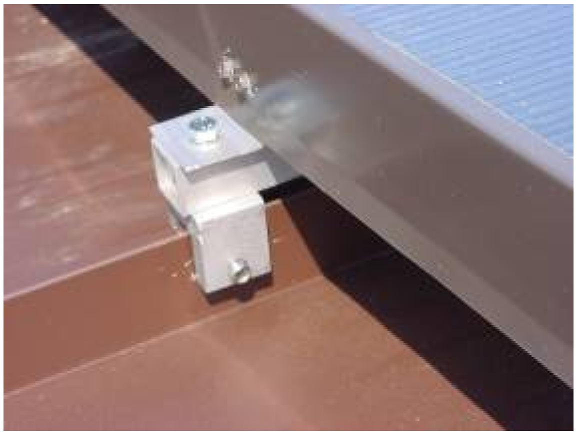


Figure 31. S-5 mini clip holding a solar module on ZEH5 to the raised metal seam.

Number 9; SIP roof installation

The quickest way to get a simple SIP house closed up in a day is to stick with a single ridge beam and have it available on site to lift in place just as soon as the walls are up, plumped, leveled and squared. With a crane on site, a rigging plan should be developed, i.e. everybody on site wears a hard hat, everybody learns the standard signals for mobile cranes, particularly "stop". (Headley 2005)

Lifting the ridge beam in place with a boom truck is the best method. Use a riggers sling made up of double choker hitches. Have the roof panels and crews in place so that once the crane arrives and the beam is placed the roof panel placement can commence immediately to keep the crane time to a minimum.

Set up a two-person crew on the ground rigging and sealing up the edges of the roof panels, and a second two-person crew installing the panels. The I joist splines in the ZEH5 roof panels were factory installed on one edge of each panel.

Figure 32 shows the SIP roof panels being installed on ZEH5. A string run from gable to gable lines up the ridge, just like setting conventional trusses. Stop blocking installed on the bottom side of the panel a distance equal to the overhang and the thickness of the wall provides a rough stop to get the panel dropped close to the string. One good idea is to not fasten down the leading edge of the ceiling panels until the next panel is in place. This enables the panels to fit together smoothly without a lot of heavy pounding on the panel edges. Aligning the panels and tightening each joint goes quickly and safely with the right work plan and good teamwork. If the roof pitch is steeper than the roof crew is comfortable walking around on, install walk boards on the top side of the panels for safety. Alternate roof panel installation with one on each side of the ridge to keep the roof forces balanced during construction.

Figure 32. The SIP roof panel installation

Number 10; Planning

Lastly and most importantly, have a good plan that matches the resources you have available. This cannot be completely articulated without many site-specific variables, but having a good plan and taking the time to meet with all the subs and key personnel will make a better whole building. Know the location of structural point loads. Continuously check accuracy of shop drawings and that the installation matches the intent of the plans. Make sure that the window and door rough openings are correct and that the HVAC chases are specified and maintained as construction proceeds. Make sure the electrical plan is complete and reflected in the panel cut drawings sent to you for your approval prior to panel fabrication. Keep all plumbing out of exterior walls and keep the electrical in exterior walls to the bare minimum. Run all vertical chases into floor spaces by routing from exterior to interior walls and then down or up. An excellent book to read before you put up your first SIP house is by Michael Morley. (Morley, 2000).

4.3 Windows

For the mixed-humid climate, with all-electric houses and energy costs around $0.094/kWh, it is recommended that the National Fenestration Rating Council R-value be at least 0.34. The solar heat gain coefficient should be no higher than 0.33. The visible transmittance for the windows used on the 5 test houses was 0.51. The warranty on the test house windows is not prorated and covers glass for 20 years and non-glass parts for 10 years. The specific vinyl-clad wood windows specified for the test houses were Andersen 200 Series tilt-wash, double-hung low-E, model numbers 244DH3030 and 244DH3050 (www.andersenwindows.com). The ten-window package for ZEH5 is estimated to cost about $2900 from a local window distributor in 2005. If you are going to install interior window trim specify jamb extensions. This will speed the window installation on site. The rough openings required for the two window sizes used are exactly 3 ft x 3 ft and 3 ft by 5 ft. Before the house wrap is installed be sure to inspect all window and door rough openings in the SIP panels. They are commonly made with a router and are rounded. These may need to be squared off, before installing the house wrap, for tight fitting windows and doors

The windows are installed after the house wrap which was DuPont's Tyvek HomeWrap (www.tyvek.com). The windows are installed as outlined below:

1. The rough opening, which is covered by the house-wrap, is cut out and except for the top, folded into the window buck after checking that rough opening will permit plumb, level, and square window installation. The top flap is folded up and out of the way until the window is installed.
2. Panned with Tyvek Flexwrap (see Figure 28).
3. Continuous bead of caulk applied to the house wrap on the outside wall around the rough opening on sides and across the top, not the bottom.
4. Flanged window is installed.
5. Window is centered in opening and shimmed. Pay close attention to the middle part of the window frame. When you are doing drywall returns shim to maintain a uniform reveal.
6. Window leveled and secured through the flange.
7. Jamb flashings on both sides installed so as to cover the entire window flange. Test houses used Tyvek StraightFlash for jambs and headers.
8. Header flashing installed covering the entire mounting flange and extended beyond outside edges of both jamb flashings.
9. Fold the taped up house wrap above the window back over the taped flange above the window and tape.
10. Insulate interior between window and wall framing on all four sides. Use low-pressure expansion foam or backer rod and caulk.

4.4 SIP Roof and Ceiling

For the mixed-humid climate affordable ZEH, a SIP with thickness of at least 10 5/16 in. and 0.95 lb/ft^2 expanded polystyrene core foam and 7/16-in. OSB facers are recommended for the roof. It is suggested that a ridge beam be used in the design of the SIP roof because it is easier to air seal the ridge. An extended overhang on the eaves of 2 ft helps control the solar gain in the summer.

The roof and wall panels should be certified by the manufacturer in accordance to:

1. Structural codes, ASTM E72 for transverse load, axial compressive load, racking shear and header loading, ASTM E695 Impact testing, ASTM E1803 cold creep
2. Fire testing with approved finishes (minimum 15-minute thermal barrier such as ½-in. drywall or 1x wood paneling) shall have passed ASTM E-119 – 1-hour fire resistant wall assembly, UBC 263 – corner room test.

Prior to ordering the SIPs, design loads must be provided, roof transverse loads (live, dead, calculation of the wind load, and total), wind loads (basic wind speed, design wind loads for walls and roof uplift), and Seismic design category. Be sure to include the weight of the solar collectors for the PV and solar water heater in the dead load calculation. If seismic hold downs are required special preplanning is necessary.

The ZEH5 ridge beam was sized to be supported by the posts embedded in the gable wall and two intermediate locations carrying the load down to a spread footer.

The roof transverse load must be less than the allowable load as provided by the SIP manufacturer that used ASTM E72. ASTM E72, section 11 is a span test that uniformly loads the panel to the point of failure. In the case for ZEH5 with a 14 ft span horizontally from the eave to the ridge. The pounds per square foot measured at failure is recorded, and divided by a safety factor of 3 determined the allowable load. Before the roof fails it will deflect. So when the span tables are generated they are presented as a function of the allowable deflection of the panel. The deflection is measured by taking the horizontal length of the roof span and dividing by a deflection factor of L/240. This means that in ZEH5 the roof when fully loaded will not deflect more than 14/240 or about 11/16 in. The ZEH5 roof used 4 foot wide panels the full length from ridge to the end of the eave, engineered I-joist splines as shown in Figures 16 and 17.

Roof with a ridge beam should be assembled by placing the roof panels in opposition, one on each side of the ridge, working down from gable to gable.

The roof should be covered as quickly as possible with #30 asphalt-impregnated roofing paper (ASTM 4869 Type II). If the SIP roof does get wet be sure it has time to dry before covering. The preferred roofing system is raised metal seam with a space left between the metal roof and the building paper to serve as a drainage plane.

5. Space Conditioning Equipment

5.1 Sizing

A ZEH in mixed-humid climates is well suited for heat pumps, either high efficiency split air source or geothermal. The fan motor needs to be a DC commutating and this contributes to the low fan power required to meet the ASHRAE Standard 62.2 ventilation air requirements. The suggestions provided are based on data from the test houses which are described in this report. Table 2 highlights the equipment technologies used in these test houses.

The manual J calculation eight edition was performed for the whole (2632 ft^2) house which includes conditioning the basement (Rutkowski, May 2004). The break down for the heating design is shown in Table 11. The cooling design load break down is shown in Table 12.

Table 11. Heating design load for ZEH5

Heating Design Load (Manual J) ZEH5 2005, July 29	**Heat Loss** (Btuh)
Vertical Glass	3641
Doors	1761
Above Grade Wall	4946
Below Grade Wall	1995
Ceiling	2952
Floor	119
Infiltration	4124
Duct	0
Ventilation	2177
Totals =	21716

Table 12. Cooling design load for ZEH5

Cooling Pie Chart For ALP ZEH5 2005, July 29	**Sensible Gain** (Btuh)
Vertical Glass	3404
Doors	898
Above Grade Wall	0
Ceiling	1429
Floor	0
Infiltration	246
Internal	7573
Duct	0
Ventilation	640
Blower Heat	685
Latent	3701
Totals =	18575

5.2 Geothermal Heat Pumps

The ZEH5 used a 2-ton WaterFurnace E-Series unit (model # W024TR111/NBDSSA), with an ECM Blower and R-410A refrigerant www.waterfurnace.com . The unit was sized to match the manual J load for the entire house of 2632 ft^2. The design heating load was 21,716 Btu/hr and the design sensible cooling load was 18,575 Btu/hr. The estimated COP at peak was assumed to be 3.66 and the EER, 16. This model did come equipped to help heat domestic hot water with an on-board, factory installed desuperheater and pump; however, unless considerable space cooling is needed at the same time as hot water is used, the measurements in ZEH3 suggest, that little hot water energy would be saved in typical applications.

The ground loop was experimental and at this time is not recommended until the full year of data collection and analysis is completed. The horizontal loop completely utilized available open trenches during construction of the house. Figure 33 shows were 1500 ft of ¾-in. high-density polyethylene pipe is installed in a six-pipe 250-ft trench made up by 115 ft of walk-out basement foundation over cut, 50 ft of water trench dug 3 ft deeper to keep the geo pipe away from the water line so as to avoid potable water pipe freeze in the winter and heating incoming cold water in the summer, 60 ft of sewer line trench running from the street to the outlet on the south side of the foundation, and 25 ft of footer drain trench run out to daylight on the southwest corner of the foundation. Three loops of 500 ft each run out and back in the full 250 ft of available trench. The three loops are headered up to a single 1.5-in. inlet and outlet pipe on the south side and run into the equipment room in a trench run under the basement slab. The inlet and outlet pipe is connected to the circulating pump in the bottom floor ZEHcor wall near the vertical WaterFurnace unit. No additional excavation was required to install this water loop.

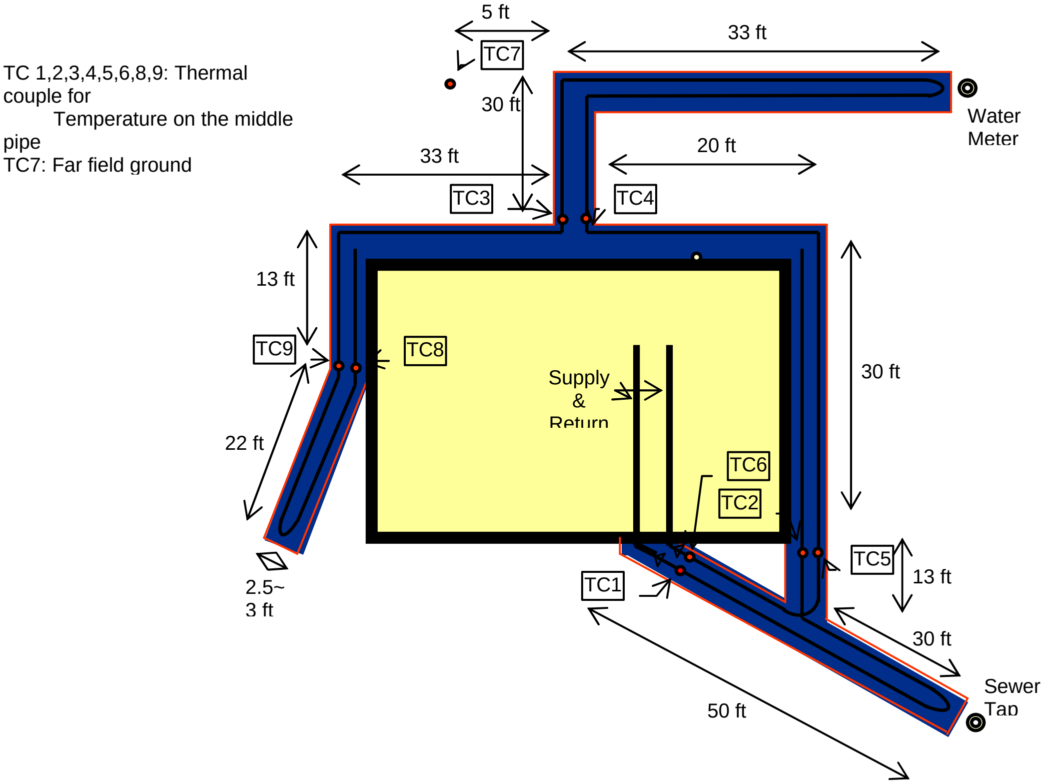


Figure 33. Ground Pipe trench location and lengths in (ZEH5)

The standard practice installation for these horizontal coils is to keep the pipe at least 10 ft away from the building foundation footer to avoid freezing the ground and potentially causing foundation structural problems. It is felt that since the foundation system is insulated on the outside wall surface with 2 3/8-in., 6 lb/ft^3 fiberglass drainage board and both external and internal footer drains run to daylight, that this will keep the soil moisture content near saturation levels and very minimum soil freezing is likely to occur and no foundation structure freezing. Even if the ground near the footer and surrounding the geothermal pipe should freeze, the insulation board would serve as a slip plane and compression cushion between the expansion and potential uplift of frozen soil. The insulation on the outside of the foundation wall keeps the temperature near inside conditions, even with no added heat in 2006 the basement area always was above 60 F. Added protection is provided by the WaterFurnace unit itself which has a lockout whenever the water circulation loop temperature drops below 15°F. Heat load at that point is met by the electric resistance emergency heaters.

The sewer runout is not separated much from the 6-pipe system. In the winter it was felt that the warm water from the waste water would be partially recovered. This experimental house has a grey water waste heat recovery system which can discharge waste water at temperatures as low as 40°F. In the summer this cool water would help provide a better soil heat sink potentially reducing the ground heat exchanger pipe length. Figure 34 shows the 3-loop six pipe ground heat exchanger being installed in the sewer trench to the street.

Figure 34. Geothermal pipe being installed in the sewer trench.

During the winter of 2005-2006 the space heating load of the first floor (1232 ft^2) was easily met with no strip heat at all and with no reduction in soil temperature next to the ground coil pipes from that measured in a far field thermocouple buried at the same average depth (about 5 ft) as the 6-pipe loop. The cost to install the loop, leak test, flush, charge, and commission the unit was $2000. It took 16 person-hours to install the loop and 8 person-hours to commission the unit. The rule of thumb at the time the installation was performed in August 2005 was that the loop is installed and unit commissioned for $1000/ton. The pipe cost is estimated at $250/ton, labor $750/ton.

5.3 Ducts

The central location of the blower equipment, with respect to the floor plan, enable short and simple duct runs. In ZEH5 one story the supply ducts are in conditioned space. The single return and the indoor fan unit are actually considered in the crawlspace. For ZEH5 two-story all of the ducts and HVAC equipment are in the conditioned space. The recommended location of the ducts in a single floor house with full insulated-cathedral ceiling like ZEH5 is in the conditioned space above the dropped ceiling. The area available for locating the ducts and indoor fan unit above the dropped ceiling in ZEH5 is shown in Figure 35. The ducts are show in this conditioned chase in Figure 36.

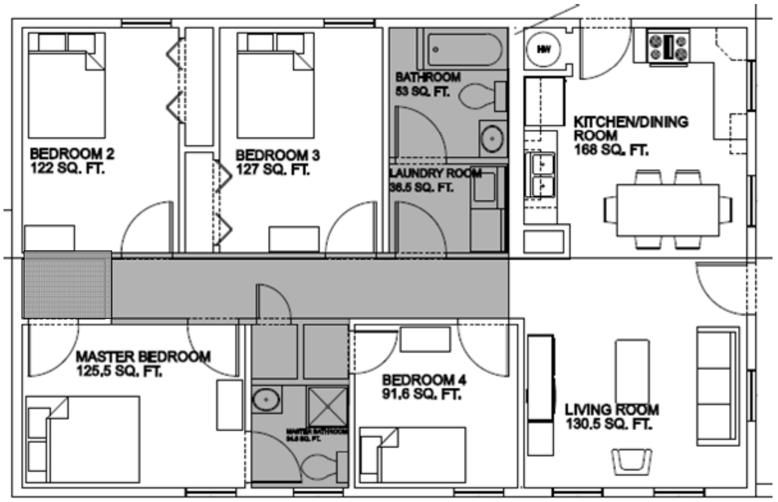


Figure 35. Shaded area marks the location were the ceiling is dropped to accommodate the HVAC system.

The ducts were sized using manual D (ACCA, 2006). The measured CFM for each room is shown in Figure 37. The needed CFM for each room comes from the Manual J room by room load calculation. The main supply trunk should be hard piped, sealed with mastic, and insulated on the floor and lifted into place. Insulated ducts avoid condensation risk. Short flex duct runs are used to connect the main supply trunk with high wall supply register in every room except the laundry in ZEH1-5.

Figure 36. Supply ducts located in the conditioned chase formed by the ceiling SIPS and dropped ceiling.

Transfer grills are used in each of the bedrooms with high registers inside the room and low in the hallway. When an internal wall chase is not available, jump ducts should be used to minimize pressurizing the bedrooms and depressurizing other areas of the house when the circulating fan is running. Keeping minimum pressure differences from room-to-room and from inside to outside helps control air flow and minimizes unwanted air and moisture exchange through the building envelope.

High sidewall supply outlets discharge air parallel to the ceiling toward the outside wall. Figure 37 shows the measured air flows delivering thermal comfort to this space for the one year measurement period. The correctly sized outlet supplies discharge pattern extends to the opposite wall and high velocity air will not drop into the occupied zone. Sidewall outlets perform best during the cooling mode, so they are more suitable for homes that are located in warm climates. The high cathedral ceilings provide an ideal mixing zone for secondary air exchanges between the supply air momentum and the room air. This enables the jet of supply discharge air to entrain a large amount of room air as it develops into a secondary air pattern. A single central return is positioned on the floor in the central hallway nearest the front door. A low-resistance return path between every room and the return is maintained by transfer grills and jump ducts. In general low return systems are used in all 5 test houses.

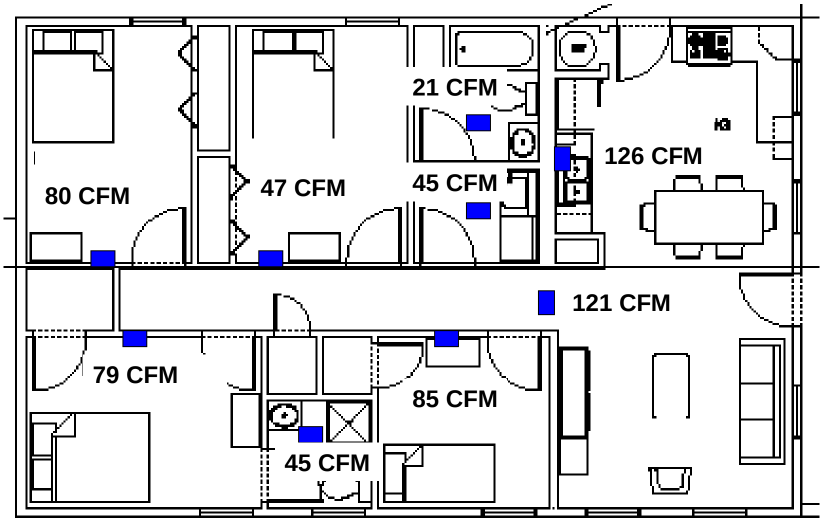


Figure 37. The measured supply CFM delivered to each room in ZEH5 and location of each register.

5.4 Ventilation Air Treatment

ZEH5 has a 6-in. fresh air supply running from the north side of the house, through the ZEHcor wall to the return side of the blower. A manual and a motorized damper control the amount of ventilation air. The Air Cycler www.Aircycler.com is used to monitor the heat pump compressor. For at least 10 minutes every half hour the motorized damper is opened and when the compressor has not needed to condition the space the AirCycler turns on the HVAC central ECM fan at low speed and brings in a prescribed amount of fresh air. The design was to meet the current version of ASHRAE 62.2, which in the case of the ZEH5 is 50 CFM for the four bedroom residences. The AirCycler was wired to signal a relay which energized the bathroom exhaust fan to help balance the house pressure and assure adequate ventilation air for indoor air quality and moisture control.

Figure 38 shows that good thermal comfort conditions were measured in ZEH5 during the period form January to December 2006 as shown by the hourly average interior temperatures and relative humidity. The sensors were located two feet above the thermostat in the central hallway.

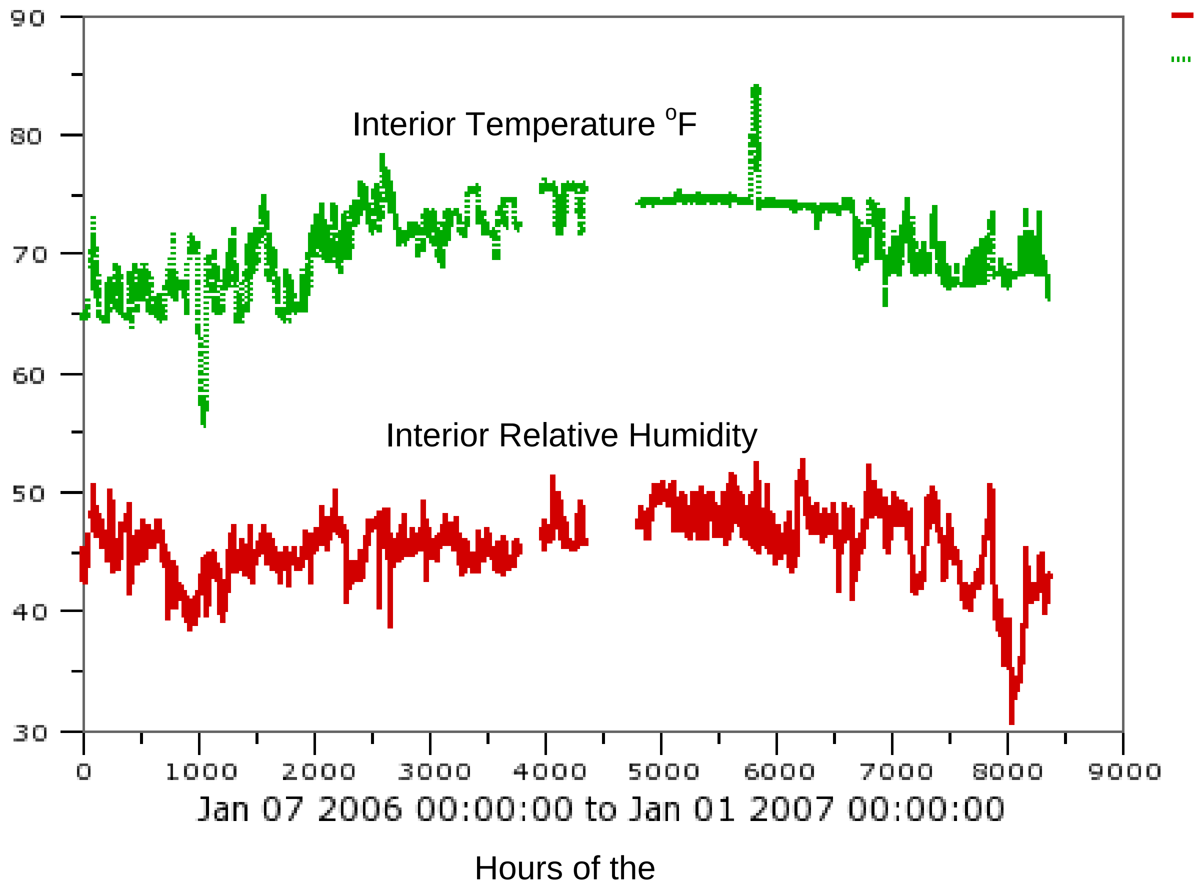


Figure 38. Measured interior temperature and relative humidity in 2006

The Manual J calculations for conditioning the top floor of ZEH5 confirm that a 1.5-ton unit would have done job in the cooling season. The ZEH5 2-ton unit with the air tight- well insulated lower level adds 1400 ft^2 to the top floor living level of 1232 ft^2. This 2-ton unit is a much better match for the 2632 ft^2 ZEH5 as found during the 2007 measurement period when both floors were continuously conditioned.

6. Electrical

6.1 Wiring

If possible consider minimizing electric wire chases in exterior walls. Chair railing and base molding can be slightly built out to form exterior wire chases. Making these out of wood can help accessorize the interior décor. In both SIP and stick construction the electric outlets are always a major residual leak after dedicated envelope air tightening. In ZEH 5 the space available above the ridge beam shown in Figure 39, 40 and 41 was used as a wiring chase to reach the ceiling fixtures. Once the wiring is complete this space is completely foamed.

Figure 39 Space above the ridge beam is used for a wiring chase.

Figure 40 Wires being pulled into the space above the ridge beam.

09.02.2005

Figure 41. A triangle bock of foam is provided by the SIP manufacture to fill the space at the ridge.

After hearing the biggest grumbles from the electrical crew on the fourth SIP house we selected a detail for ZEH5 that allowed the electricians to run wires more easily from the basement into the wall. Vertical wiring chases cut into the panels every 4 ft starting 2 ft in from each vertical seam. Figure 42 shows how the panel does not sit on top of the floor, but rather at the same level as the 20 inch floor trusses giving plenty of access to fish wires.

Figure 42. Mounting the wall panels on the side of the floor trusses leaves easy access to run electric wires from the basement into the vertical wiring chases in the wall SIPS.

6.2 Ceiling Fans

Location of ceiling fans and heavy ceiling light fixtures should be clearly marked on drawings sent to the SIP manufactures. The added pullout strength needed for ceiling fans can easily be accommodated at the factory as well as the location of all embedded wiring chases. Look for Energy Star rating on all ceiling fans purchased for your ZEH.

6.3 Lighting

The goal is to install all florescent lighting. Some ceiling fans more easily accommodate a CFL than others. Consider using either globe or scones lighting packages. Under- and above-cabinet fluorescents in the kitchen work great. Wall scones work well with compact fluorescents, as shown in Figure 43. In the ZEH5 the only place incandescent lighting was used is around the bathroom mirrors. There are now reasonably priced bulbs available to incorporate florescent in these applications. In the bathroom the exhaust fan/ceiling light has CFL. Placing the first switch nearest the bathroom door for the CFL is a subtle way to develop lower lighting energy usage.

Figure 43. Sconces with compact fluorescents.

6.4 PV Solar Systems

6.4.1 PV System designed for ZEH5

Figure 31 shows the suggested method of attaching the PV modules to the raised metal seam roof with no penetrations. TVA's Green Power Generation Partners program pays homeowners $0.15/kWh for all the AC solar power generated in a grid tie arrangement. A schematic of how TVA requires the PV system to be tied to the grid is shown in Figure 44. All interconnected equipment used must be UL listed to the appropriate UL Standards for terrestrial power systems. The system must have a lockable disconnect device accessible outside the house and a standard watt-hour meter base to measure the AC output of the generation system located at the same vertical level as the billing meter and within one linear foot of the billing meter. The systems must be installed in full compliance with all requirements of the latest edition of the National Electrical Code (NEC) (ANSI/NFPA-70). The PV system designed for ZEH5 is described below.

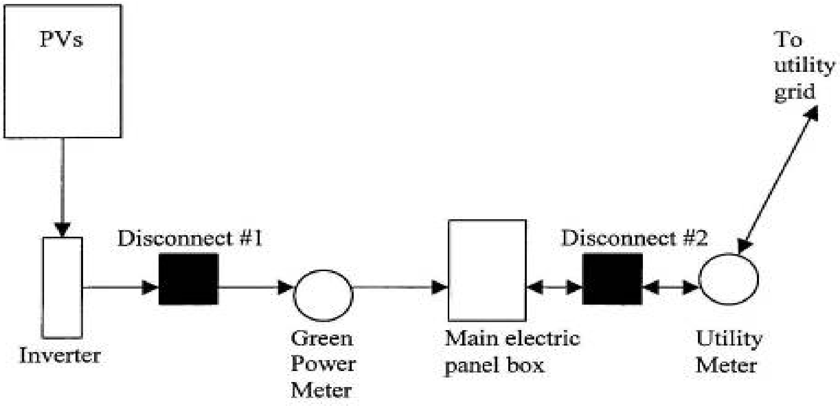


Figure 44. TVA Solar grid-tie connection schematic.

6.4.2 Modules

Twelve 180-W polycrystalline modules (Evergreen Solar ES-180s) make up a 2.2-kWp photovoltaic system. These modules are designed for a maximum allowable pressure of 80 lb/ft^2, which corresponds to a wind speed of more than 125 mph. These modules come with the same power output warrantee as the Sharp modules on ZEH2 shown in Figure 45.

Figure 45. Solar modules sit very nicely on the roof of ZEH2. The dark green roof makes for a very pleasing appearance with the dark bluish-green polycrystalline module

The manufacturer suggests a clearance of at least four inches under the module to permit air circulation and cooler operating temperature. Elevated temperature not only lowers operating voltage it also shortens service life. The modules are 37.5 in. x 61.8 in. and about 1.5-in. thick. Each module weights 40.1 lb. This amounts to an added dead load to the roof of 721 lbs. The south facing roof area of ZEH5 is 865 ft^2. The added roof dead load attributable to the solar modules amounts to less than one lb/ft2.

Twenty PV modules were installed on ZEH4 on aluminum rails bolted to 7-in.-high standoffs by Big Frog Mountain http://www.bigfrogmountain.com/ . The completely installed modules are shown in Figure 46. In May 2004 the distributor/installer cost for these 20 solar panels was $9580. The next most expensive item was the Sunny Boy 2500U SBC w/LCD Inverter at $2905. The electrical and mounting hardware totaled $3308. Labor for system design and installation which took two workers a day, was $2000. Shipping of this equipment to the site in Lenoir City, TN added another $700. This totals $18,500. In the long term the cost of the modules and the inverter is expected to come down. The world supply and demand situation in July 2006 finds the cost of solar modules as shown in Figure 47 at 11% higher than the costs in May 2004 http://solarbuzz.com. This would put the estimated installed cost in August 2007 at about $20.5K.

Figure 46. Modules are clamped to aluminum rails and carefully grounded.

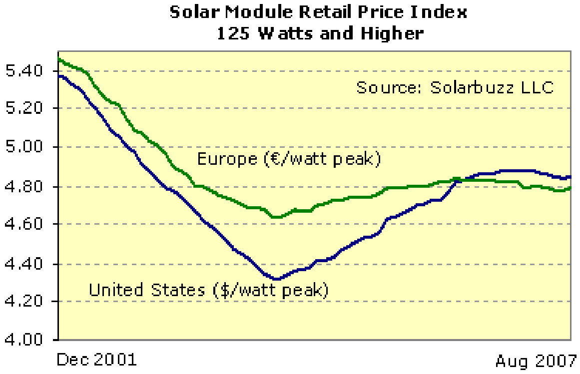


Figure 47. Solar module cost in the US and Europe from 2001 to August 2007.

6.4.3 Inverter

ZEH4 uses a Sunny Boy SWR 2500U inverter. This inverter has on-board islanding protection and meets UL 1741. The unit is 17 in. x 12 in. x 8.5 in. and weights 70 lb. Inverter location should be at eye level, as shown in Figure 48, on the north side under the extended roof overhang. The unit should not be in direct sun and exposure to rain should be minimized. There is no fan to dissipate heat; instead a heat sink is mounted on the top and it can reach 175°F, so good natural air circulation around the inverter must be maintained. The unit at times will have an audible hum and should not be located close to living spaces in the house.

Figure 48. Sunny Boy (red box at left) installed in TVA-approved Green Power

7. Water Heating

ZEH5 was designed with a solar water heater shown in Figure 49. ZEH1, 2 and 4 all used heat pump water heaters and the results overall were very positive. In fact it was felt that in these particular houses a HPWH was the preferred option compared to solar. However the performance of the solar water heater selected exceeded expectations as discussed in section 1.2.2 of this report. Figure 50 shows that for the month of June if the daily hot water demand was less than 50 gallons that the average daily energy consumption was only 0.328 kWh. For the entire year for a household demanding 47 gal per day it is estimated that the solar water heater would use 0.053 kWh/gal. The best performing HPWH was in ZEH2 and we measured an average daily hot water usage of 36 gallons. The total annual energy used by the HPWH was 961 kWh. Using the energy gauge model to predict the total amount of electric back up energy need by the solar water heater installed in ZEH5 if only 36 gallons of hot water were needed per day would equate to 470 kWh.

The solar water heater installed in ZEH5 is a SolarRoofs, SkyLine System 5. This water heater was developed partially under a Technology Transfer Program managed by ORNL funded by the DOE Office of Industrial Technology. One of the appealing features is the easy of installation. The solar collectors are very light and can be placed into position quickly. A very nice set of instruction and complete kit of parts was included that fit with the desire to reduce first cost by making the assembly of the entire house very easy and “Kit friendly”. The material cost including the 80 gallon tank was $2400. The installation took two man days by two semi-skilled Habitat for Humanity volunteers with modest plumbing experience. It is estimated that installed cost value would have been $3200.

This solar system meets the Solar Rating and Certification Corporation standard. Two 20 square foot solar panels were mounted on the raised metal seam roof of ZEH 5 as shown in Figure 31. Figure 7 shows that we did make two penetrations for the two pipes leading to and from the water tank. The H5 mini clips, shown in Figure 31, were used for both the solar collectors and the small 20 Watt PV module for powering the 12 V DC circulation pump. The controls are entirely by the sun. When the PV collector voltage reaches a minimum threshold the pump is powered and circulation is initiated. A flow meter installed in the loop measured a maximum circulation of 0.41 GPM. The 80 gallon heat exchanger storage tank is Rheem/Rudd/Richmond Model Number 81V080HE180.

Figure 49 SolarRoofs, SkyLine System 5 with 38 ft2 of solar collector area is installed on the roof of ZEH5.

The current installation instructions can be found at http://solarroofs.com/purchase/documents/060503Sys5InstallManual.pdf We used the August 2005 version of these instructions.

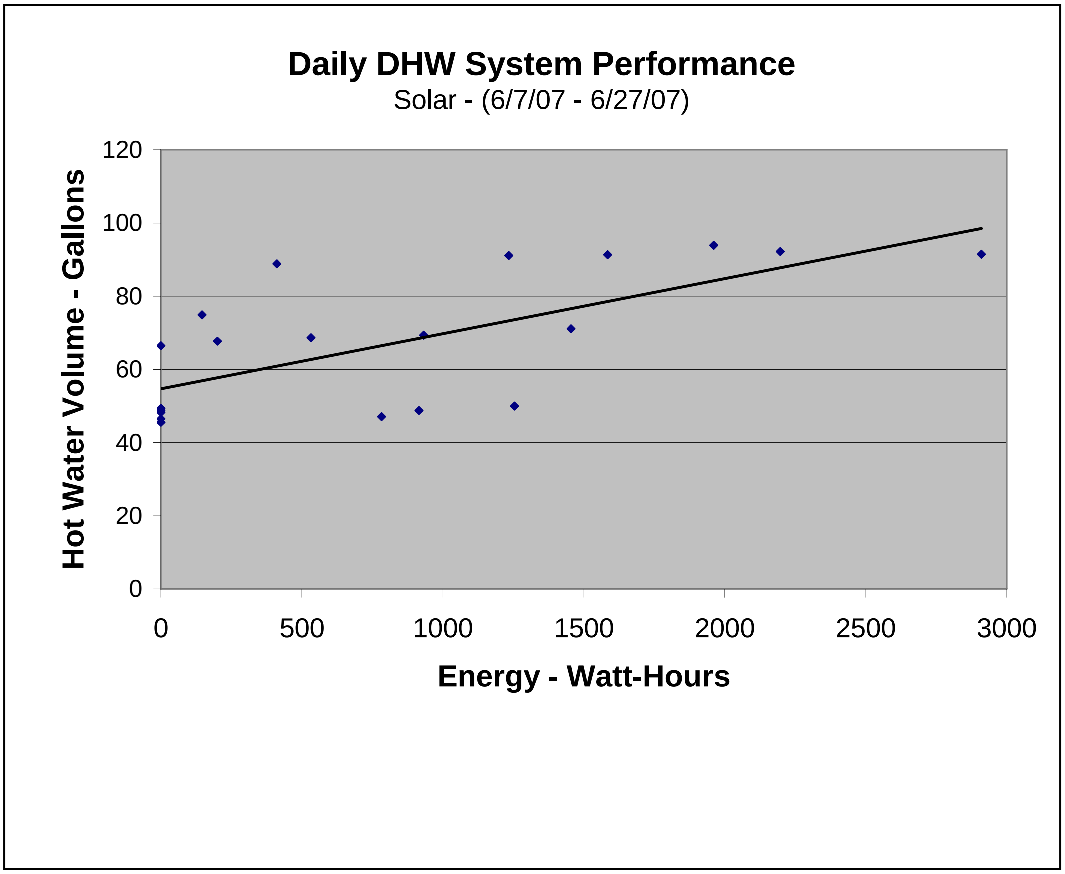


Figure 50. In June Solar Water Heater brings back up energy needs to zero.

8. Appliances

You should purchase Energy Star appliances — fridge, oven, clothes washer, dryer, and dishwasher. Refrigerators and clothes washer manufacturers have made significant energy savings improvements in the last decade. Including more efficient appliances in the mortgage of the new home means that the slightly higher first costs are spread over the life of the mortgage and offset by lower energy costs. Consider also having built in energy star entertainment center and home office equipment. Be sure to select LCD screens not Plasma. The Energy Star ratings are updated periodically, and options are often available that go beyond Energy Star standards.

The ZEH5 has a Whirlpool 18 cu ft Energy Star® refrigerator that was donated by the Whirlpool Corporation. In August 2007 a small Kill-A-Watt meter measured an average daily refrigerator energy consumption of 0.97 kWh/day. The kitchen temperature during that period was 73 F. The average daily energy demand by this refrigerator in the occupied ZEH4 during the 2006 measurement period was 1.3 kWh/day. The full year energy demand was 475 kWh/year. The monthly average daily energy demand for the fridge for each month of the year in ZEH4 and for only August the fridge in ZEH5 is shown in Figure 51. The refrigerator in ZEH5 is in an office setting not an occupied house as the fridge in ZEH4. Three people were living in ZEH4 during the year. Many more door openings and groceries stored and removed from the ZEH4 fridge. Few meals were eaten out.

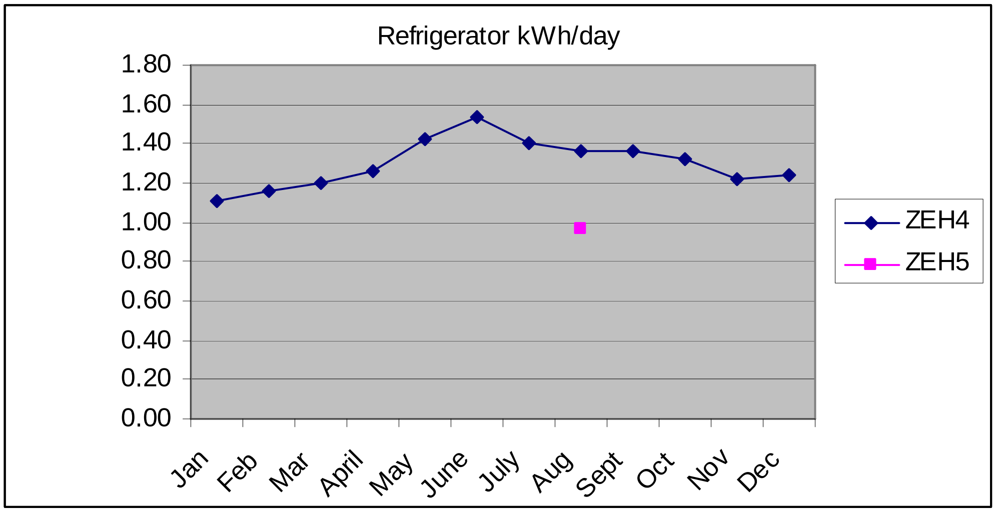


Figure 49 Energy demand for 18 ft3 energy star refrigerator per day by month

9. Summary

ZEH5 one story is a semi occupied house that was monitored for a one year period. It is a DOE Building America 47% energy saver without the addition of PV. Accounting for the PV delivers a house that is 62% energy saver. Detailed cost are presented for this house. The actual construction cost accounting for all the donated equipment and labor as well as the cost for a 2.2 kWpeak solar PV system in 2005 totals to $143,300.

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