How to Build Small Affordable Houses That Use 30% Less Total Energy in the Mixed-Humid Climate

Jeff Christian
Oak Ridge National Laboratory

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 high performance affordable house that will achieve 30% whole house energy savings using proven, commercially available technologies in the mixed-humid climate region.

This information package 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 fresh air ventilation, heating, cooling, dehumidification, and water heating. This package also includes lessons learned and advice on key construction and commissioning steps, such as blower door tests and envelope air sealing.

Most of the lessons-learned come from experience gained from designing, building, and monitoring five affordable energy-efficient houses through collaboration among Habitat for Humanity, 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 Building America teams and constructed by Habitat volunteers in Lenoir City, Tennessee.

1.2 The Net-Zero-Energy Test Houses

The construction methods, building products, appliances, and equipment that were used, including photovoltaic (PV) energy systems, resulted in dramatically low energy use in these all-electric, single-family houses, approaching "net zero energy." (A net-zero-energy building is one that produces as much energy as it consumes on an annual basis.) Data collected on performance characteristics of each house was used to develop the guidelines presented in this report.

Each of the test houses was equipped with 40 to 80 performance measurement sensors to record values such as temperature and relative humidity (ambient, indoor, and crawl space), hot water usage, heat pump operation, indoor CO_2 level, and other data (Christian 2006c). We have accumulated 15-minute-interval data for at least one year for the first four houses that were built (ZEH1, 2, 3, and 4). (We are still recording a year's worth of data for ZEH5, which was finished in late 2005.) The data were analyzed to determine component performance and energy consumption and to validate computer models (Christian 2006a; Christian 2006b; Christian 2006c). These houses reached daily costs for all off-site energy of $0.60/day and construction cost of $60/ft2 in 2006.

The construction costs for each of the houses ranging in size from 1060 to 2600 ft^2 and built between 2002 and 2005, were between $100 and $60/$ft^2$, including the cost of the rooftop solar PV systems. These houses can be assembled quickly by workers with limited skills, making them ideal for rebuilding on a large scale.

1.2.1 Technologies

Tables 1 and 2 list building envelope and mechanical features used in the four near-zero-energy houses and in 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	2
floor ft^2	1056	1056	1060	1082	1200	2600
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 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), surface 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	2 ton air-to-air HP, SEER 14, variable-speed compressor, ECM indoor and outdoor fan	2 ton water-loop geothermal, R-410A, variable speed ECM indoor fan
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, 48 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 strandboard; SEER = seasonal energy efficiency rating; SHGC = solar heat gain coefficient; SIP = structural insulated panel; XPS = extruded polystyrene

Each house has a rooftop solar PV grid-tie system with a rating of about 2 kWp. Each house is equipped with two electric utility meters, one to track solar PV system generation and a net meter to track whether the house is using more energy than it produces, 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.

Supply mechanical ventilation is provided in compliance with American Society of Heating, Refrigerating, and Air-Conditioning Engineers Standard 62.2 (ASHRAE 2004). The HPWHs in these houses are more than twice as efficient as conventional electric water heaters (Christian 2006). An extensive moisture management package is provided in all five test houses.

1.2.2 Cost

The cost-effectiveness of near-net-zero-energy houses will vary with energy costs, climate, energy-consumption habits, utility, state, and federal incentives for PV systems, and the cost of the selected technologies. The electricity rate in 2004–2005 was $0.068 per kWh, below the national average of around $0.086 per kWh. Energy cost savings would be greater in regions with higher electricity and solar credit rates.

The economic justification for net-zero-energy houses is that energy savings plus revenue from renewable energy sold to the utility grid help offset the added price of construction. For the first four houses, utility bills averaged less than $1 per day after credit for the sale of solar. The fourth house built had an average daily cost for electricity of 75 cents per day. A conventionally built house of similar size in the same community would be expected to average $4 to $5 per day for electricity. Figure 1 shows the energy consumption of ZEH1, 2, 3, and 4, compared to the base house.

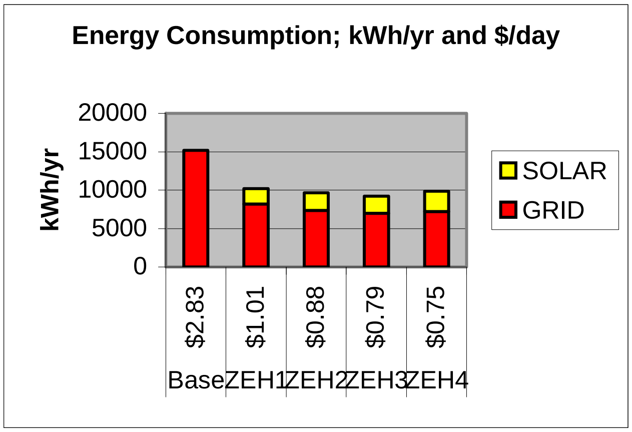


Figure 1. Energy consumption of ZEH's.

Table 3 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 first four study houses (not including the cost of land and infrastructure and the PV systems) ranged from about $79,000 to $88,000. The base house cost was about $59,300. The test houses' construction cost was about $100/ft^2. The fifth house with the walk-out insulated basement is under $60/ft^2 (not including the cost of drywall and painting the basement ceiling and walls).

Table 3. 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	ZRH5 2600 ft^2
House	59,295	78,914	83,953	87,889	85,189	108,340
Land and infrastructure	14,500	14,500	14,500	14,500	14,500	14,500
Cost of solar	0	22,388	16,000	16,000	14,935	15,000
Incentives (Fed+TVA)		-2,800	-2,800	-2,800	-2,800	-2,800
Total cost	73,795	113,002	113,153	119,529	111,824	135,040
$/ft^2	69.62	106.60	106.75	112.76	93.18	52.00

2. Floor Plans, Cross Sections, and Elevations

2.1 ZEH1

ZEH1 is a one-story dwelling as shown in Figure 2, containing 1056 ft2. The floor plan has three bedrooms, a living-dining room, a kitchen, and 1.5 baths. Its 4.5-in.-thick walls, 6-in. floors, and 8-in. ceiling are all constructed of SIPs made with expanded polystyrene insulation sandwiched between two 7/16-in. sheets of oriented strand board (OSB).

Figure 2. ZEH 1.

The air changes per hour (ACH) at 50 Pascals is 1.35. The HVAC unit is a 13.7-SEER, 1.5-ton air-source heat pump with a 2-speed indoor circulating fan. The occupants kept the temperature at about 75°F year round, on average. The roof is gray reflective metal, hidden raised seam, with a 4/12 pitch. On the roof is a 2-kWp 48-panel solar PV system Hot water is supplied by a 50-gal HPWH installed to recover waste heat from the refrigerator. For more detail see (Christian 2006c). ZEH1 also has a heat recovery shower that captures the waste heat from warm water going down the drain to preheat the cold water before it flows into the water heater. The house was equipped with 75% fluorescent light fixtures (It is highly recommended that 100% fluorescents be used). Figure 3 shows the ZEH1 floor plan.

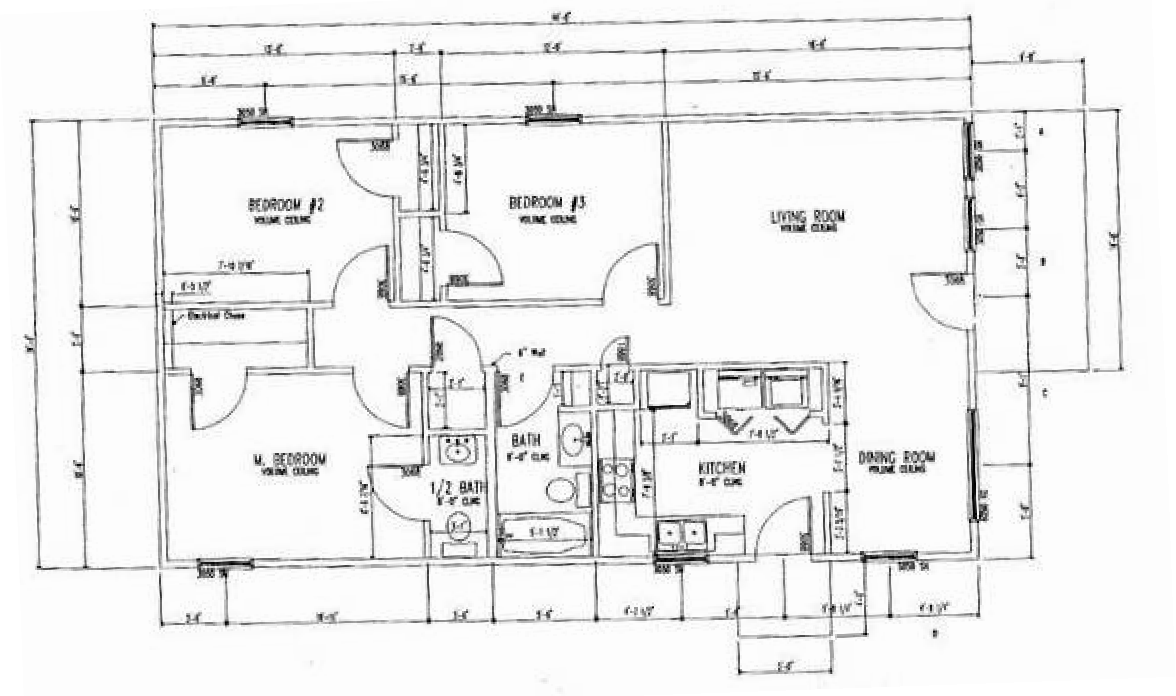


Figure 3. ZEH1 floor plan.

Built in 2002, ZEH1 used 10,216 kWh of electricity between March 2003 and February 2004, which is about 40% less than the base Habitat house. The energy cost (electricity purchased from the utility minus the amount of surplus solar power sold to the utility) amounted to $1.01 per day. The rooftop solar PV system supplied 2006 kWh, about 20% of the energy used over the year. About 40% of the PV power was produced at a time in which it was not needed in the house. The PV power was produced mostly on hot summer afternoons and reduced the house's peak load by a daily average of 40% between June and August. Table 4 shows the monthly measured energy usage for ZEH1 from

March 2003 through February 2004. Lighting, appliance, and plug loads ("other") accounted for ~60% of the energy used.

The occupants of ZEH1 used less than 40 gal of hot water per day, about 43% less than the national average of 64 gal/day estimated from a national survey of hot water usage (U.S. DOE 2004). The low hot water draws are due in part to reduced distribution losses resulting from the compact plumbing system.

Table 4. ZEH1 measured energy use, March 2003-February 2004

Month	**Space heat (kWh)**	**Space cool (kWh)**	**Hot water (kWh)**	**Other (kWh)**	**Total electric (kWh)**	**Solar generated (kWh)**	**Solar sold to utility (kWh)**
March	127	0	124	325	575	167	91
April	64	0	146	419	629	195	100
May	0	94	109	460	663	188	90
June	0	204	87	490	781	213	88
July	0	314	74	494	882	209	79
Aug	0	359	70	536	966	219	76
Sept	0	187	82	491	760	195	95
Oct	34	17	117	518	686	159	77
Nov	141	0	138	518	797	121	45
Dec	401	0	187	650	1238	115	15
Jan	473	0	219	540	1232	120	23
Feb (2004)	344	0	196	466	1007	105	25
Total	**1584**	**1175**	**1549**	**5907**	**10216**	**2006**	**804**
% of total	15.5%	11.5%	15%	58%	100%	20%	
Annual cost	$100[a]	$74[b]	$98	$372	$644	-$301	
Daily cost	$0.51[a]	$0.44[b]	$0.27	$1.02	$1.76	-0.82	

[a] Heating days only [b] Cooling days only

2.2 ZEH2

The 1060-ft^{2},one-story floor plan for ZEH2 is shown in Figure 4.

ZEH2's wall and ceiling SIPs have slightly higher density and R-value than in ZEH1, and its ACH 50 is 1.15 ACH. Unlike ZEH1, ZEH2 has an insulated crawl space. The 14-SEER air-source heat pump is a 2-ton unit with a two-stage compressor and variable-speed indoor circulating fan. The two-stage compressor was selected to provide better humidity control during the summer months. The temperature was kept at about 75° year round. The humidistat was set at 55% RH during the summer months. The 50-gal HPWH shown in Figure 5 performed at a higher efficiency (2 compared to 1.7) than the unit in ZEH1; the setup for the air supply to the HPWH is more compact (Christian 2006a). The ceiling is 6.5-in.-thick SIPs, and the roof is forest green metal with a standing seam and 6/12 pitch. The PV system is rated at 1.98 kWp and has higher efficiency modules than used in ZEH1, resulting in only 12 modules, compared to 48 for the system on ZEH1.

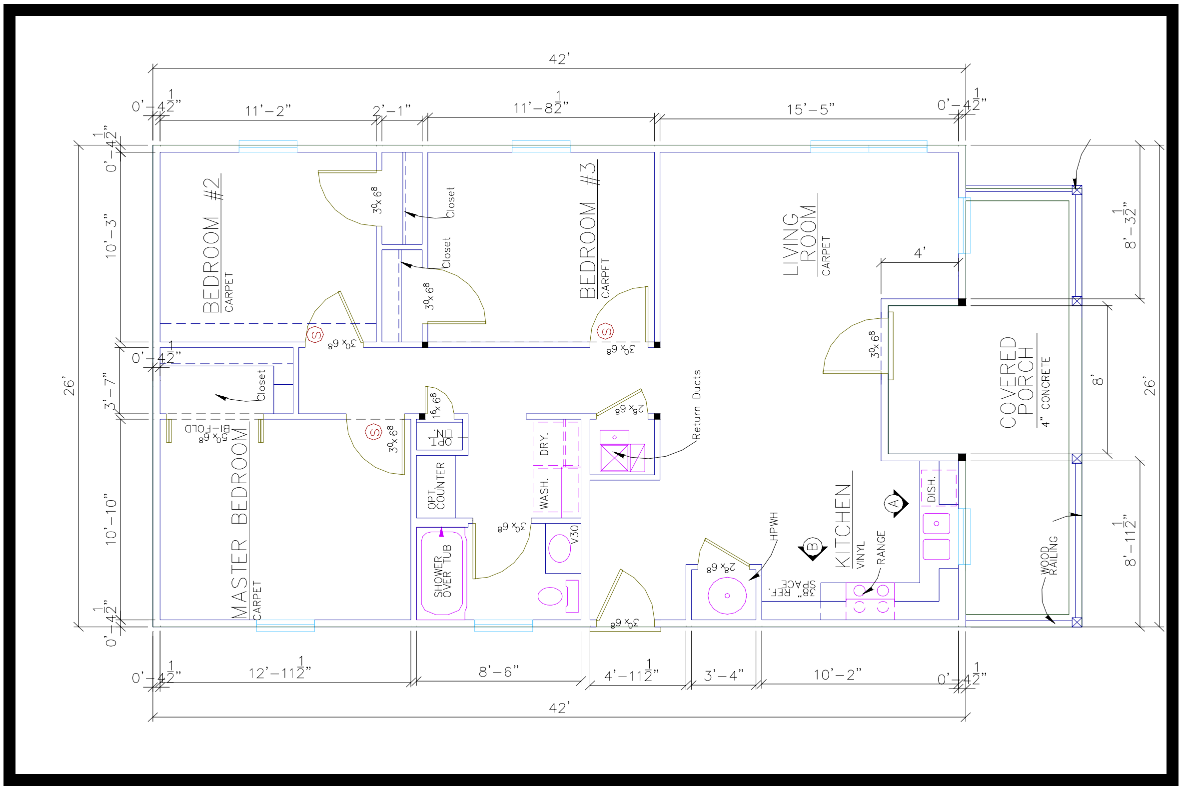


Figure 4. ZEH2 floor plan.

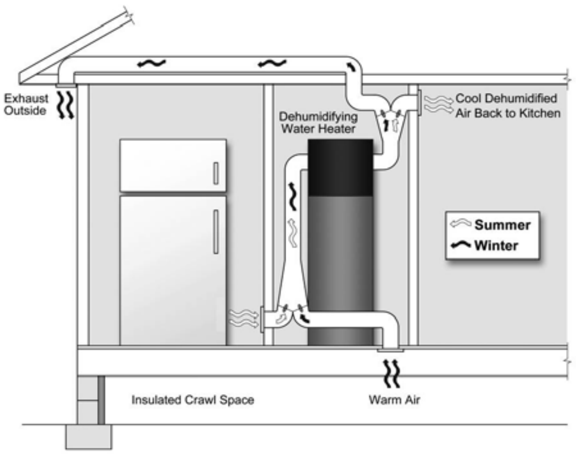


Figure 5. Air flow to and from the heat pump water heater in ZEH2

ZEH2 occupants consumed a total of 12,207 kWh from April 1, 2004, through March 31, 2005, and the PV system generated 2305 kWh. About 34% of the solar energy was collected at a time when it was not needed in the house. Table 5 shows the energy usage breakdown.

Table 5. ZEH2 measured energy use, April 2004-March 2005

Month	Space heat (kWh)	Space cool (kWh)	Hot water (kWh)	Other (kWh)	Total electric (kWh)	Solar generated (kWh)	Solar sold to utility (kWh)
April	0	159	87	418	664	203	99
May	0	488	66	359	913	234	78
June	0	498	57	336	891	215	76
July	0	347	59	325	731	250	110
August	0	280	60	344	684	233	86
Sept.	0	246	56	299	601	217	102
October	280	0	70	346	696	159	65
Nov.	624	0	78	359	1061	145	30
Dec.	1420	0	109	403	1932	148	19
January	1392	0	118	382	1892	136	15
February	756	0	99	352	1207	142	34
March	442	0	102	391	935	223	81
Total	**4914**	**2018**	**961**	**4314**	**12207**	**2305**	**795**
% of total	40%	17%	8%	35%	100%		
Annual cost	$334[a]	$137[b]	$65	$293	$830	-$346	
Daily cost	$1.83[a]	$0.75[b]	$0.18	$0.80	$2.27	-$0.95	
Adjusted daily cost	$0.95[c]				$1.83[c]		

[a] Heating days only

[b] Cooling days only

[c] Based on correctly charged heat pump using 2544 kWh rather than the actual 4914 kWh that was used by incorrectly charged heat pump

The measured net daily cost of off-site energy to run this all-electric house was $1.32, compared to the daily energy cost of $1.01 for ZEH1. The higher energy cost is attributable to a low coolant charge on the heat pump. The performance penalty estimate for the low charge lead to the adjusted daily cost shown in Table 5 (Christian 2006a), assuming a properly performing heat pump. The resulting adjusted energy use for October 2004 until the end of February 2005 is 2370 kWh or $0.44 per day. This reduction in heating energy for ZEH2 was 2544 kWh. The resulting adjusted daily HVAC cost is $0.85 per day, which yields a total whole-house daily energy cost after solar credits of $0.88. Assuming a properly functioning heat pump, the solar energy collected on site amounts to 23% of the house's total electric demand of 9837 kWh/year, 3% higher than found in ZEH1.

2.3 ZEH3

ZEH3, shown in Figure 6, is one story with 1060 ft^2. The ACH 50 rated at 1.09. The biggest difference between ZEH3 and the other three houses is that its heating/cooling system (2 ton, 16.6 SEER) is a direct-exchange geothermal heat pump (Christian 2006b).

ZEH3 has 6.5-in.-thick SIP walls and 10-in.-thick SIP ceiling panels. It has the same 6/12 pitch (26.6°) as ZEH2. The floor plan is shown in Figure 7, the wall elevations in Figure 8. The green metal standing-seam roof has an infrared-reflective pigmented paint that makes it 35% more reflective than the similar-looking green roof of ZEH2. It has the same 6/12 pitch (26.6°) as ZEH2.

The PV system, like the one in ZEH2, is a 12-panel system rated at 1.98 kWp. The water heater is a 50-gal electric-resistance unit with an efficiency rating of 94%. Water heating is augmented by a desuperheater, a heat exchanger that uses superheated exhaust from the heat pump compressor to heat water for the hot water supply. The occupants of ZEH3 kept the temperature at around 72°F year round.

ZEH3 occupants consumed a total of 11,014 kW from March 1, 2004 until February 28, 2005, and the PV system generated 2241 kWh, including 29% collected during times when the energy was not needed in the house. Table 6 shows the actual energy usage in ZEH3.

The net daily cost for off-site energy to run this all-electric house was $1.13. The “other” loads in this house of 7388 kWh were much higher than ZEH1 (5907 kWh/year), ZEH2 (4314 kWh/year), and the suggested internal loads from the Building America Benchmark house (6512 kWh/year). In part this is explained by the house being mostly occupied during the day 7 days a week. Also a significant load was due to unusually extensive outdoor holiday decorations during November through January. To be able to more directly compare ZEH3 with the other houses and the Building America Benchmark, the kWh for “other” loads for ZEH3 is reduced (Christian 2006b). The average for “other” loads of ZEH1, ZEH2, and two Building America Benchmark houses is 5604 kWh/year, or $1.04 /day. This would reduce the “other” load by 1784 kWh, which would represent a cost reduction to the homeowner for off-site energy shown in Table 6 of $0.34/day, resulting in an average daily net cost for off-site energy of $0.79. This compares to $1.01/day for ZEH1 (Christian 2005), and $0.88/day for ZEH2 (Christian 2006a).

The HVAC cost on ZEH3 with the geothermal heat pump averaged only $0.44/day, compared to $0.51 per day on ZEH1 with a 13.7-SEER, single-speed compressor. The final adjusted daily HVAC cost for ZEH2 came to $0.85/day.

With an adjusted “other” load for ZEH3 of 5604 kWh/year, this all-electric house’s fraction of solar energy collected on site amounts to 24% of the total electric demand of 9230 kWh/year, an improvement of 4% over ZEH1. ZEH2 attained 23% of its total energy needs from the solar PV system.

Figure 6. ZEH3.

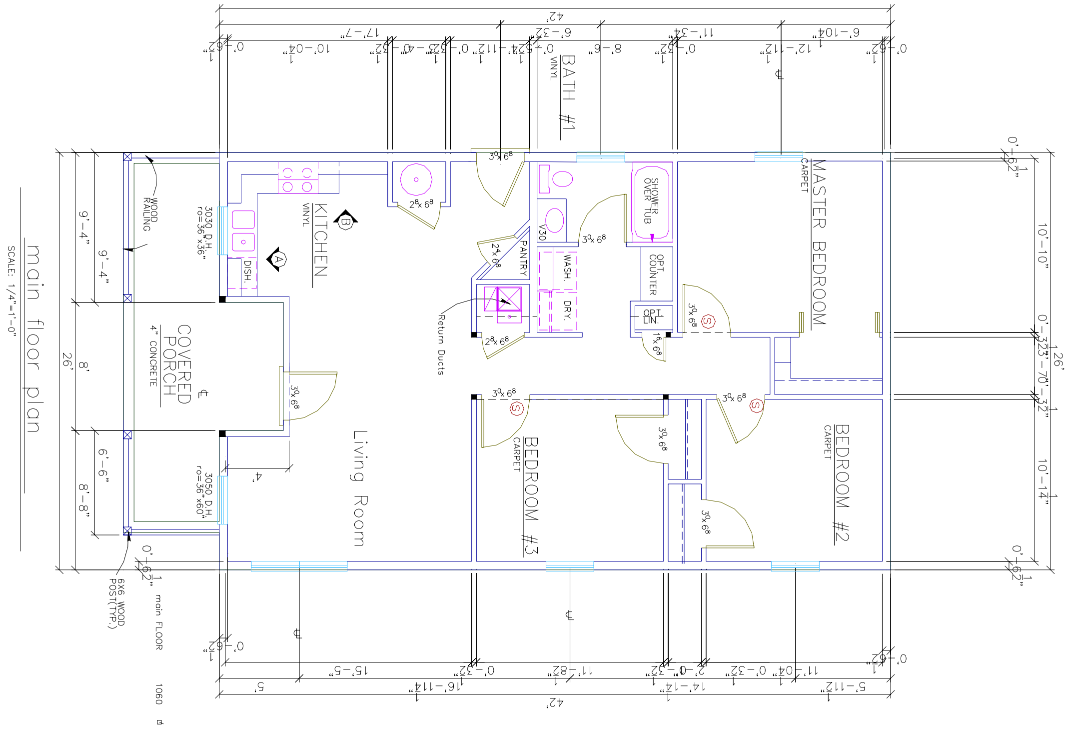


Figure 7. ZEH3 floor plan.

Table 6. ZEH3 measuredenergy use, March 2004-February 2005

Month	Space heat (kWh)	Space cool (kWh)	Hot water (kWh)	Other (kWh)	Total electric (kWh)	Solar generated (kWh)	Solar sold to utility (kWh)
March	69		108	486	663	231	116
April	0	77	108	489	674	226	100
May	0	319	90	560	969	221	48
June	0	346	76	511	933	213	56
July	0	394	76	569	1039	232	48
August	0	352	76	603	1031	222	41
Sept.	0	290	79	483	852	201	55
October	57	0	99	560	716	154	49
Nov.	50	0	104	738	892	135	37
Dec.	132	0	148	1174	1454	142	28
January	176	0	144	620	940	131	40
February	85	0	171	595	851	133	41
Total	**569**	**1778**	**1279**	**7388**	**11014**	**2241**	**659**
% of total	5%	16%	12%	67%	100%		
Annual Cost	$39[a]	$121[b]	$87	$502	$749	–$336	
Daily cost	$0.22[a]	$0.66[b]	$0.24	$1.38	$2.05	–$0.92	
Adjusted daily cost				$1.04[c]	$1.71[c]		

[a] Heating days only

[b] Cooling days only
[c] Based on normalized “other” usage of 5604 kWh rather than the actual 7388 kWh

---

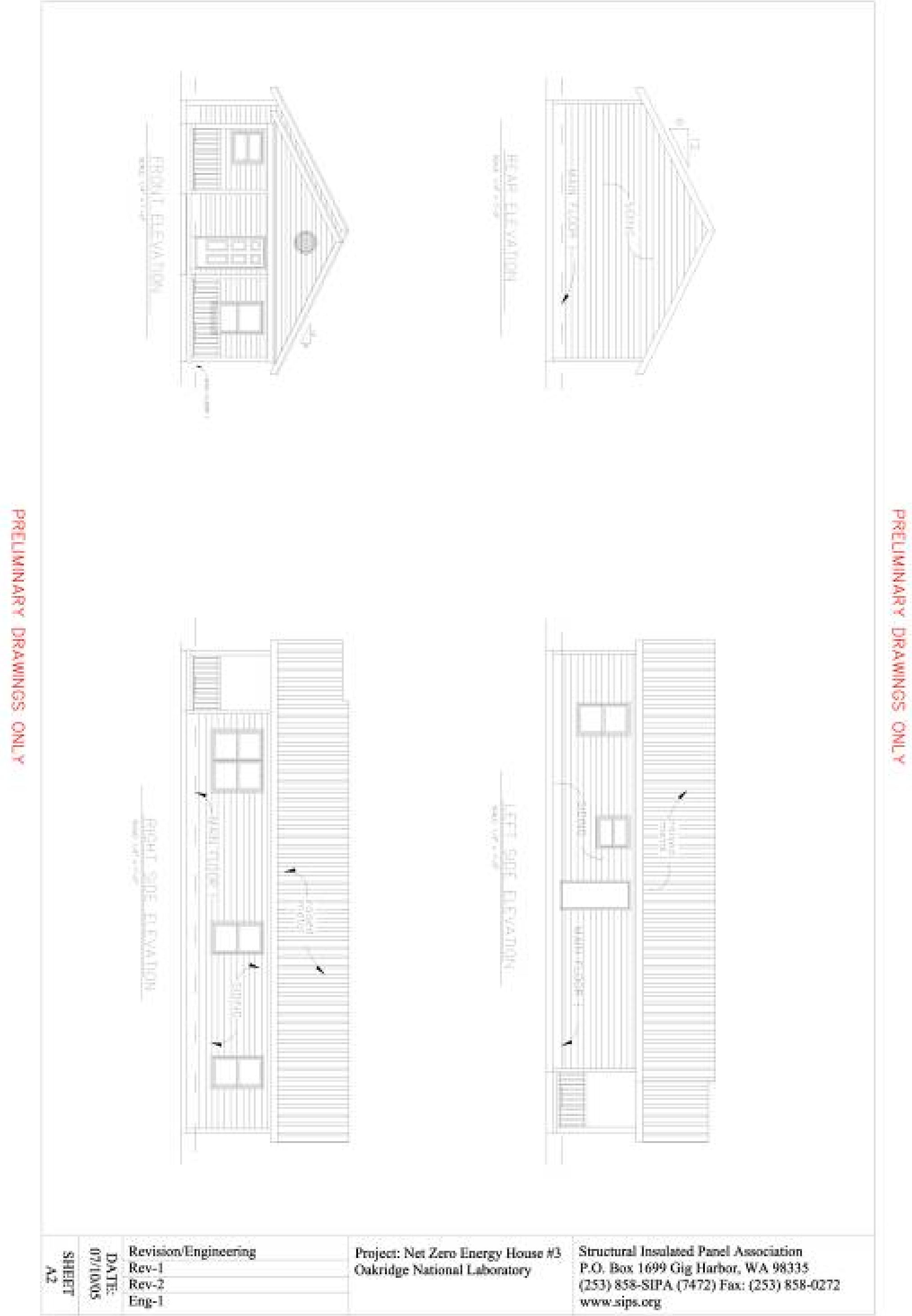


Figure 8. ZEH3 wall elevations.

To see a larger elevation drawing for this house please see ZEH3elevations.pdf.

Figure 9 shows the crawl space foundation plan for ZEH3. To see a larger crawl space foundation drawing see ZEH3foundation plan.pdf.

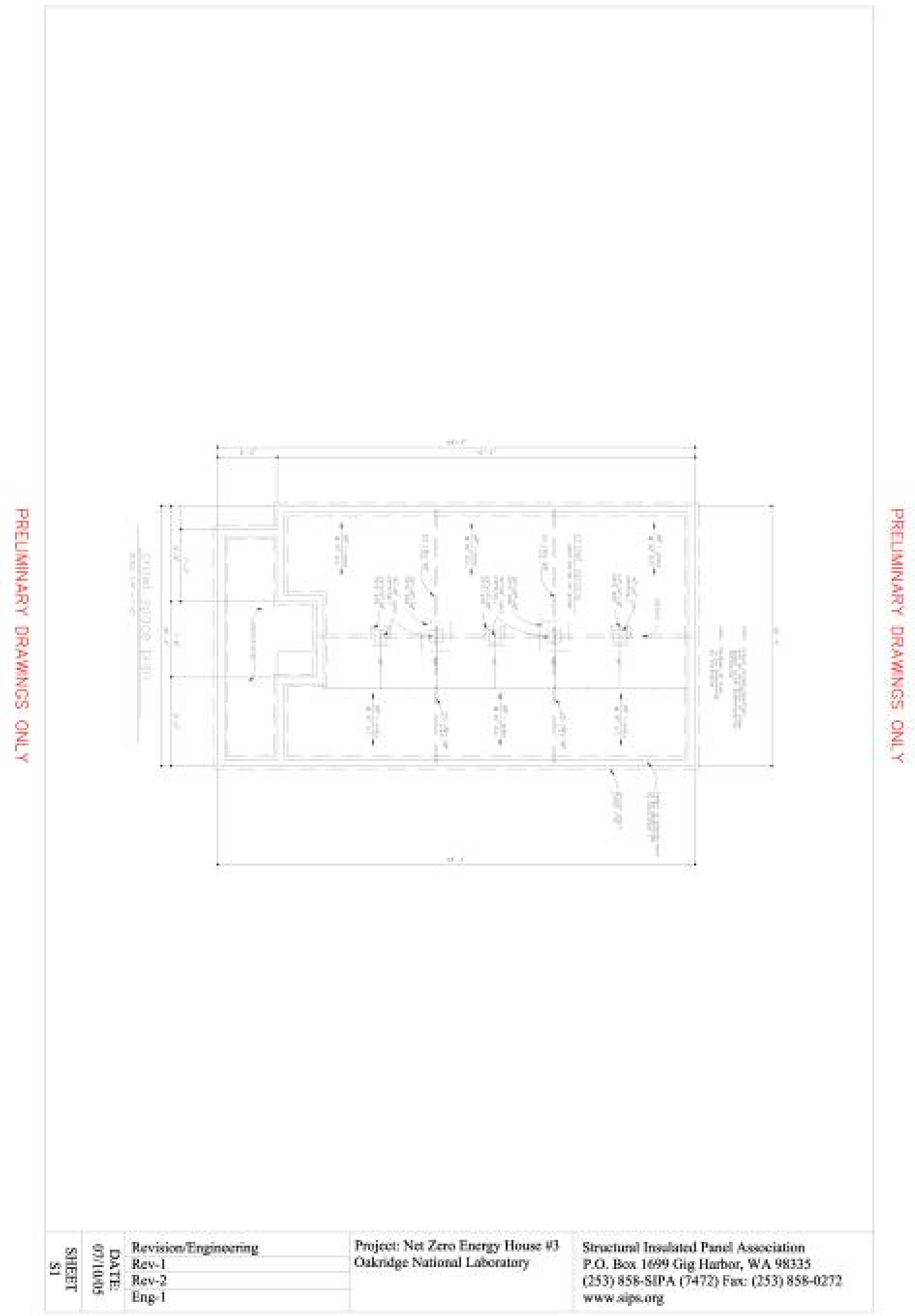


Figure 9. ZEH3 crawl space foundation plan.

Based on the house plans like those shown in figures 7, 8, and 9, the SIP manufacturer develops a set of panel cut drawings like those shown in figures 10 and 11.

Figure 10 shows the ZEH3 panel drawings for constructing the gable walls. To see a larger file of the panel drawings for the ZEH3 gable walls see ZEH3gablewallpanel dwg1.pdf.

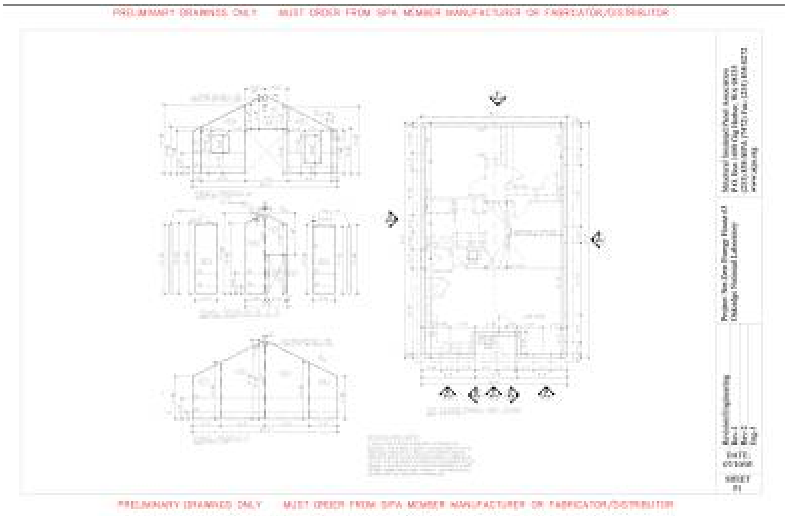


Figure 10. ZEH3 gable wall panel cut drawings.

Figure 11 shows the panel cut drawings for the ZEH3 long eave walls. To see a larger file of the panel drawings for the ZEH3 longer eave walls see ZEH3longeavewallpanel dwg2.pdf.

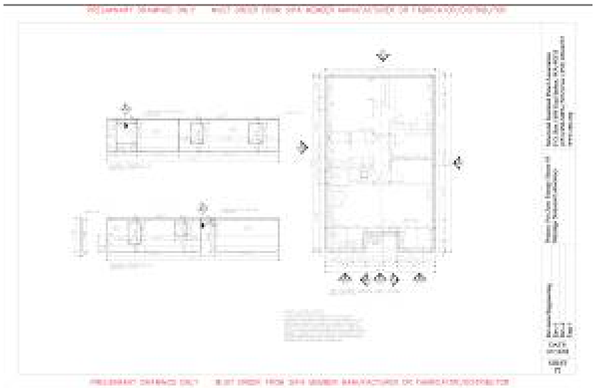


Figure 11. ZEH3 long wall cut drawings.

2.4 ZEH4

ZEH4, shown in Figure 12, a two-story house, contains 1139 ft^2. It was built in two stories because of the steepness of the lot. Instead of a crawl space, it has a walk-out basement, opening on the south side, which contains three bedrooms.

Figure 12. ZEH4.

The basement walls of ZEH4 are four T-Mass® pre-cast panels of polyisocyanurate insulation sandwiched in concrete (www.t-mass.com). The walls were precast with electrical chases and receptacle boxes installed and with rough openings provided for the windows and doors. On below-grade surfaces, 60-mil waterproofing was sprayed and covered by ¾-in. glass fiber drainage boards. Tmass walls were chosen because they provide thermal mass to store and release heat, aiding in heating and cooling and because they aid in moisture management by offering hygro-buffering. The SIPs used in ZEH4 are polyisocyanurate foam sandwiched between layers of OSB, which has a higher R-value per inch than the expanded polystyrene SIPs used in ZEH1, 2, and 3. The ACH 50 rated at 1.64. The roof is light gray aluminum simulated tile and has a 4/12 pitch. The PV system has 20 panels and is rated at 2.2 kWp, about 10% more capacity than the PV systems on ZEH1, 2, and 3.

ZEH4 occupants consumed a total of 9843 kWh from August 1, 2004, through July 31, 2005, and the solar system generated 2627 kWh. About 46% of the solar was collected at a time when it was not needed in the house. Table 7 shows the energy usage broke down.

The net daily cost for off-site energy to run this all electric house was $0.75. The HVAC cost for ZEH4 with the SEER 17 air-source HP averaged $0.51/day. This all-electric house's fraction of solar energy collected on site amounts to 27% of the total electric demand of 9843 kWh/year, the highest fraction of on-site generation among the four-house set.

Table 7. ZEH4 measured energy use, August 2004-July 2005

Month	Space heat (kWh)	Space cool (kWh)	Hot water (kWh)	Other (kWh)	Total electric (kWh)	Solar generated (kWh)	Solar sold to utility (kWh)
August 2004	0	204	168	503	875	279	126
Sept	0	145	114	580	839	236	77
Oct	73	0	115	474	663	176	87
Nov	152	0	138	449	739	144	70
Dec	429	0	186	425	1041	146	62
Jan	438	0	190	441	1068	137	62
Feb	322	0	162	359	843	146	67
March	297	0	196	439	932	247	126
April	0	99	169	422	690	255	134
May	0	102	144	376	622	324	201
June	0	199	116	402	717	286	120
July 2005	0	267	120	427	814	251	87
Total	1711	1016	1819	5297	9843	2627	1219
% of total	17%	10%	18%	54%	100%		
Annual cost	$116[a]	$69[b]	$124	$360	$669	–$394	
Daily cost	$0.32[a]	$0.19[b]	$0.34	$0.99	$1.83	-$1.08	

[a] Heating days only
[b] Cooling days only

The architectural drawings for ZEH4 are shown in figures 13-18, followed by the panel drawings for the basement floor, which were made using TMASS precast insulated concrete panels (figures 19 – 26). The SIP panel drawings are shown for the top floor in figures 27 – 36.

The heating/cooling system is a 17-SEER, 2-ton air-source heat pump with a two-speed compressor and DC commutating indoor fan motor. The water heater is an HPWH. Unlike the other HPWHs in ZEH1 and 2, it draws warm air from the refrigerator condenser year round; also unlike the others, it exhausts cool, dry air into an adjacent half-bath year-around. The ventilation scheme for the house prevents the cool, dry HPWH exhaust from being a comfort issue during the heating season yet helps dehumidify in the summer. Every 20 minutes the fresh air inlet opens and the half-bath exhausts about 40 cfm. ZEH4 has compact fluorescent bulbs in about 75% of its light fixtures.

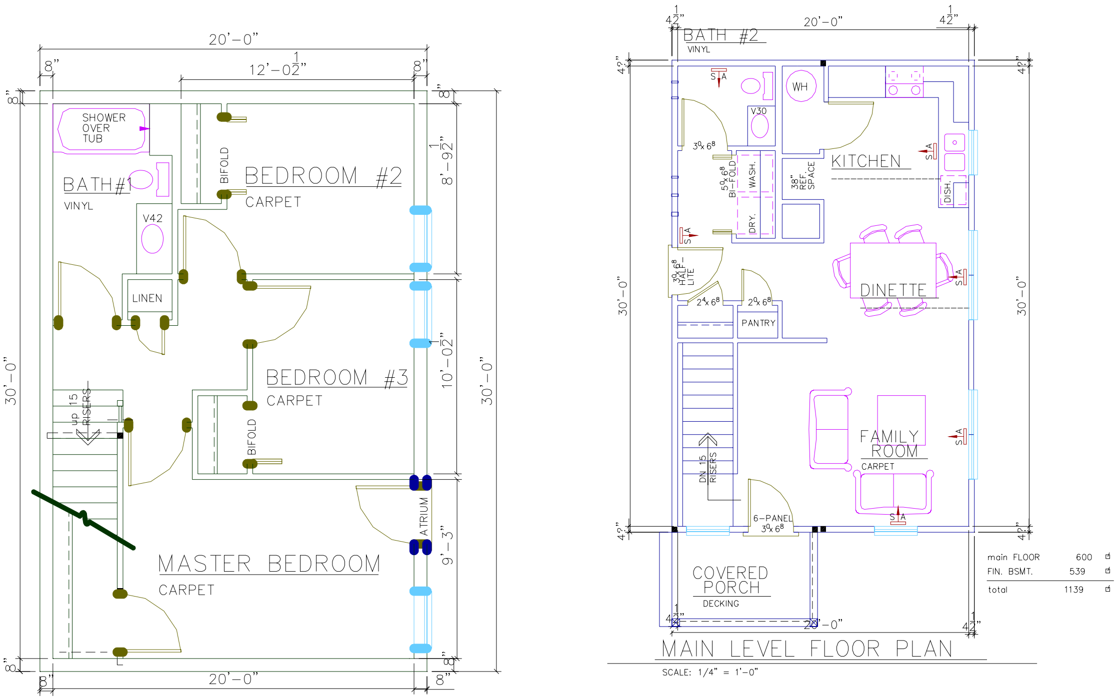


Figure 13. ZEH4 floor plan. Bedrooms on first floor (left); living areas on second floor.

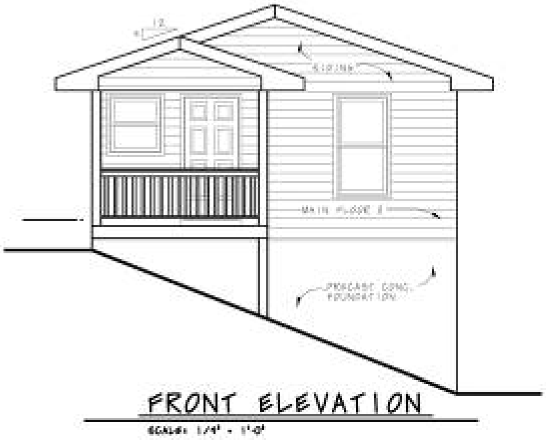


Figure 14. ZEH4 front elevation. The porch roof is also made with SIPS with 2-ft extended overhangs.

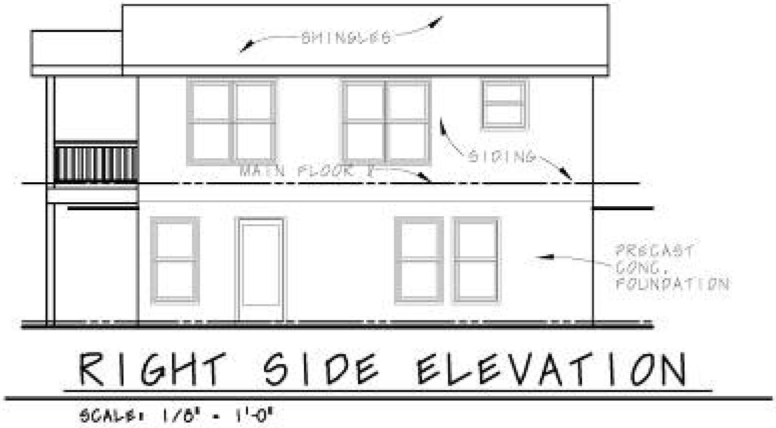


Figure 15. South elevation of ZEH4 with most of the windows provides good daylighting. It would be good to add some shading for the bottom floor windows.

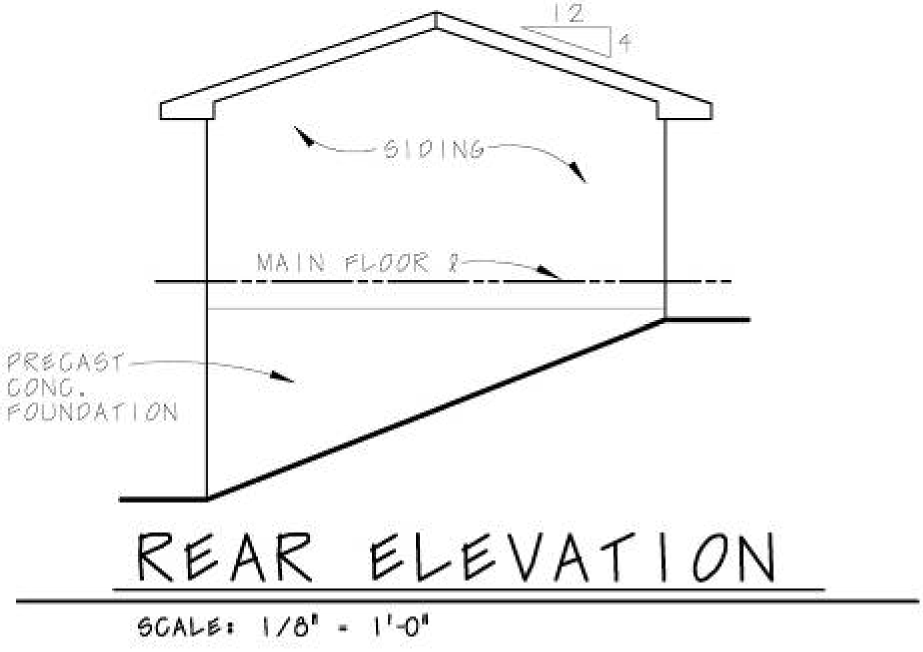


Figure 16. ZEH4 rear elevation, faces east.

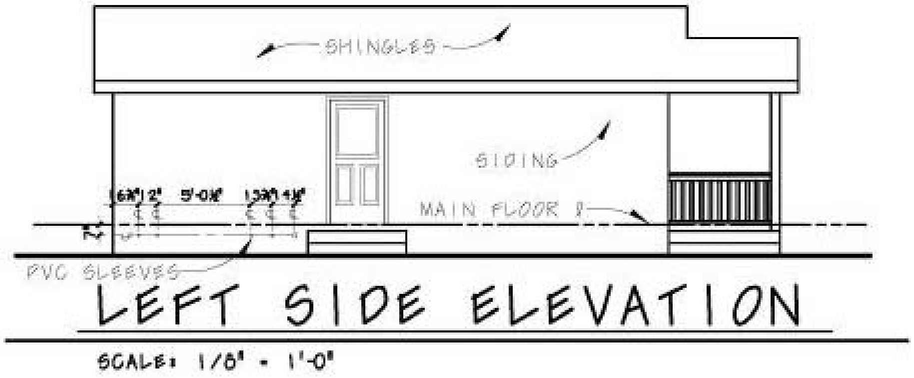


Figure 17. The north elevation shows the penetrations needed for utilities in the precast concrete foundation wall.

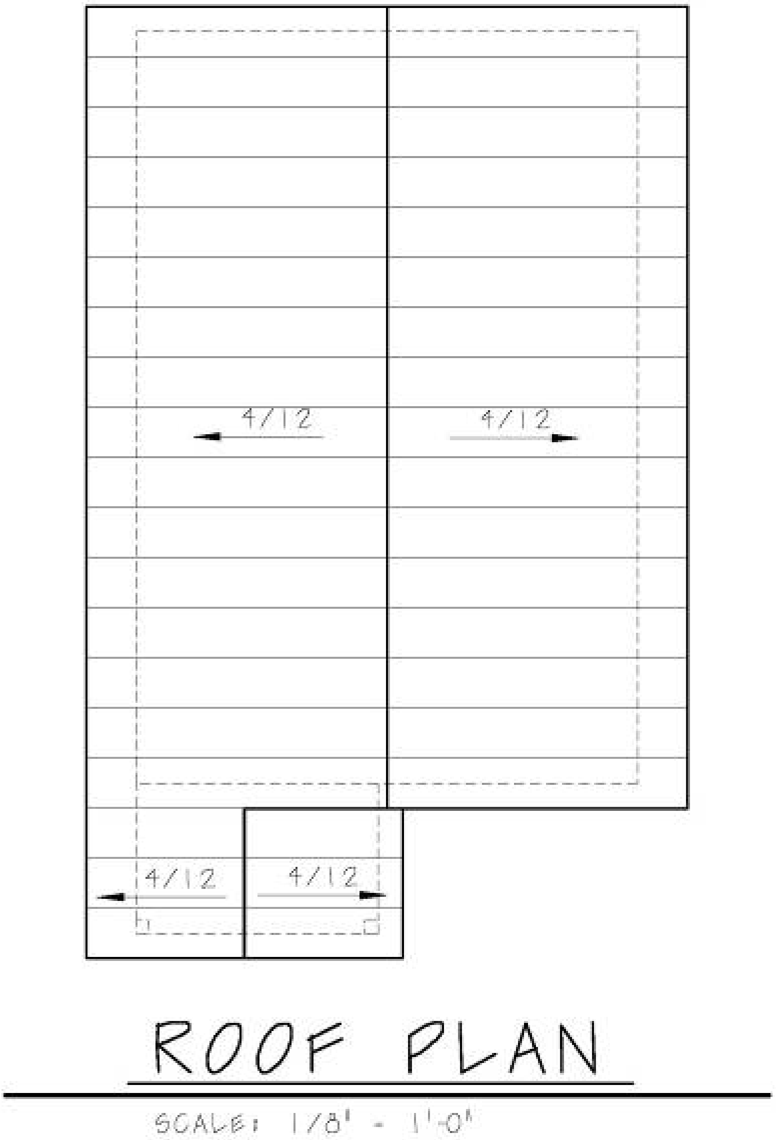


Figure 18. The ZEH4 roof plan was designed to be panel-friendly; all panel widths are 4 ft.

TMass precast insulated concrete foundation panels were used. These were developed by Chris Helms at International Precast in Siler City. NC. They have licensed the right to manufacture the

TMASS wall system from Dow.
(http://www.precast.org/publications/solutions/2006_spring/green_zone.htm) .

Note that the drawings in figures 19 – 26 are copyrighted and cannot be used without permission of the Dow Chemical Company.

Figure 19 shows the plan for the framed footer, to which the four wall panels will be welded in the field. Formed footers are easier to keep level. It is important to have a level footer both to more easily align the welding plates and to keep a controlled gap of about ½-in. seal with expandable clay strips and high strength concrete grout between the top of the footer and the bottom of the precast insulated walls. On both sides of the footer you should install footer drains. Position a sleeve through the footer forms prior to the concrete pour to provide a passage to direct the footer drain to a solid pipe run out to daylight. Not shown on the footer drawing are the intermediate structural load points that carry the roof load. (In ZEH4 there is one load point that is shown in figures 31 and 32.)

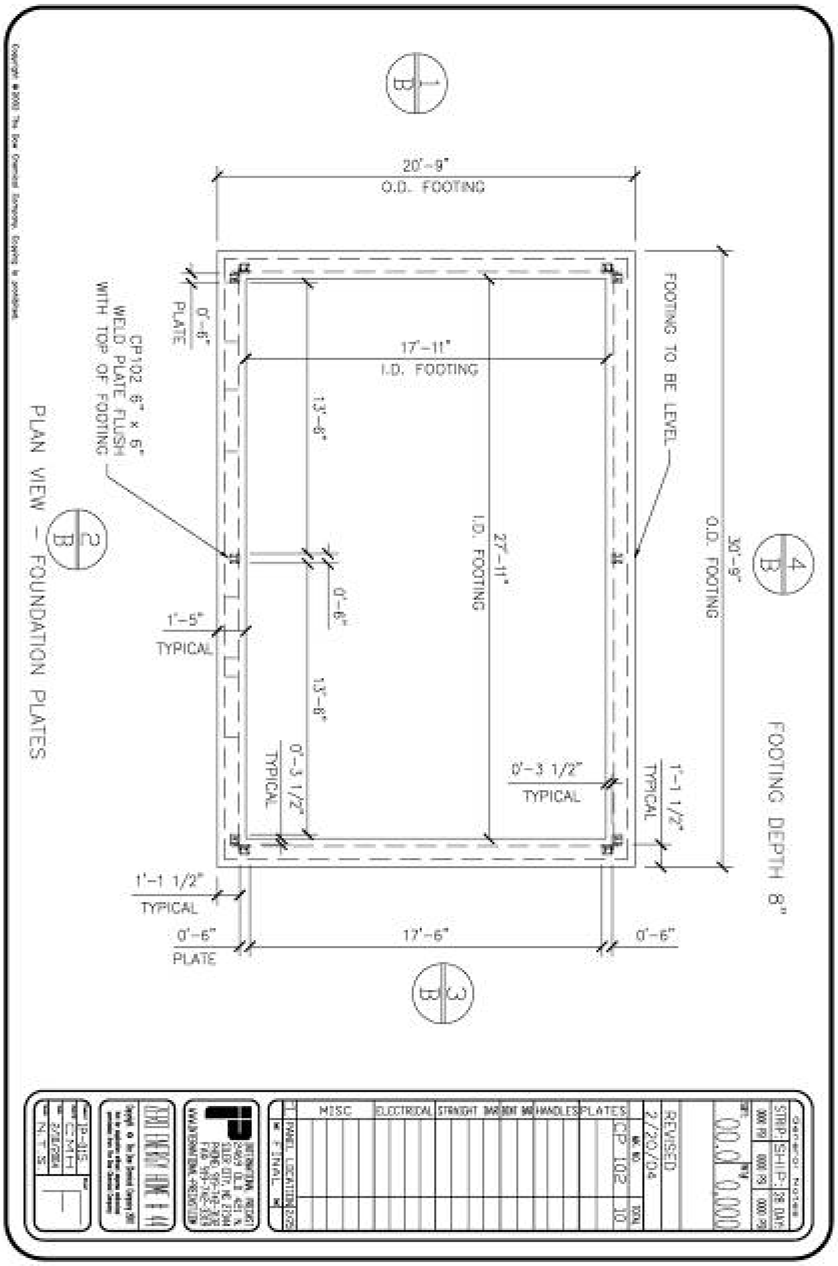


Figure 19. ZEH4 framed footer plan.

Figure 20 shows the plan view of the walk-out basement and the location of the four TMass precast insulated walls supported by the footer and the location of the internal walls, which are all stick framed. Figures 21-24 show an elevation at top view of the walls 1B - 4B.

Figure 21 is the west wall (labeled “1B” on the plan drawing shown in Figure 20) for the insulated precast ZEH4 bottom floor. You can see where the ½-in. PVC electric chase and electric outlet boxes are place in the wall. These are all positioned on the shaker table in the factory prior to pouring the first 4-in. layer of concrete.

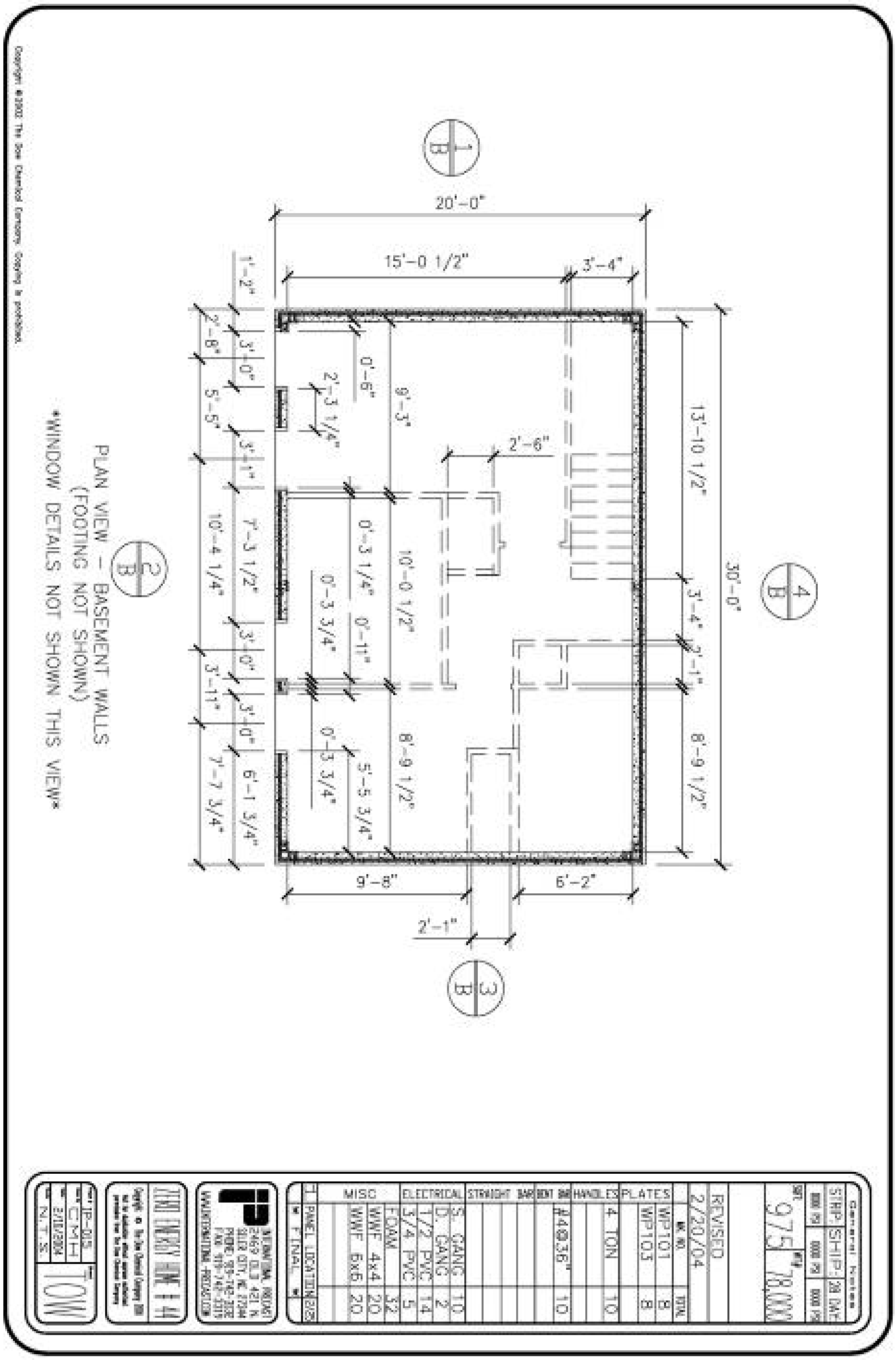


Figure 20. ZEH4 basement plan view.

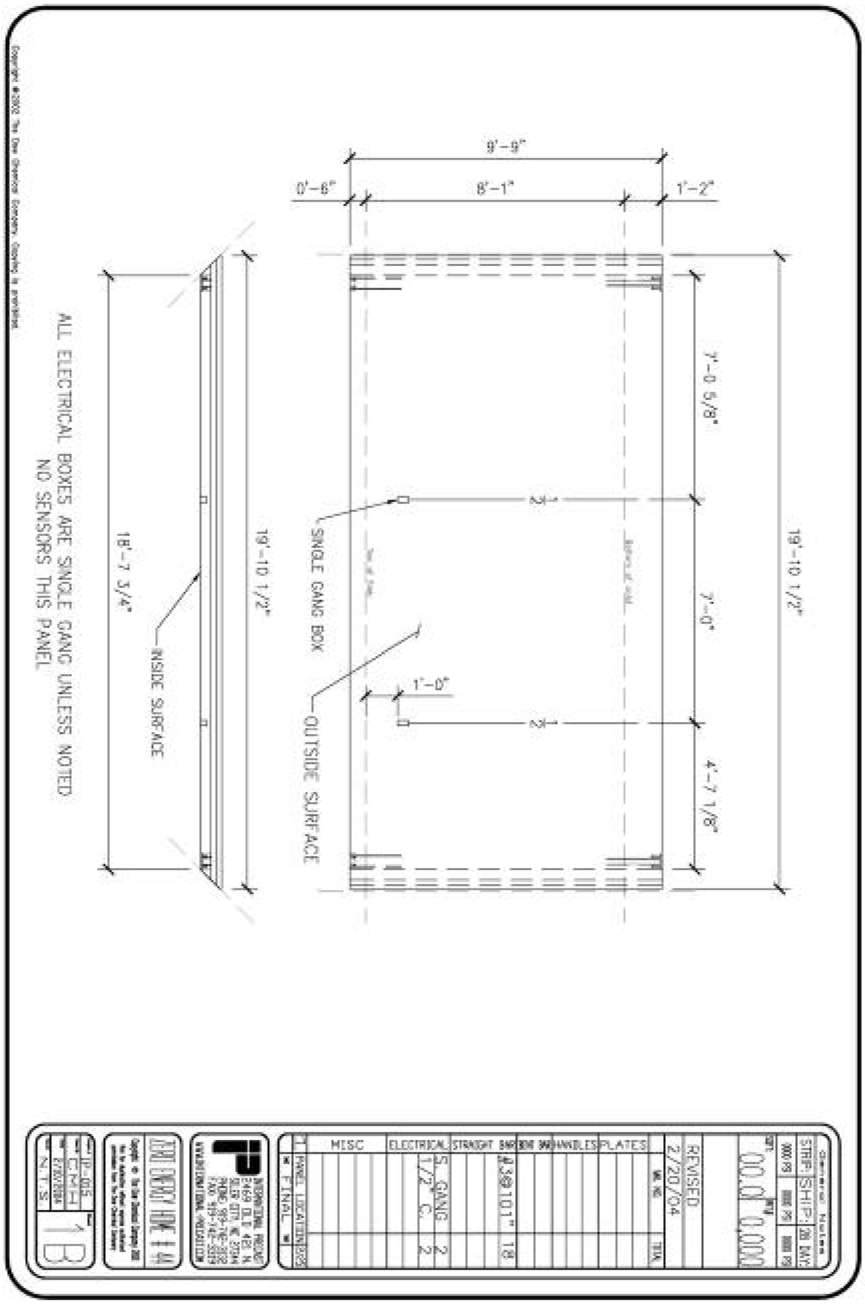


Figure 21. ZEH4 precast west wall panel elevation and top view.

Figure 22 shows the drawing for the south wall of ZEH4. This is by far the most complicated wall to make. Pressure-treated wood is positioned for the window and door bucks and for the floor truss nailing header at the top. It is very important that you make sure the windows and doors are in the right location and have the correct rough openings on the drawings before you approve them. Installing the three windows and door went very well. The details to inset these windows were designed by the ORNL-led team. Good moisture practices are embedded to minimize the risk of moisture damage. In fact this wall system could withstand flood waters and be dried out with minimum damage.

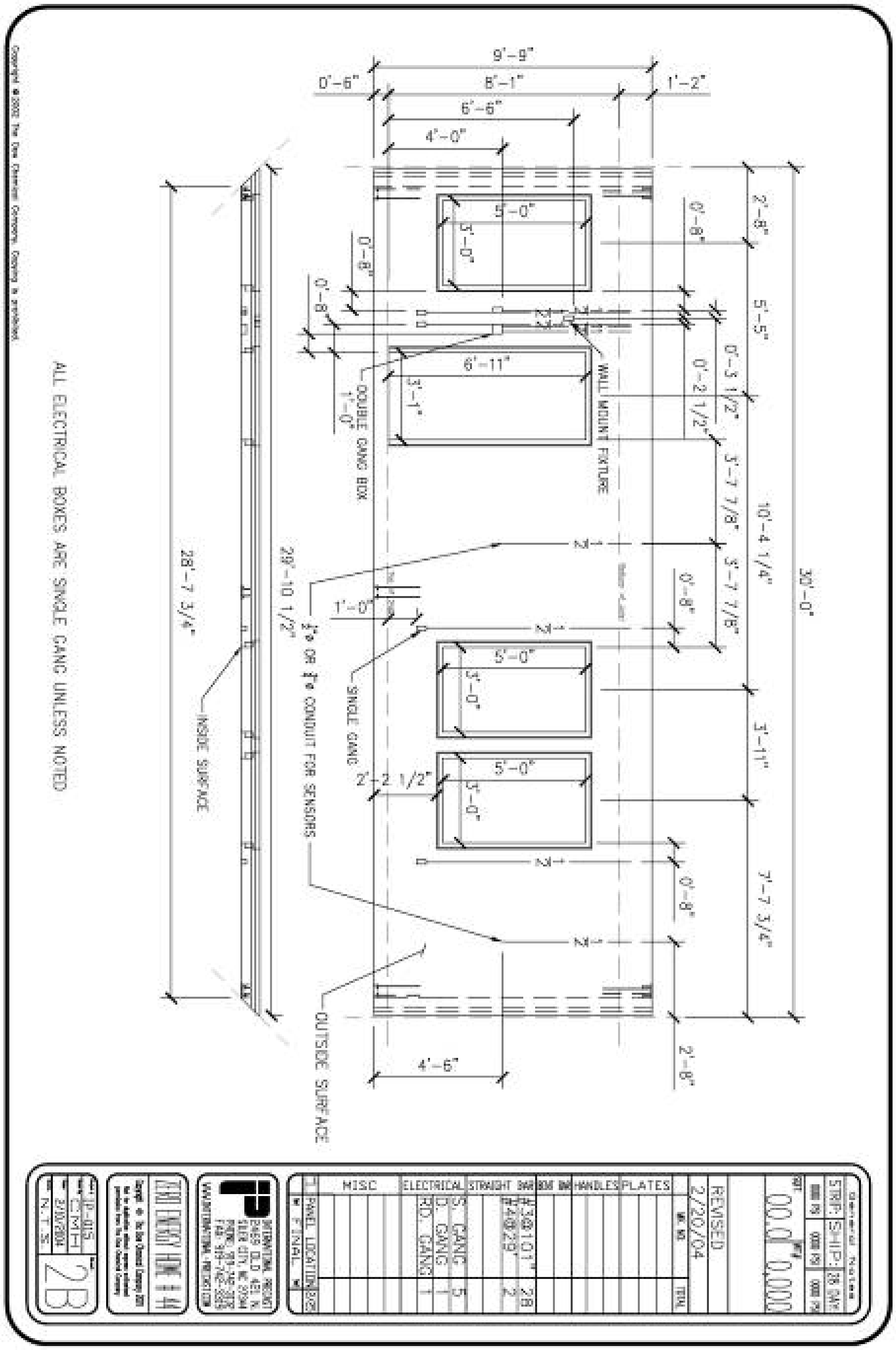


Figure 22. ZEH4 precast south wall.

Figure 23 shows the elevation and top view of the walk-out basement east wall of ZEH4. These drawings are all signed off by the contractor prior to initiating the precasting in the factory.

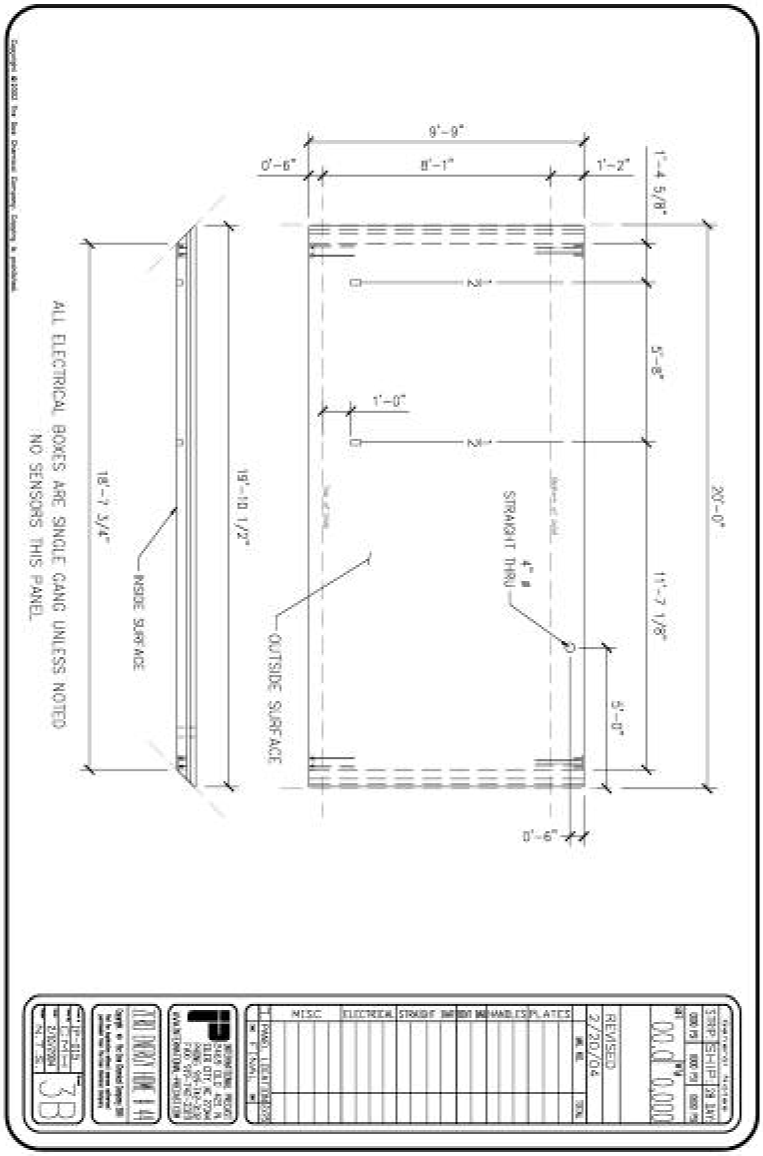


Figure 23. ZEH4 insulated precast east wall panel.

Figure 24 is the north wall of the walk-out basement of ZEH4. Since this design calls for the 2 x 4 floor trusses to be hung from the top of the precast walls, it is most important to design for all the utility penetrations. In this house plan the electrical wires exit the Tmass wall in the header positioned at the inside top of the wall. You must also maintain the wire chases that come from the above SIP wall. This was not done on this set of plans and should be added in your plans. With a complete electrical plan in hand make sure the Tmass drawings all show the electrical chases that come from the above SIP wall into the Tmass and out into the floor truss space, which is an easy location to pull electrical wires to the electrical power circuit box. With an examination of the complete house plans including the electrical design, it would have been very easy to add the ½-in. chases to pull wires from underneath the floor into the precast wall and up into the SIP wall above. Getting them on the plans is a good start, maintaining their continuity during construction is the second task.

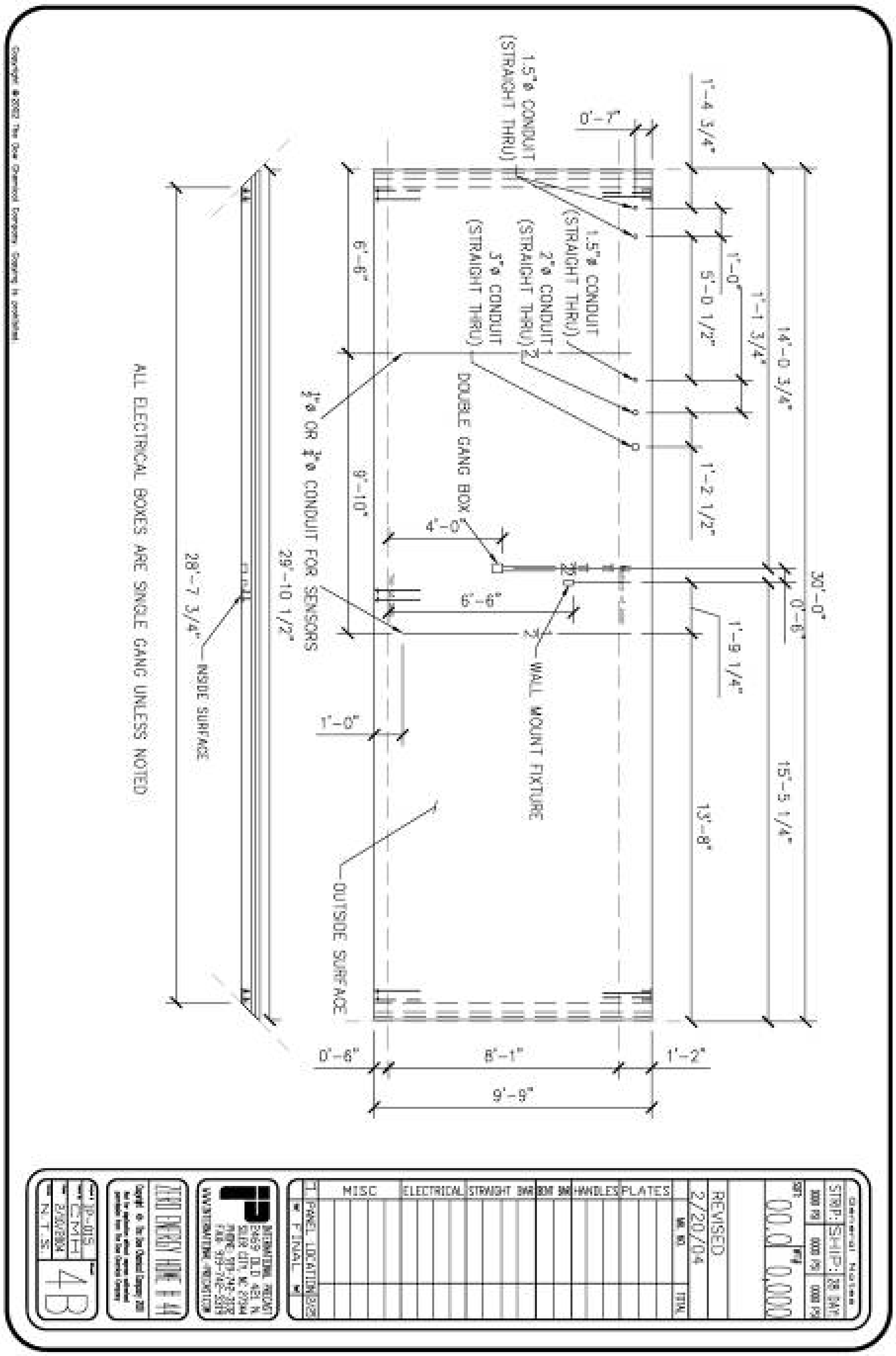


Figure 24. ZEH4 insulated precast north wall panel.

In the case of ZEH4 the aluminum flashing (termite screen and capillarity break), ¾-in. plywood subfloor and sill sealer all need to be drilled to keep those chases open while the floor is being laid. The bottom plate for attaching the SIP panels also need to be drilled to keep these chases open and finally the SIP electrical chases need to be aligned with the chase leading to the floor. There should be very few electric chases that need to be maintained that go from the SIP panel through the base plate, subflooring, sill sealer, into the Tmass wall elbow, and out the Tmass wall interior service into the floor chase. The bulk of electric wiring connected to electrical outlet and switch boxes in the exterior SIP walls and ceiling panels can be run to interior walls and than down into the floor.

Figure 25 shows the very important window and door rough opening details. Extensive work was spent on the design to minimize the risk of moisture leakage. The fenestrations are inset to stay inside the drainage plane of this wall. Note how even the drip edge was cast into the top of each window and door opening. Although not shown on this drawing, but which should be added, is a slight slope of the window ledge toward the outside wall surface to drain away any water that might penetrate the window or window/wall moisture seal.

For all below-grade surfaces the Tremco waterproofing system (http://www.tuff-n-dri.com/Default.asp?bhfv=5) was installed on ZEH4. This system consists of 60-mil polymer-enhanced asphalt, water-based spray, covered with ¾-in.-thick fiberglass drainage board. The 4 ft x 8 ft drainage board has the ability to drain 74 gallons of water per hour per linear foot.

Figure 26 is a drawing of the header detail for the precast first floor. The pressure treated wood is embedded during the precasting. This wall is designed for floor trusses that are hung from the top of the concrete wall. This enabled the rim joist to be well sealed and insulated. These four precast concrete wall panels were leveled plumbed, squared and welded to the footer after a strip of bentonite was centered below each wall along with two beads of high-density concrete grout. An approximate ½-in. gap was left between the footer and the bottom of each wall to accommodate the seal. The foundation was ready for the floor in 6 hours. Even if after a heavy rain the seam between the top of the footer and bottom of the TMass walls should leak it will not enter the conditioned space. The water that leaks in would find a gravel seam with an embedded interior footer drain leading down-slope to daylight.

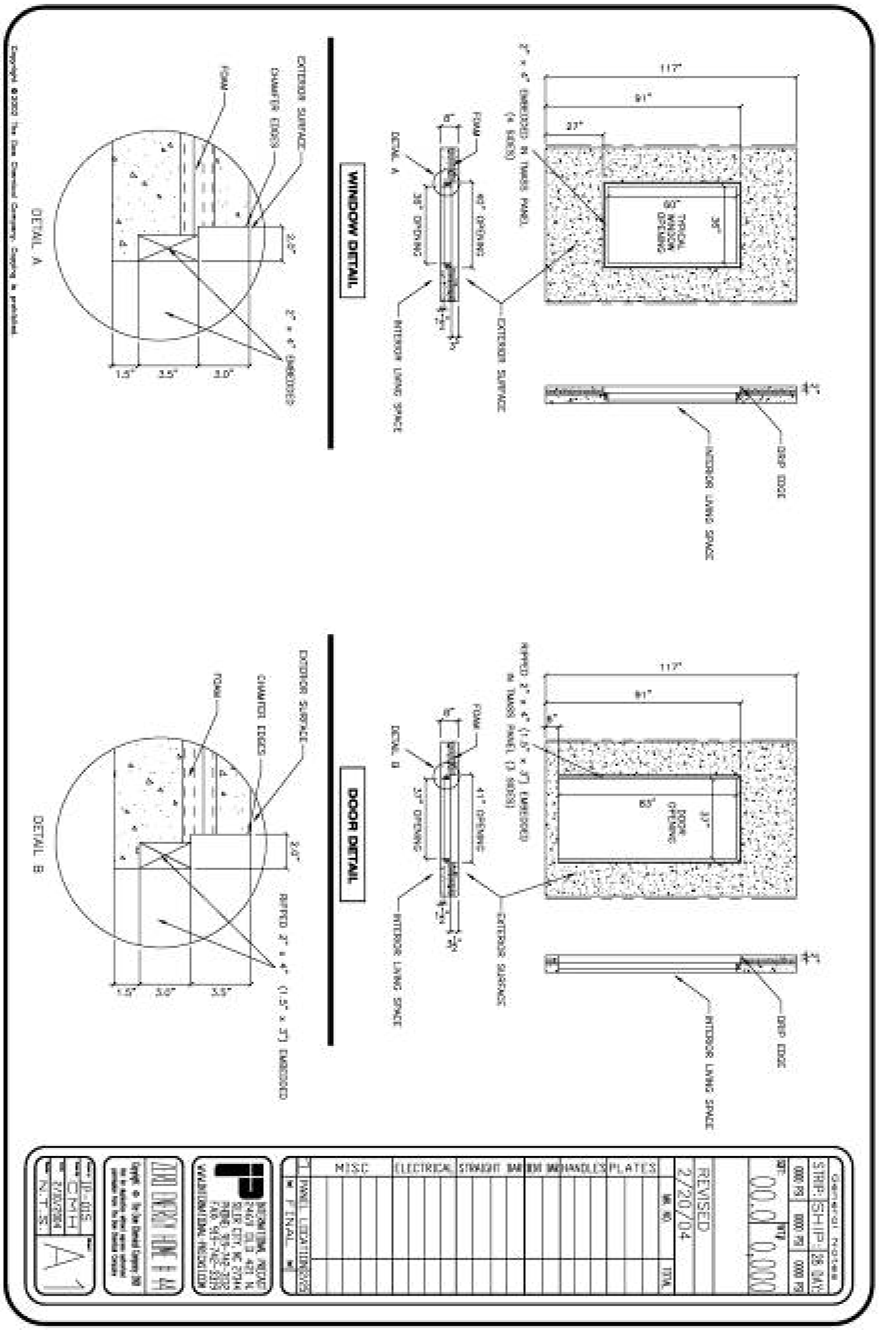


Figure 25. ZEH4 TMass precast window and door opening details.

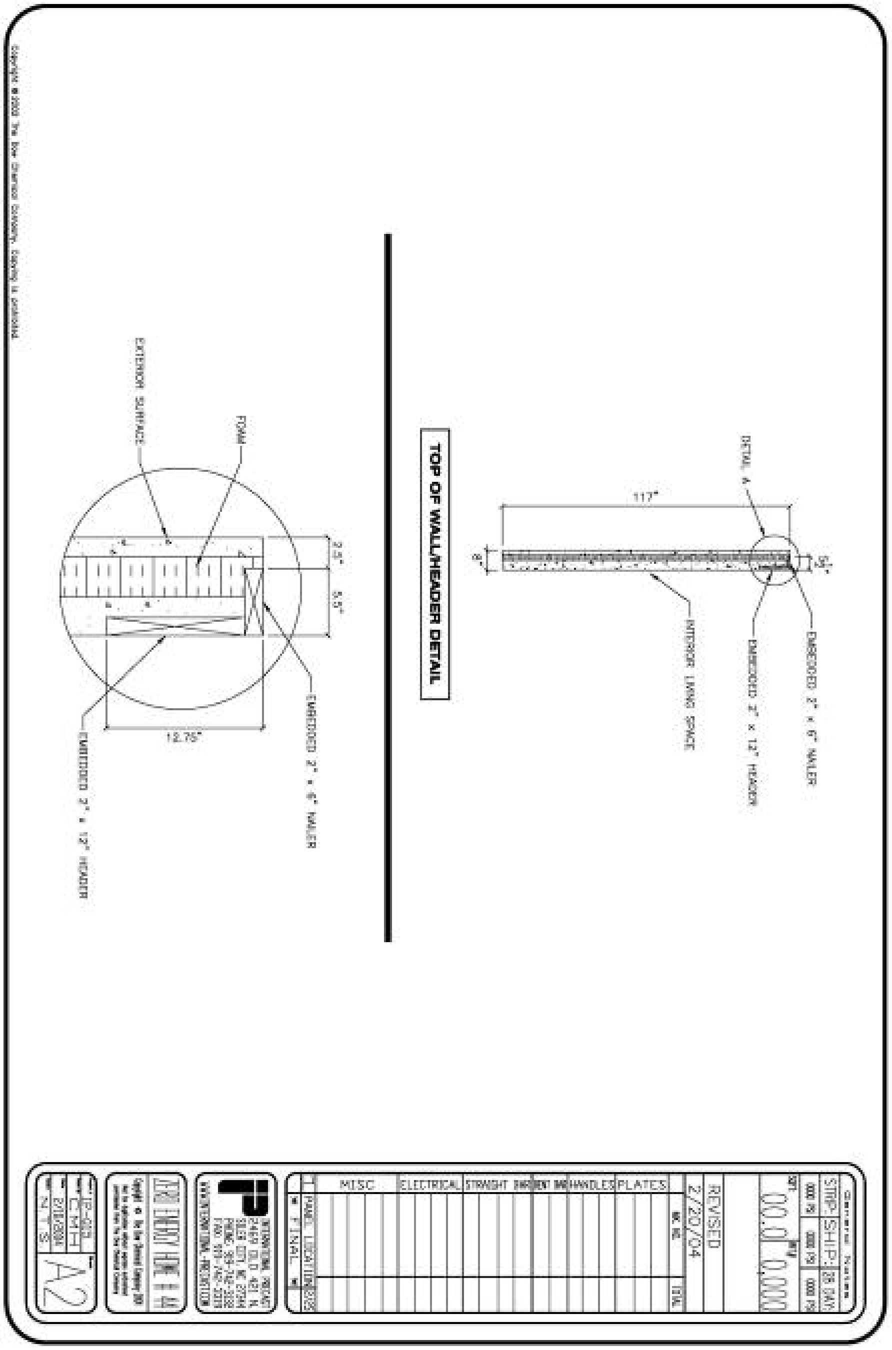


Figure 26. ZEH4 Tmass wall top plate detail.

The drawings in Figures 27-33 show the location of each SIP used to construct the second floor. These drawings are made by the SIP manufacturer based on the house designs you send them. These are used to cut out the panels for your house in the factory.

They are also used by yourself first to make sure what they are going to make is really what you want, and then later to show you how the panels all fit together.

Figure 27 is the SIP west wall panel layout. Five panels 4-ft wide make up this wall. The rough openings are indicated and are cut out in the factory before shipment. The panels are held together by the use of surface splines. In three locations you can see where pockets are cut in the panels for structural porch beam support. The panels arrive with the matching markings A1-A5. The first step prior to installing the panels is to install the base plate all the way around the perimeter of the floor. Note that this is located at least ½ in. from the edge of the outside of the Tmass basement wall. This is necessary to provide structural support for the outside OSB face of the SIP. Be sure to remember to provide a double caulk sealant between the flooring and the bottom of the base plate to avoid air leakage.

Figure 28 shows the panel layout for the south wall. Notice that rather than gang the two sets of double windows, double 2 x 4s are used to carry the load from the floor to the roof (see Figure 44). This eliminates the need for an all-wood structural header above these windows. Eleven panels make up the south side, labeled B1 through B11.

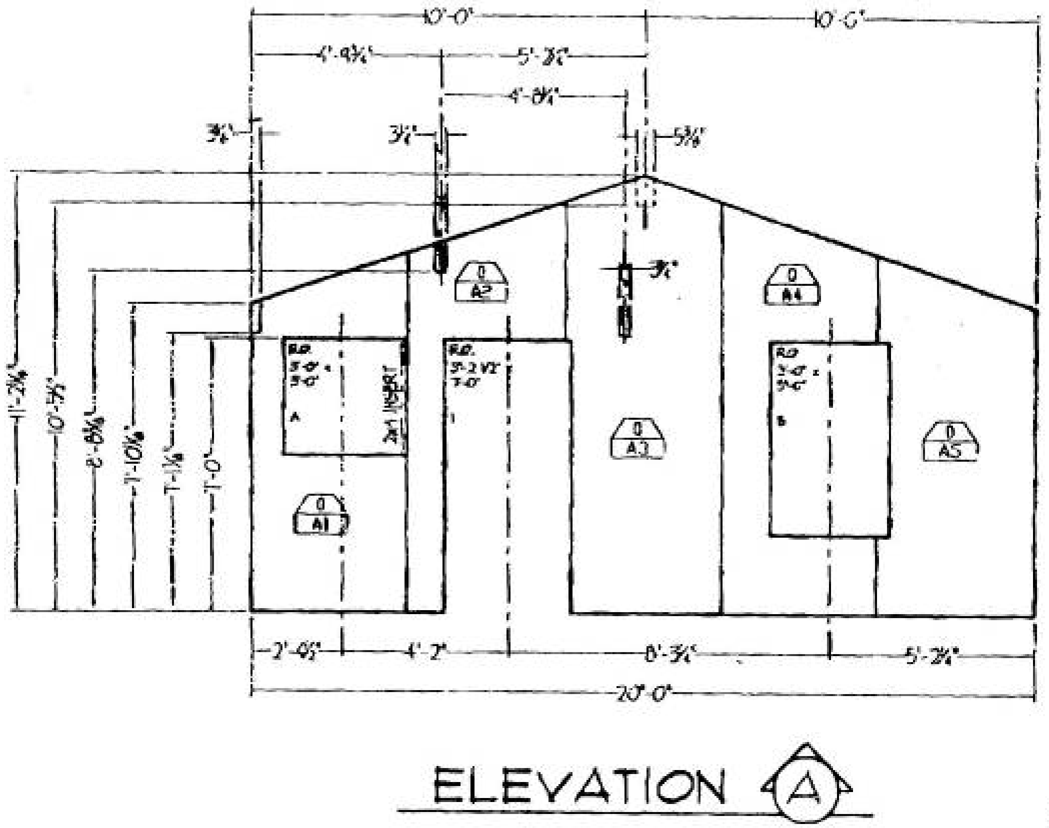


Figure 27. ZEH4 west wall SIP cut drawings.

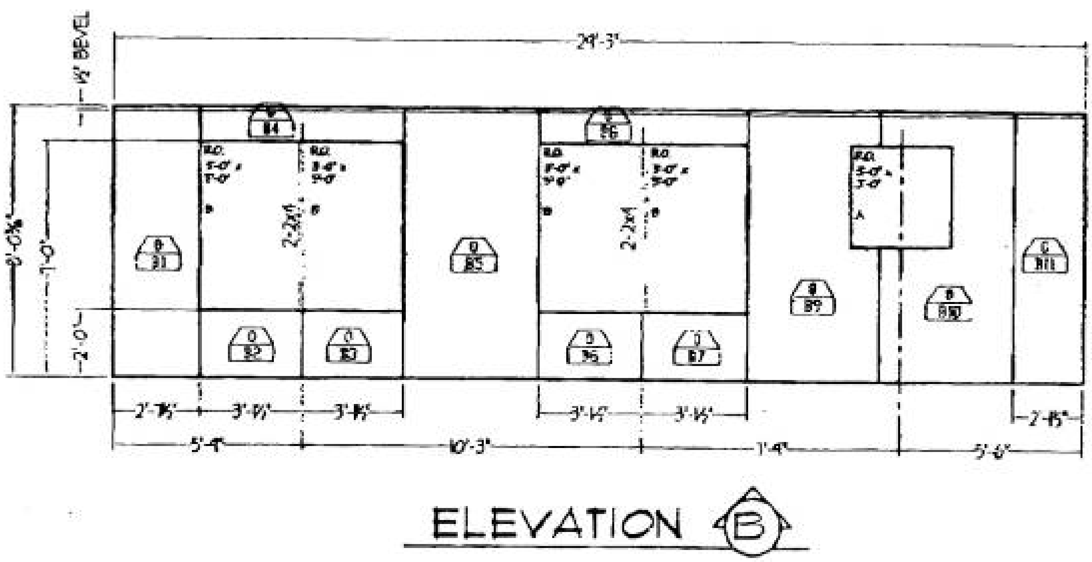


Figure 28. ZEH4 SIP south wall cut drawings.

Figure 29 shows the east wall panel layout. Five panels all 4 ft wide make up this wall, labeled C1-C5. The middle panel, C3, has the pocket for the ridge beam. The detail for showing how to mount this beam is provided in Figure 36. The drawing does not show a 4 x 4 post positioned under the ridge beam, but one is installed. The foam was cut out and a cavity left in place to slip this post in prior to installing Panel C-3.

Figure 30 shows the north wall panel layout. The wall is made with eight panels labeled D1 through D8. They are all full size panels except for panel 1. They are all fastened together with surface splines.

Wall panels are set by starting in one corner, plumbing, leveling, and squaring the two panels that form this first corner. ZEH4 was started with the northeast corner, panels D8 and A1, and working clockwise around the perimeter.

The roof framing plan shown in Figure 31 shows the 5–1/2-in. x 9-in. glulam ridge beam, the location of the single intermittent load point that must be carried all the way to the ground. A small sketch shows how the ridge beam is beveled to provide more flat surface on which to rest the roof panels. The size and amount of intermittent support is based on the design load required for each location. The dead load, which is weight of the roof itself, and the live load, which accounts for wind and snow loading, are calculated and then distributed to all the walls and to the intermittent point loadings. The drawing shows that the structure was designed to support 5813 lb at that location. This was made up of a live load of 2702 lb and a dead load of 3111 lb. This calculation needs to be done for each house to account for design variations and local code requirements. With the subflooring in place the panels were unloaded, walls set in place, and ridge beam lifted into position in five hours.

The main house section (Figure 32) shows the required length of the 2 x 4 post, 10 ft–5 ½ in. The floor trusses and the ¾-in. subfloor that extends to the outside edge of the Tmass wall system are shown. Prior to hanging the floor trusses a piece of metal flashing should be fastened to the top of the Tmass wall. This provides a termite shield and a capillarity break to avoid moisture uptake through the Tmass system and into the above-grade wood. It also will provide flashing to direct the drainage plane of the above-grade wall out away from the house. Be sure to maintain any electrical chases that will be needed to run wires from the SIPs into the floor chase below.

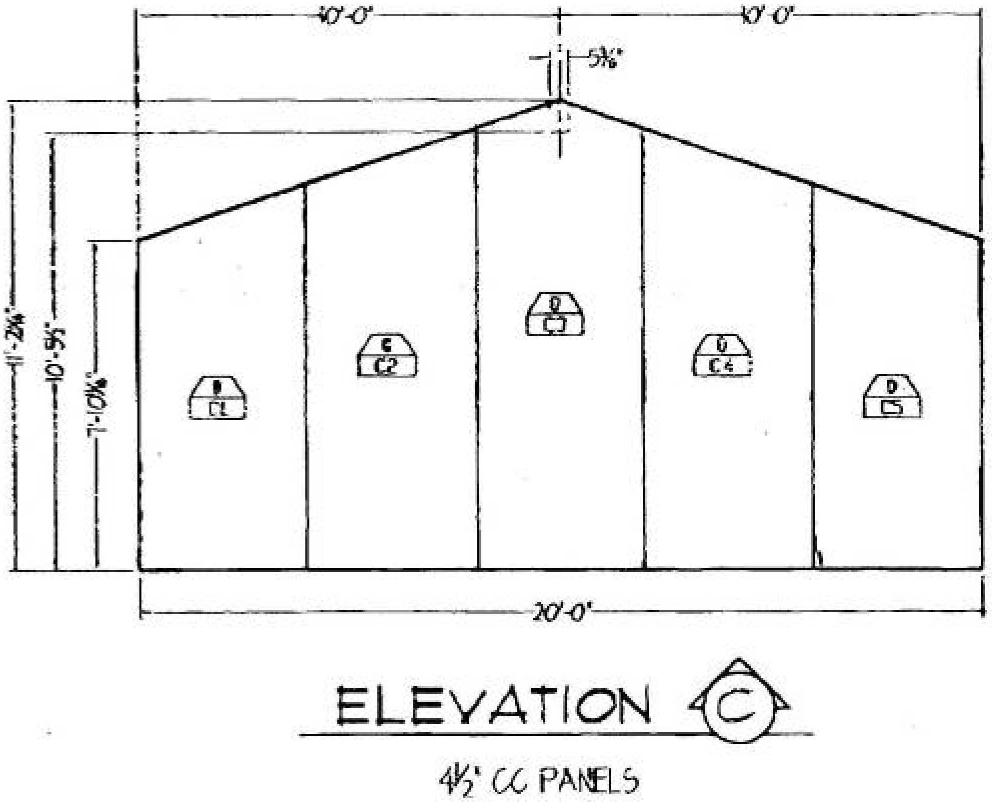


Figure 29. ZEH4 SIP east wall cut drawings.

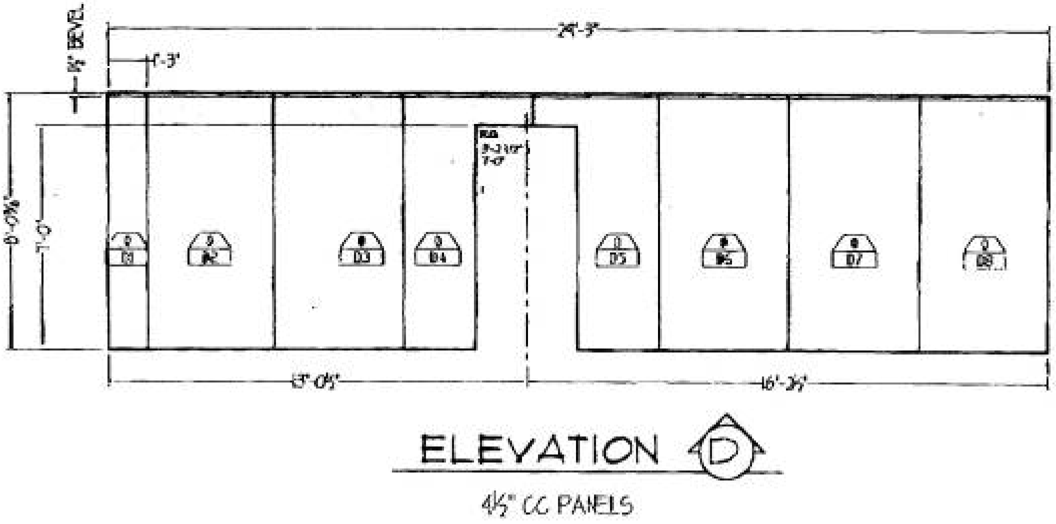


Figure 30. ZEH4 SIP north wall elevation cut drawing.

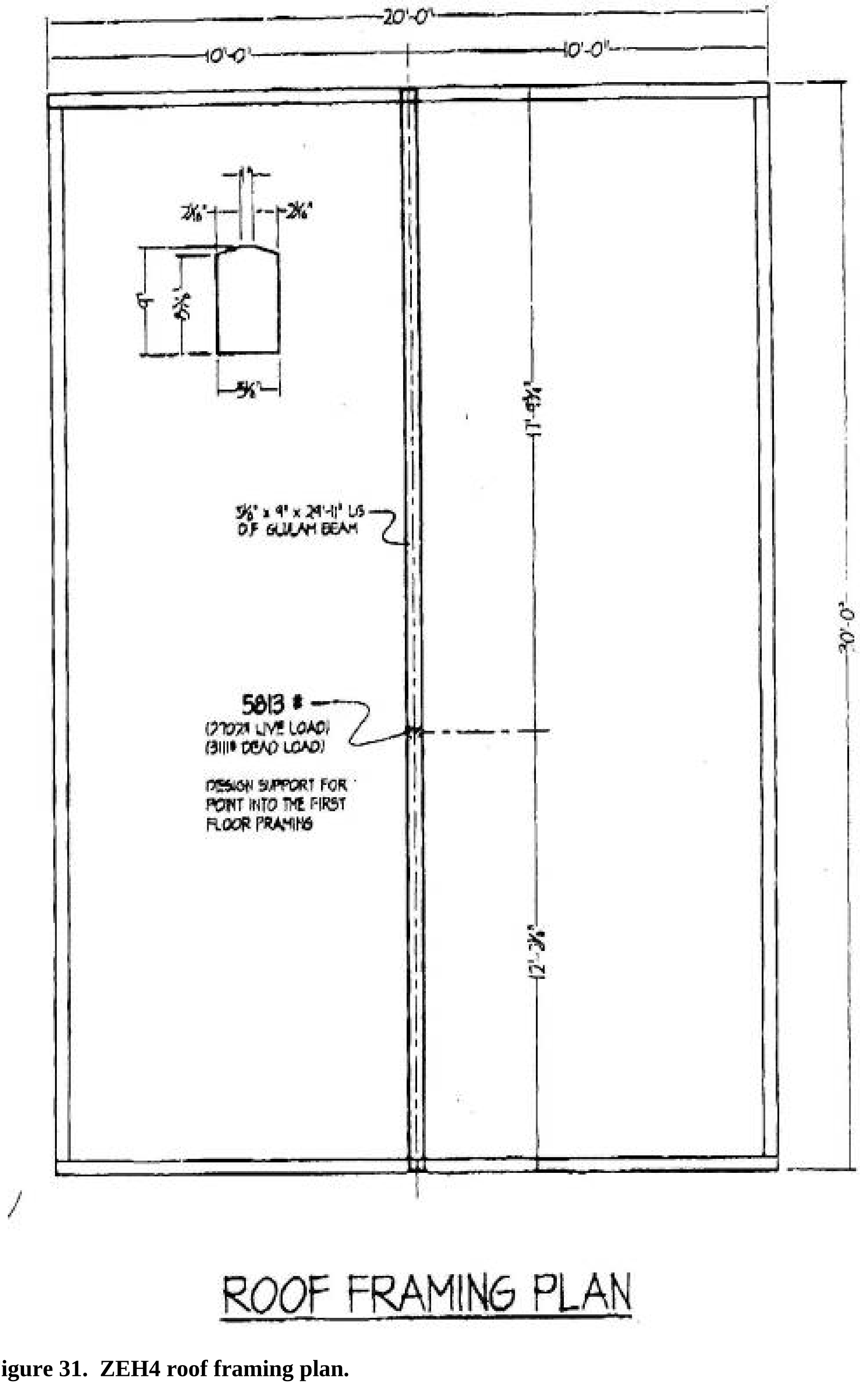


Figure 31. ZEH4 roof framing plan.

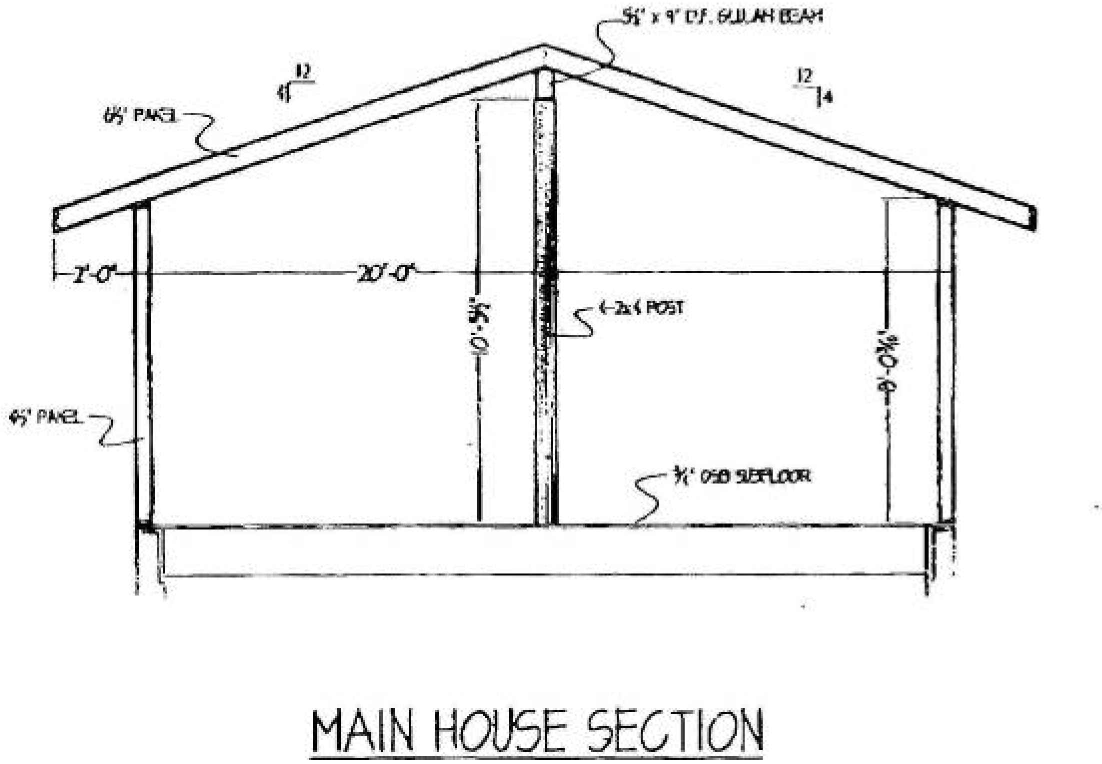


Figure 32. ZEH4 showing the intermediate load point for the roof.

The house roof panel layout in Figure 33 shows that this roof is made up of 18 full 4-ft-wide panels, labeled R1 through R18. This provides a 1-ft overhang on the gables. The porch roof is also made from panels and the ones on the north face are splined together in the same plane as the house. Each panel is 12 ft–10 in. long and this provides a nice 2-ft extended overhang to enhance the rain drainage away from the house and to better shade the south-facing windows of the top floor in the summer and allow more passive heating in the winter. It is very important to make sure that before you approve the roof panel layout you see clearly on the drawings the desired panel thickness. As you can see, these drawings called for “6 ½-in. CC panels.” All of the roof panels are the same except those that extend over the gables — R1, R11, R8 and R18. They will all be routed out to support a 2 x 6 fascia board. All the other seams will be cut out to accommodate surface splines. The four porch roof panels are also shown in the roof panel layout. Notice the notch in panel R19 to accommodate the 1-ft gable overhang. The main roof panels were lifted into place with a crane in three hours with a three-person ground crew attaching the rigging and a three-person roof crew positioning and fastening the panels to the walls, ridge beam, and themselves. Just before each panel is lifted off the ground the caulk/adhesive should be spread on the portion of the top plate and ridge beam on which that panel will rest.

The porch roof structure shows the location of the two 6 x 6 corner posts and the four 2-2 x 8 beams in Figure 34. This is more beefy than is needed in most cases; consult a structural engineer to downsize. Three pockets are cut into the SIP panels to support the porch ridge and eave beams on the house side. The porch gable is extended 1 ft just like the main roof and the extended overhangs on the eave are also the same at 2 ft. The undercarriage of the porch was filled in as built but leaving this open provides a more interesting architectural detail.

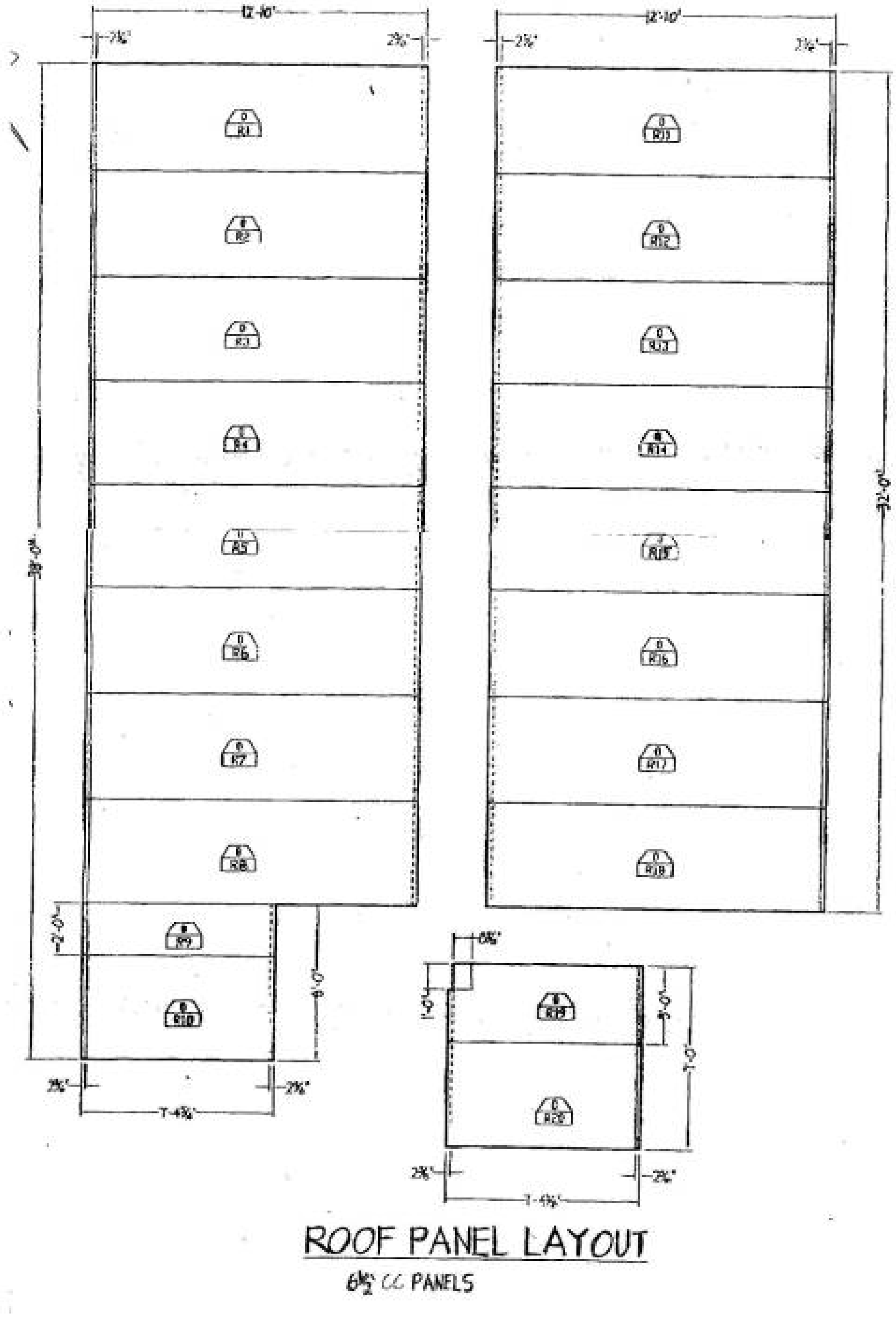


Figure 33. ZEH4 roof panels.

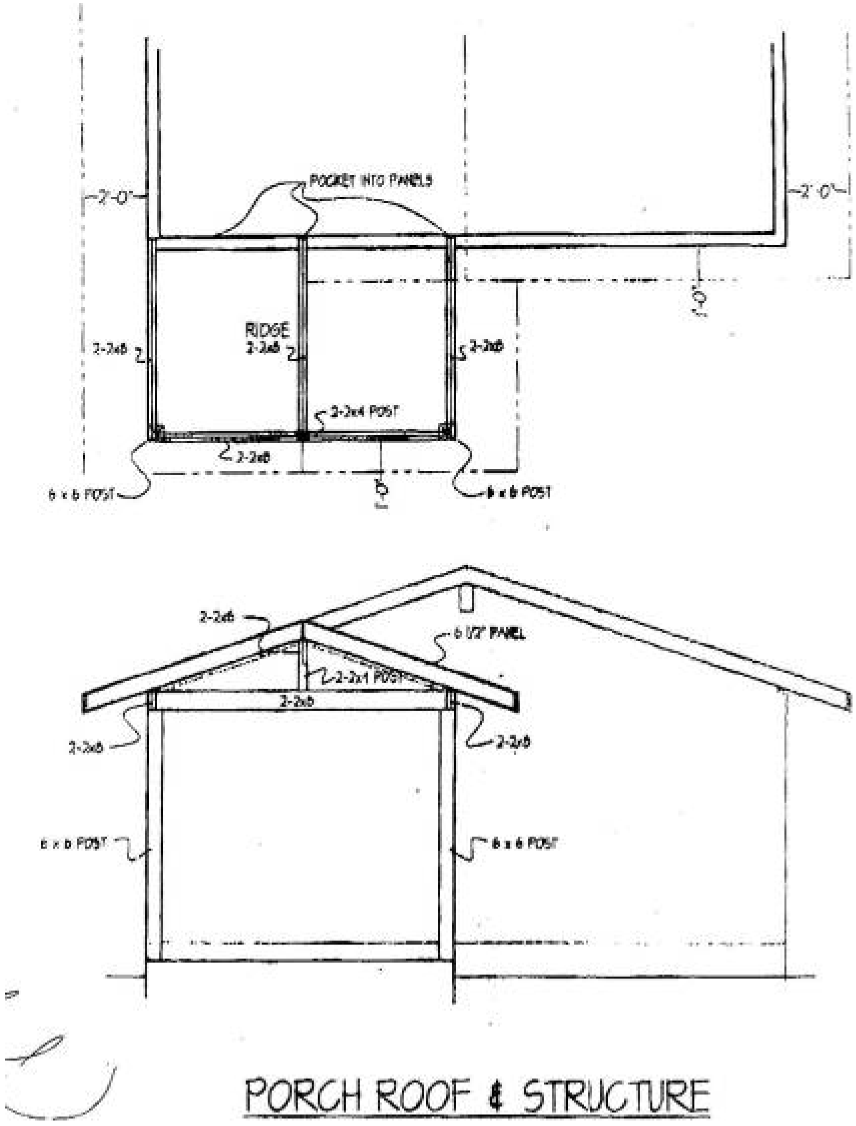
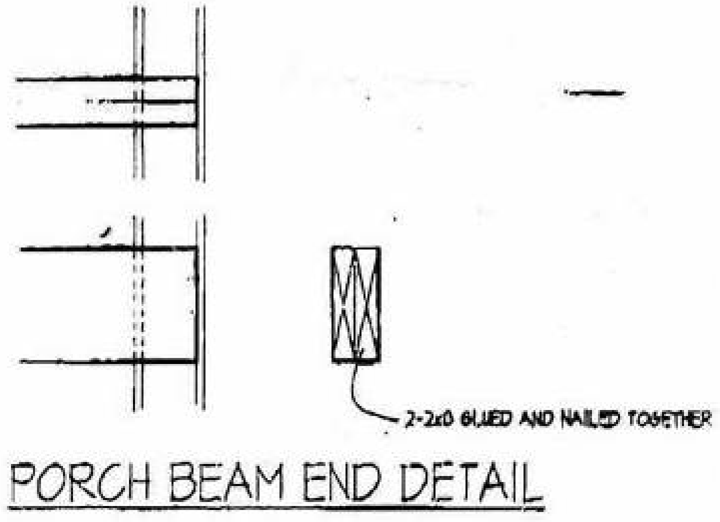


Figure 34. ZEH4 front porch details.

The ridge beam detail in figures 35 and 36 illustrate that 2 x 4 scabs are first glued and screwed to the ends of the bean prior to lifting into place. The lifting of the ridge beam is best done with the assistance of a crane. However, this house was small enough and we had enough muscle power on site to hand lift the beam into location using well laid out scaffolding, and staging several lifts, first 4 ft off the floor and then 8 ft and finally up to the beam pockets.



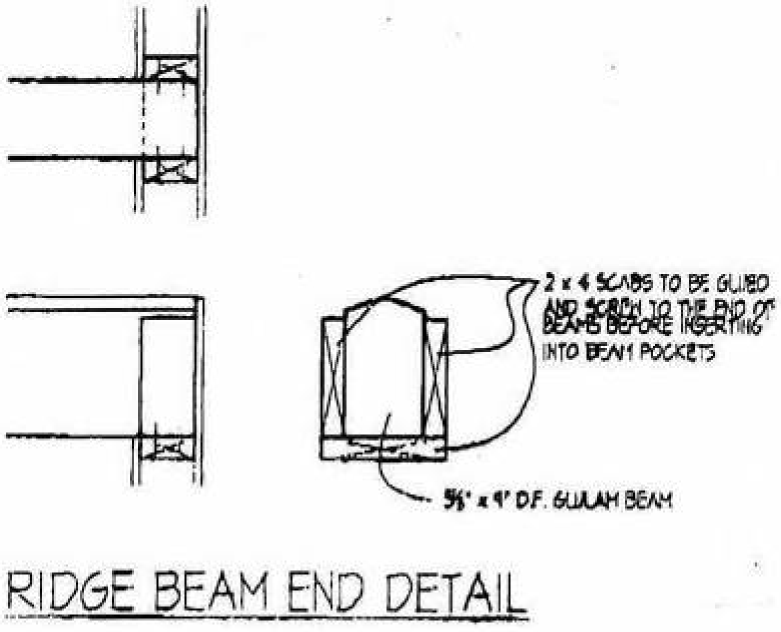


Figure 35 (top). ZEH4 porch beam detail. Figure 36 (bottom). Ridge beam detail.

3. Site Characterization and House Orientation

Typically it is recommended that selecting a site that encourages an orientation to the south in the mixed-humid climate will make it easier to reach 30% energy savings. This means picking lots or sites with views from the house to highlight 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. 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. Lots that are deep from north to south will offer the most control over the areas of solar access. A larger percentage of these types of lots will be found in developments where streets have been laid out to run east and west. Most homes on such streets will be built with the front of the house facing the street, keeping the home's long axis east to west (thus minimizing windows facing directly east and west). House plans that maximize use of the sun in the front should be sited on the north side of the street. If the larger fenestration area is in back of the house, then site on the south side of the street. Solar access on the front of a house has the street itself serving as a buffer against future building or large trees on adjacent property that could block future solar access.

In planned sustainable communities that ultimately want the majority 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 that is gaining popularity around the country. The narrow lot dimension reduces the street paving and allows land somewhere else in the development or hopefully conserved. All of the ZEH case studies in this report fit this growing need.

High performance house development, street and lot layout that is conducive to 30% energy saving houses as initially built should always be sensitive to keeping the longer term capacity to add solar PV and HW.

With the Appalachian Mountains running through the middle of the mixed-humid climate and most of the flat land already developed in the valleys, flat sites for solar orientation are limited. Because these ridges and valleys cut across this area in more of an east to west direction, developments often build off the main east–west transportation arteries in the valleys. Thus the land that is being developed tends to be long and narrow and run up the ridges in a north-south direction, initially leading to lots being orientated the wrong way. The general solution is to develop conservation communities with the housing in higher density patterns. The smaller lots are more conducive to the type of shotgun-style housing illustrated by the housing described 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 and utility length adds $100 to development cost. Infrastructure cost savings can be put into more thoughtful layout of small, deep, long, narrow lots with minimum road expense and maximum solar roof access.

ZEH5 was modeled using Energy Gage (FSEC 2006) and then rotated in each cardinal direction, north, south, east, and west. The resulting heating and cooling loads are shown in the middle column in Table 8. When one makes a few adjustments if the design is less than optimum for the orientations other than south, such as moving a window or two where practical, the loads can be reduced for the other directions, as shown in the right-hand column in Table 8.

Table 8. Heating and cooling loads calculated for ZEH5

	Percent higher than true south orientation before adjusting the design	Percent higher than true south orientation after adjusting the design
South		
East	10%	8%
West	15%	12%
North	5%	3%

4. Envelope Specifications

Table 1 highlights the envelope technologies used in these test houses. The total daily energy costs for these houses ranged from $1.00 to $0.60 per day, compared to about $3.00 per day for a benchmark house (ASHRAE 2005, ASHRAE 2006A, ASHRAE 2006B, ACEEE 2006, FEMP 2006).

4.1 Foundation

4.1.1 Crawl Space

Install lapped and taped ground cover, air seal, insulate walls to R-10, and provide some conditioning, at least 50 cfm in June, July, and August, to control humidity. ZEH1, ZEH2, and ZEH3 all have unvented crawl spaces. ZEH1's floor, above the crawl, is a 6-in.-thick SIP laminated on the underside with 22-gage aluminum sheet. It worked well, and the relative humidity (RH) rarely got above 75% through the summer of 2003. In ZEH2 and 3 we used wood I-beam joists insulated to R-22 with R-19 in the cavity, and then mechanically fastened ¾-in. XPS (extruded polystyrene foam insulation) to the underside of the floor joists. This task was cumbersome, and when the TV cable was added the XPS was disturbed and never reattached by the ZEH3 homeowner. We also insulated the inside of the crawl space walls with 2-in.-thick Polyisocyanurate boards providing an R-12. This removed the hygro buffering of the 2-hollow core block, which caused the absolute humidity of this space to rise higher than in ZEH1 with the block wall left exposed to the inside of the crawl space. The approach that is recommended is to provide some conditioned air to the crawl space, which is consistent with the Building America best practices guide (Mixed-Humid Climate Best Practices Guidebook, Beckler and Love 2005).

We recommend that a 4-in. supply duct be brought into the crawl space with a constant airflow regulator placed at the end that automatically regulates about 40 cfm of airflow during June, July, and August. This duct should also be equipped with a manual damper and should be able to be shut off during the remainder of the year. Monitoring the temperature and RH will help you determine the seasonal conditioning. The Constant Airflow Regulator is available from American Aldes (www.americanaldes.com) and costs about $30. Adding the back draft damper and transition collar as shown in Figure 37 adds another $20. A back flow damper is also suggested to avoid crawl space air from flowing into the conditioned space when the supply fan is not operating. This airflow regulator automatically regulates airflow to the crawl space at constant levels. Operation is completely passive. No electric or pneumatic sensors or controls are needed. The active element of the regulator is a flexible silicone bulb which inflates and deflates in response to the static pressure difference across the control. The constant airflow regulator is made for use in a temperature range of –25 to 140°F. It is available in 4-in., 5-in., 6-in., 8-in., and

10-in. diameter sizes regulating from 10 to 380 cfm (each diameter has a limited number of preset possibilities). Constant airflow regulators maintain airflow accurately to within 15%.

The added 50 cfm will require a small amount of energy form the heat pump, but with 700 cfm of conditioned air already being provided to the conditioned space, this is estimated to result in less than 7% from the condenser unit. In ZEH1 the outdoor unit in June through July consumed 735 kWh. A 7% increase would be 51 kWh, or about $3.60 worth of electric power for the entire 90-day period. This adds another one cent per day for the total energy cost to operate these houses in the mixed-humid climate with TVA residential electric rates of about $0.07/kWh in 2006.

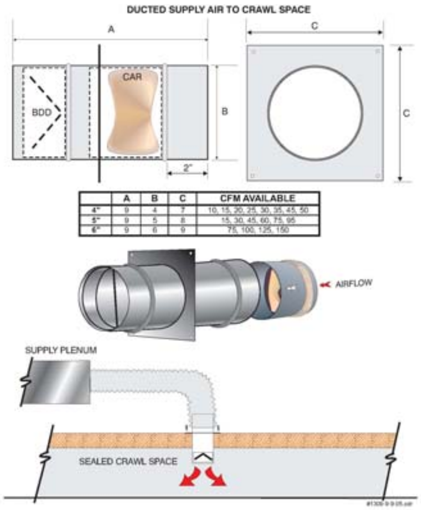


Figure 37. Sketch from American Aldes of ducting to insulated and air-sealed crawl space.

The addition of a crawl space drain to daylight and reverse shingle lapped ground covering should also be specified. The constant collection of ground moisture on the underside of the 6-mil ground cover can be drained away. If sufficient slope is not available for drainage a sump pump may be necessary.

4.1.2 Basement

This is the preferred solution for the foundation with the right south facing slope. The basement provides low-cost livable space if waterproofed and insulated correctly. The ZEH4 plan (see Figure 13) places the bedrooms on the bottom floor and utilizes the TMASS thermal mass to help stabilize the interior temperature by diurnal storage and release of heat. It went in very easily with the help of good planning. The footer needs to be a raised above the ground level; therefore some type of forming is required. It may be a good idea to use one of the left-in-place form systems that will also serve as the footer drain on the inside and outside of the footer. ZEH5 used a standard 2-hollow core block wall with complete footer drains on both the inside and outside the first course of basement block wall. We used an exterior R-10 fiberglass drainage insulation board for this foundation and it performed very well.

4.1.3 Slab

It’s hard to beat the cost of a slab foundation. We built a habitat house with similar floor plan as ZEH1, 2, and 3 on a slab and recommend insulating the stem wall on the inside as shown in Figure 38. Make sure to provide a thermal break at the slab edge. If the land is flat enough this is usually the lowest-cost foundation system. However, great care is necessary to plan for all of the embedded utilities, water lines, electrical and sewage, CATV cable, etc. Make sure you have at least an equivalent of 1 in. of XPS or R-5 insulation placed between the slab edge and the foundation wall. The slab heat loss without the slab edge insulated increases by 40% compared to just placing 4 ft of R-5 horizontally underneath the slab perimeter of a typical house (Builders Foundation Handbook, May 1991, Carmody, Christian and Labs).

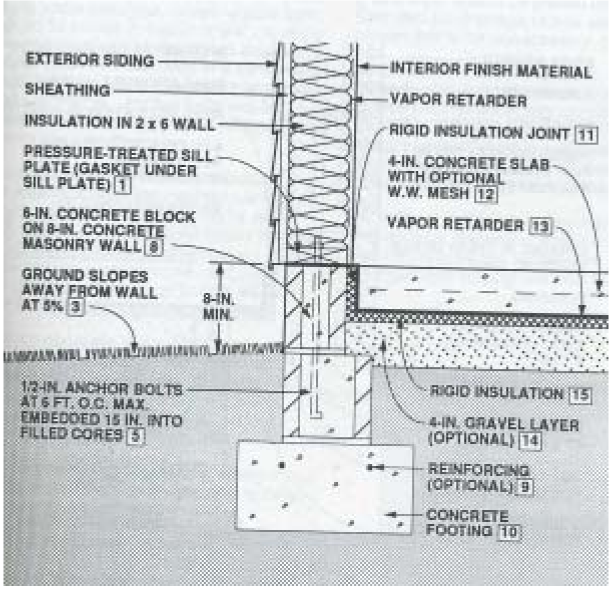


Figure 38. Be sure to insulate the slab edge as shown to avoid a significant thermal short.

4.2 Walls—SIPs

We chose SIPs because in our hot box thermal performance tests they performed thermally very well. 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 reported for a conventional 6-in. SIP was 21.6 hft^2/Btu. SIPs when installed correctly have few thermal shorts and the first-hand experience with five test houses built in 2002–2005 demonstrated they are easy to 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 easy 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 do suggest specifying the peel-and-stick tape manufactured by Ashland Chemical (http://www.ashchem.com/ascc/) at panel to panel seams. Twelve-in.-wide tape should be used at the ridge and at the wall roof interface. For all other roof and wall seams at the corners and straight panel-to-panel connections, 6-in.-wide tape is sufficient, as shown in Figure 39.

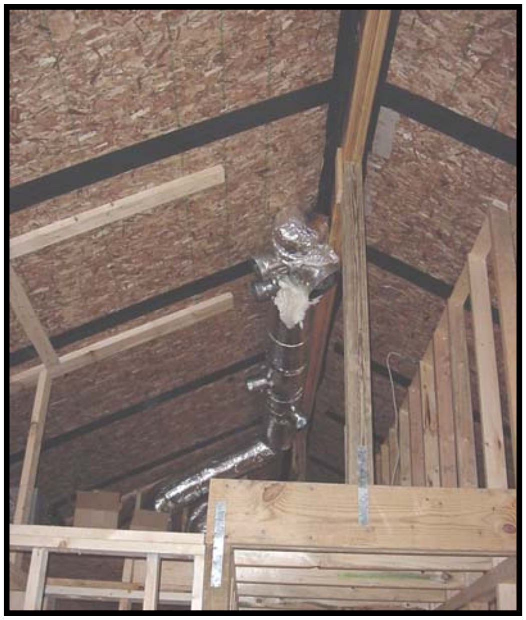


Figure 39. Peel-and-stick panel tape provides added insurance that panel seams will remain airtight.

SIP manufacturers that can prepare precut kits such as those used to construct the five near-ZEH's are the following.

- 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)

4.2.1 Working with SIPs

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

4.2.2.1 Trained personnel

Either train yourself or have trained personnel involved in the project at as early a stage as possible. The Brotherhood of Carpenters Union is preparing certified training with detailed training following this outline:

1. Planning and production setup

2. Material handling
3. Fabrications
4. Layout and job site preparations
5. Mechanical interfacing
6. Installation and assembly
7. Exterior finishes
8. Hybrid systems (like SIP and Tmass used in ZEH4)
9. Metal-skin SIPs

Several two-year college programs are available that are focused on advanced high-performance housing, such as the program at Cleveland State Community College in Cleveland, TN (Figure 40).

New

at:

CLEVELAND STATE COMMUNITY COLLEGE

Cleveland, Tennessee

A solar energy emphasis within a certificate and degree program in the residential construction field

Associate of Applied Science Degree
Construction Technology Concentration
(in Industrial Technology Major)

This concentration is a two-year AAS degree program designed for those students interested in residential and commercial building including techniques for energy efficiency and solar power installation for residential construction.

Completion of the first year of the program completes the requirements for Cleveland State's Construction Technology Emphasis – Workforce Preparedness – Technology CERTIFICATE.

In addition, as a part of passing the North American Board of Certified Energy Practitioners (NABCEP) preparation course and their in-class exam in the first year of the program, the student will have obtained the NABCEP Entry Level Certificate for knowledge of photovoltaic (PV) systems. The student will also be prepared for the exam for the more comprehensive NABCEP Solar PV Installer Certification.

Upon completion of the two-year program, the student needs only complete one year of experience in the field and pass the NABCEP exam to obtain that national NABCEP Solar PV Installer Certification.

Completion of the second year meets the requirements for an Associate of Applied Science Degree.

For more information:

Bob Lantz, Associate Professor
Technology Department
Cleveland State Community College
rlantz@clevelandstatecc.edu
(423) 473-2447

or contact the college admissions office

Figure 40. A new two-year degree program teaches young and recently retired how to build a ZEH.

This new program offers an Energy Efficient Residential Construction CST-2060, PV installation certificate, and a North American Board of Certified Energy Practitioners (NABCEP) certificate, as well as geothermal design and SIP installation. This program was developed using an $850,000 Department of Labor Community Based Job Training Grant and has incorporated the near-zero-energy test houses into the curriculum.

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 integrated 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 341). 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.

4.2.1.2 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.

4.2.1.3 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 cutter should be on site.

4.2.1.4 Foundation accuracy

There is less room in SIP construction than in stick construction for lack of plumb, level and square. Figure 41 shows the precast insulated Tmass foundation system that went together perfectly thanks to good design and construction management. 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.

Figure 41. ZEH4 TMass foundation in place and ready for floor trusses.

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.

4.2.1.5 Drain plane

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

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 dooras shown in Figure 42. 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.

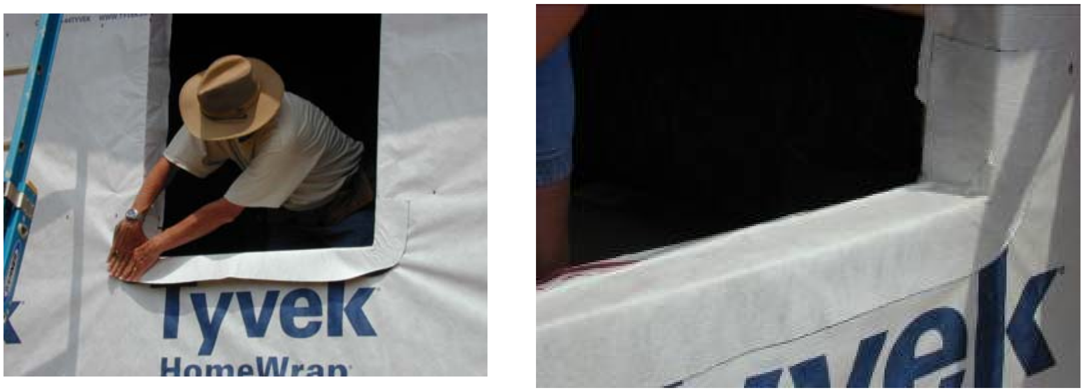


Figure 42. Panned window opening.

With a SIP roof it is also recommended that a roof drainage plane be provided. Figure 43 shows the drainage plain between the 30 lb felt paper and the metal tile roof. This gap not only provides moisture control, it also provides a cavity in 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.

Figure 43. Roof drainage plane.

4.2.1.6 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. 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 in the SIP ceiling panels. With a little planning the desired location of these fixtures can be aligned with the panel splines and additional solid wood inserted in the panels at the factory.

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. The only one that had a detectable air leak was ZEH1, which had no ridge beam. This leakage area was easily sealed during the blower door testing prior to drywall installation. Established SIP manufacturers have been aware of the importance of ridge detailing for a long time. It appears that about half are suggesting 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!

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. A small hand-held anemometer works well for generating measured differences to help you calibrate your hand. Those that are high can generally 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.

4.2.1.7 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. 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 chaseways 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. Figure 44 shows double 2 x 4s being installed to form two separate window rough openings, negating the need for a wood header above the wide window opening, which conducts a relatively high amount of heat.

Figure 44. Structural support placed between two windows eliminates need for wood header.

4.2.1.8 Attaching solar modules to SIPs

The recommended roofing to cover a SIP roof structure is raised metal seam (www.atas.com/dutchseam , www.Englertinc.com) 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 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 standing seams on the roof allow for attachment of the 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 45, the photovoltaic arrays can be installed on the roof with no penetrations.

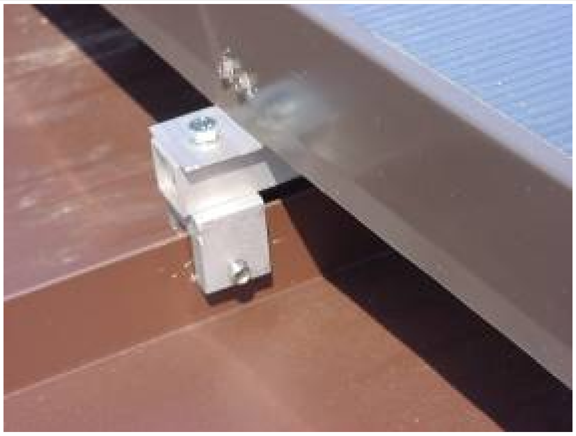


Figure 45. S-5 mini clip holding a solar module to the raised metal seam.

The other option for attaching solar modules to a SIP roof was developed for the metal simulated tile roof on ZEH4, which has no raised metal seams to attach to. The standoffs were installed prior to installation of the metal roof as shown in Figure 46. This was done by drilling a 1.5-in.-diameter hole in the top OSB facing of the roof SIP where each standoff was to be placed. We lined up the penetration in the metal tile roof to land at the high point of the simulated tile, to minimize leakage if the rubber boots should ever come loose.

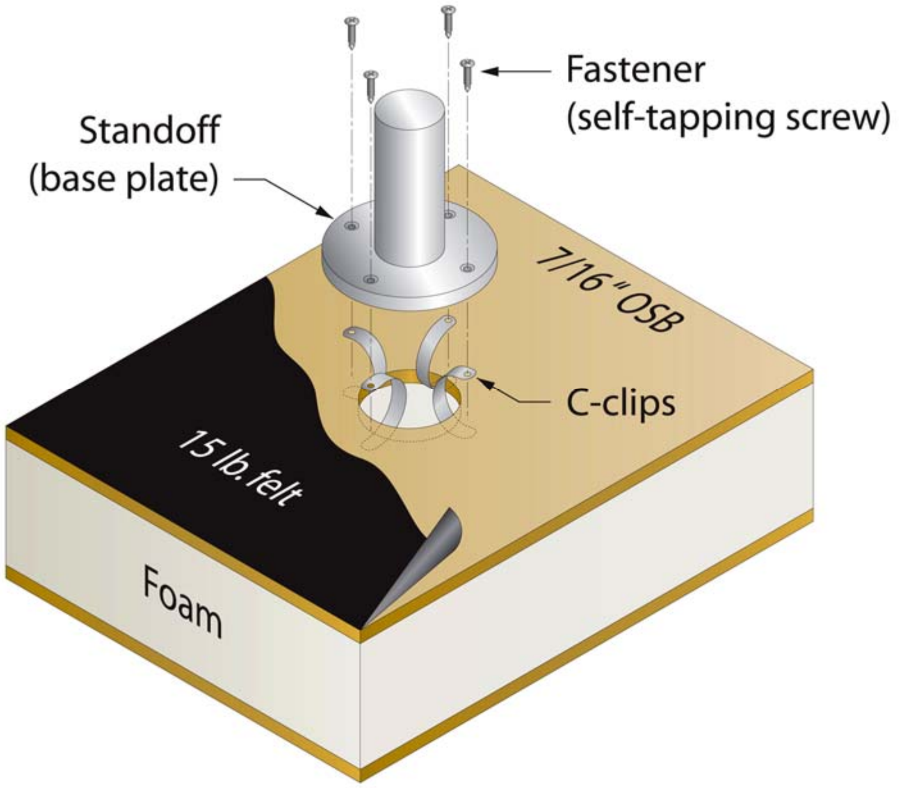


Figure 46. ZEH4 solar module roof mounting standoffs.

The standoff base plate was centered over the hole, and the locations of four holes spaced 90° for fasteners to hold the standoff to the SIP were marked. These hole marks were used to center four C-clips for the self-tapping screws connecting the standoffs to the SIP. Metal C-clips were designed and manufactured with a larger hole than the self-tapping fastener on the top leg of the clip and no hole in the bottom leg. The four clips were inserted onto the top layer of the OSB with the top leg resting on the upward-facing surface and the bottom C-clip leg pushed into the glue seam between the top OSB face and the foam core. The four holes in the base plate of the standoffs were lined up and self-tapping screws drilled through them, the hole in the top leg of the C-clip, the top layer of OSB, and into the bottom leg of the C-clip. The design wind uplift loading was obtained from the company that sold us the hardware to attach the solar modules to the roof (www.unirac.com). The pull out strength was exceeded by using a tension meter to measure at what force the standoff pulled away from 7/16-in.-thick OSB, the same thickness as the SIP facer.

4.2.1.9 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. The next task is to 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. Figure 47 shows the SIP roof panels being installed on ZEH1 and ZEH5. A string run from gable to gable lines up the ridge, just like setting conventional trusses. 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. Aligning the panels and tightening each joint goes quickly and safely with the right work plan and good teamwork.

Roof panel placement – String, Blocking, and Rigging

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

Title_date

UT-BATTELLE

26

Figure 47. The SIP roof panel installation

4.2.1.10 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 in the factory. 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.

4.2.2 Other Wall Systems

The DOE-funded ORNL Buildings Technologies Center has tested more than 400 wall systems, and SIPS are just one option. Other envelope systems to consider are the following.

1. 2 x 6 optimum-value-engineered dimensional lumber wall system. This is the system with the lowest material cost, and with good framing crews the walls can go up quickly. There are many very tight stick-built houses reported. The experience with the same habitat affiliate crews that built the five near-zero-energy test houses is that they cannot get them quite as tight as the SIP wall and ceiling systems. The range of blower-door-based estimates for natural air change for the five near-ZE test houses are from 0.04 to 0.07 and for the stick houses are 0.18-0.22. However, the window package in the case of the stick houses is not as good as that used in the near-ZE houses.

2. The same construction crews did build one of the habitat houses out of insulated concrete forms (ICFs), and ORNL conducted a side by side unoccupied house study for a one-year period. This wall system is more labor intensive than both SIPs and stick construction. But there are features that favor the use of ICFs. ORNL also tested a house with the same floor plan that used an autoclave concrete wall system for a one-year unoccupied period. This was 8-in.-thick block walls with no insulation added to either side. The hot box testing of this system found the equivalent performance was about the same as a 2 x 6 frame wall with R-19, but the whole house testing did not find much benefit in the form of air tightness. In fact, after the block was laid, considerable effort was needed to air seal the wall before installing siding and drywall.

4.3 Windows

For the mixed-humid climate, with all-electric houses and energy costs around $0.08/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 nine-window package for these test houses would have cost about $2500 from a local window distributor in 2003. If you are going to install interior window trim you will need to specify jamb extensions. This will speed the window installation on site. The rough openings required for the two window sizes used are 3 ft x 3 ft and 3 ft by 5 ft.

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 folded into the window buck after checking that rough opening will permit plumb, level, and square window installation.
2. Panned with Tyvek Flexwrap (see Figure 42).
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.

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. Insulate interior between window and wall framing on all four sides. Use low-pressure expansion foam or backer rod and caulk.

4.4 Roof and Ceilings

4.4.1 SIPs

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 loads (live, dead, and total), wind loads (basic wind speed, design wind loads for walls and roof uplift), and Seismic design category.

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). 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.

4.4.2 Attic Truss and Dropped Ceiling

If a conventional truss roof system is used on a one-story affordable NZE house it is suggested that the ducts be placed in a dropped ceiling ideally above the central hallway and closets and in kitchen, laundry, and bathroom soffits. Constructing these dropped chases is an extra task that comes at a time in which you need to seal the plane under the truss with some material and drywall is not on site yet. Scrap OSB works, and you must remember to air seal at the ceiling plane just below the bottom cross member of the attic trusses. It is much easier to seal before the drywall workers arrive. With an 8-ft ceiling, dropping down 10 in. is about as far as you can go without interfering with the door frames. Hallway ceiling lights need to be eliminated. Consider wall scones instead, like the one shown in Figure 48. They provide ideal fixtures for compact fluorescent lighting.

5. Space Conditioning Equipment

NZE houses in mixed-humid climates are 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.

5.1 Air-Source Heat Pumps

The ZEH4 heat pump unit is a Lennox HPx19 prototype. (For more information go to http://www.lennox.com.) The outdoor unit is on the predominately shaded north side of the house. It is a 2-ton heat pump with a two-stage compressor. The air-handler unit is a 2–2.5-ton, multi-position, variable-speed, blower coil unit. This model was a first of its kind with a 17 SEER value. The total daily energy cost for the ZEH4 was only $0.75/day. The HP used only 2727 kWh/yr to heat, cool, and ventilate and the interior space air temperature was kept a steady 74-76°F year around.

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 2600 ft^2. The design heating load was 20,358 Btu/hr and the design sensible cooling load was 17,259 Btu/hr. The average estimated COP was 3.66 and the average EER was 16. This model did come equipped to help heat domestic hot water with an on-board, factory installed pump; however, unless considerable space cooling is needed at the same time as hot water is used, the measurements in ZEH3 suggested 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. A total of 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 Rescor wall near the vertical WaterFurnace unit. No additional excavation was required to install this water loop. 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 at or below saturation levels and very minimum soil freezing is likely to occur. 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. 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.

During the winter of 2005-2006 the space heating load of the first floor (1240 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

Ducts are in conditioned space, central supply, single return per floor, interior high wall supply registers. 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 a supply register in every room except the laundry in ZEH1-5. Transfer grills are used in each of the bedrooms with high registers inside the room and low in the hallway. When an internal chase is not available, jump ducts should be used to minimize pressurizing the bedrooms and depressurizing other areas of the house. 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.

5.4 Ventilation Air Treatment

For small ZEH’s bring a 6-in. fresh air supply to the return side of the blower. Install a manual damper and motorized damper to control 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 Air Cycler turns on the 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 test houses was 40 CFM for the three-bedroom and 50 CFM for the four-bedroom residences. The Air Cycler 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. Two problems continued to plaque the ZEH test units. The first was the occasional high RH during June, July, and August in the mixed-humid climate. It would have been desirable to reduce mechanical ventilation air when the house was not occupied during these three summer months. None of the occupants complained about this occasional high RH. The ceiling fans seemed to provide an adequate thermal comfort solution. Part of the problem was that even with the typical heat pump dehumidification control packages maintaining RH below 55% was not attained, because in three of the first four test houses the 2-ton system even with two-speed compressors did not have long enough run times to effectively remove the latent load. Manual J calculations in these houses indicated 1.5-ton units would have done a better job in the cooling season.

The ZEH5 2-ton unit with the well insulated lower level adds 1360 ft^2 to the top floor living level of 1240 ft^2. The same size 2-ton unit actually does a better job of cooling twice the space as is available in ZEH2, 3, and 4.

5.5 Dehumidification

In four of the five test ZEH's a heat pump water heater (HPHW) was installed. In ZEH5 an experimental dehumidifying heat pump water heater was tested. This is a true dual appliance that can provide hot water and dehumidify independently. If the heat from the dehumidification is not needed to recharge the water heater, then a second condenser rejects the heat. If the heat pump water heater is located in the bathroom with the exhaust fan that helps ventilate the house, this excess heat in the summer in part will be exhausted. If you do install a HPWH consider using a time clock control so as to delay the morning water heater recharge until p.m. hours. The humidity peak seems to occur from 1:00 to 3:00 p.m. Then shut the unit off from 4:00 until 6:00 to keep the house peak load low during typical electric utility system peak demand. The recharge of a heat pump water heater takes a longer time than a resistant heater. Some experimentation should be conducted to find the right match of dehumidification with water heater recharge/ peak load reduction and minimum call for back-up resistance heat.

6. Electrical

6.1 Wiring SIPs

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.

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 florescents in the kitchen work great. Wall scones work well with compact fluorescents, as shown in Figure 48. In the test houses the only place incandescent lighting is still used is over the dinning room table and around the bathroom mirrors. There are solutions to incorporate florescent in these applications but in the intensive focus on budget for affordable housing, these are not always exercised. The Habitat for Humanity program calls for the homeowners to purchase the lighting fixtures. This generates the challenge of even $5 more per fixture as being hard to come by to bring home that Energy Star label or even higher purchase cost light bulb. In the bathroom the exhaust fan/ceiling light has CFL. The vanity lights around the mirror tend to be incandescent. Placing the first switch nearest the bathroom door for the CFL is a subtle way to develop lower lighting energy usage.

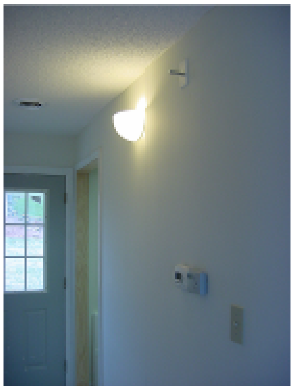


Figure 48. Sconces with compact fluorescents.

6.4 PV Solar Systems

Figure 45 shows the suggested method of attaching the PV modules to the raised metal seam roof. 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 49. 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 systems installed in ZEH3 and ZEH4 are described below.

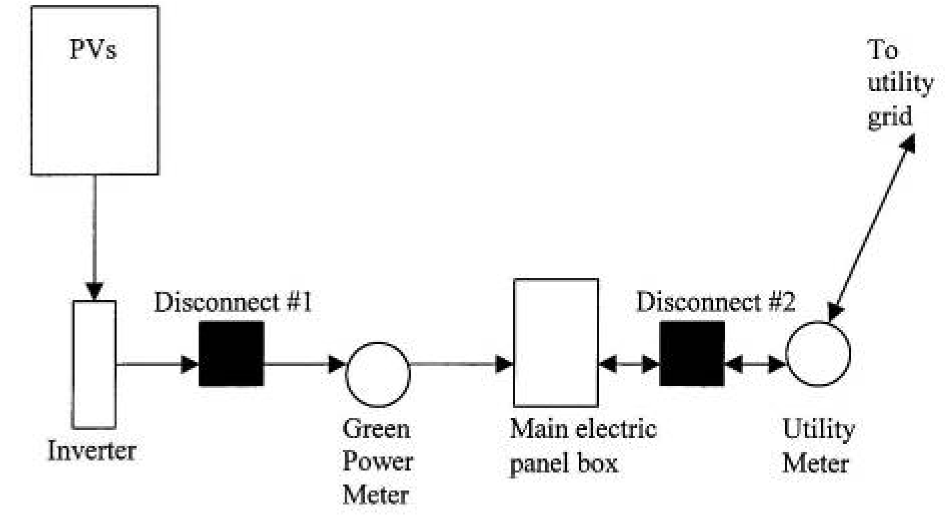


Figure 49. TVA Solar grid-tie connection schematic.

6.4.1 PV System in ZEH3

6.4.1.1 Modules

The photovoltaic (PV) system used for ZEH3 is a 1.98-kWp (kilowatt-peak) capacity comprised of twelve 165-watt, nominal DC 24V, multi-crystalline silicon modules (Sharp model number NE-Q5e2U, sharpusa.com). The module conversion efficiency is 12.68%. The modules are UL1703 certified. Size of the modules is 62-in. length, 33-in. width and 1.8-in. depth. Each module weights 37.5 lb. The modules come with a warranty for 25 years, the first 10 for a minimum of 90% rated power output and the next 15 years for a minimum of 80% of rated power output. The PV system is attached to the 26.6^o-tilted roof and faces directly south. With only 12 panels, the PV system resembles an attractive skylight (see Figure 50). All PV cells contain a semiconductor material, usually silicon, which absorbs the light energy from the sun. This energy allows electrons to break loose and flow freely. Electric fields in the PV cell force the electrons to flow in a certain direction and the current that results can be drawn by placing metal contacts on the top and bottom of the cell.

Figure 50. ZEH-3, with the twelve solar panels of the PV system on the roof.

6.4.1.2 Inverter

The direct current (DC) from the sun's light is then converted to usable alternating current (AC) by a Xantrex/Trace Sun Tie solar inverter (model number STRx2500, http://www.xantrex.com/) located on the north side of the house. This AC current then goes to the electrical panel box on the house before being sent to the utility grid. There are two meters on the north side of the house as well. One of these keeps track of the total amount of AC energy that the PV system is producing. The other meter is a net-meter and has the capability of going both forwards and backwards, depending on whether the house is producing more energy than it is using or vice versa. The sum of these two meter readings yields the total amount of energy the house is consuming. All solar equipment was purchased and installed through Big Frog Mountain Corporation at http://www.bigfrogmountain.com/.

The Xantrex inverter can be mounted outside but must be shielded from wind-driven rain. The rain cover must be installed for outdoor installations. You need to identify the following wire routes.

1. AC wiring from inverter to main service panel. To keep this short it is recommended that the inverter be installed as close to the utility service panel as possible.
2. DC input wiring from the PV array to the inverter
3. DC ground from the PV array to an external ground rod.

Keeping the distance between the PV array and inverter to a minimum means less distance, smaller diameter copper wire, and less cost. Copper prices went up 65% in a four-month period in 2006. The main service panel must dedicate a 15 amp minimum, double pole breaker (120/240 volts AC) to operate the inverter. Key electrical specifications; AC output voltage 240 VAC, continuous AC output at 32-113 F, 60 Hz frequency, and wakeup DC voltage-50 VDC. The inverter dimensions are 33.25 in. x 13.25 in. x 9.5 in.

This inverter has forced air (fan) cooling, which does make some noticeable sound, and active islanding protection with over/under AC voltage and frequency detection. When the electric utility grid goes down, the inverter senses the loss of voltage and shuts down. The inverter continuously checks to see if voltage and frequency has been restored on the electric utility system side of the meter and after it has detected the grid is back up it waits 5 minutes before resuming solar generation. This inverter came with a two year-warranty. The Xantrex inverters in ZEH2 and ZEH3 have had no performance problems after they were fully commissioned in February 2004.

6.4.2 PV System in ZEH4

6.4.2.1 Modules

Twenty 110-W polycrystalline modules (Evergreen Solar EC-110s) make up the 2.2-kWp photovoltaic system installed on ZEH4. These modules are designed for a maximum allowable pressure of 50 lb/ft^2, which corresponds to a wind speed of approximately 125 mph. These modules come with the same power output warrantee as the Sharp modules on ZEH3. 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 26 in. x 63 in. and about 2-in. thick. Each module weights 30 lb. The aluminum rails to mount the ZEH4 modules are shown being installed in Figure 43. The ZEH4 20 modules installed on aluminum rails bolted to 7-in.-high standoffs. The completely installed modules are shown in Figure 51.

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 about 9.5% higher than the costs in May 2004 (http://solarbuzz.com).

Figure 51. Modules are clamped to the rails.

6.4.1.2 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 52, 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. The Sunny Boy has performed flawlessly since installation in May 2004.

Figure 52. Sunny Boy (box at left) installed in TVA-approved Green Power Generation hookup.

7. Water Heating

The water heater that worked the best for the test ZEH's was a heat pump water heater. The unit now under study in ZEH5 is manufactured by SciCool in Ashville, NC. This integrated appliance has the ability to both provide hot water and dehumidify. There are two condensers, one that rejects the heat to the water tank and the second to reject heat to the air around the unit when dehumidification is needed and the tank is fully charged. This unit is expected to be commercially available in 2007. The unit has a slightly larger footprint than more common water heaters, with a diameter of it is 23 in. The compressor and air stream inlet and outlets are all located at the base of the unit. The water heater should be located in conditioned space. In ZEH4 we located the HPWH in a utility closet next to the refrigerator. A transfer grill opened the inlet up to the back of the refrigerator, and the exhaust from the evaporator was ducted to the adjoining half-bath, which has the exhaust fan to help mechanically ventilate the house. Whenever ventilation air was needed the ECM blower motor opens the intake from the outside and turns on the bath exhaust to prevent over-pressurizing the house.

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. The Energy Star ratings are updated periodically, and options are often available that go beyond Energy Star standards.

9. References

[ASHRAE] American Society of Heating, Refrigerating, and Air-Conditioning Engineers. 2004. "Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings." *ANSI/ASHRAE* 62.2-2004. Atlanta, Ga.: American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

Christian, Jeffrey E. 2005. "Ultra-Low-Energy Residences." *ASHRAE Journal*. January.

Christian, Jeffrey E., and Jan Kosny. 1995. "Towards a National Opaque Wall Rating Label." In *Proceedings for ASHRAE/DOE Thermal Performance of the Exterior Envelope of Buildings Conference VI*, Clearwater Beach, Fla., December 4-8.

______. 1996. "Thermal Performance and Wall Ratings." *ASHRAE Journal*, 38 (3). March.

Christian, Jeffrey E., Paige Pate, Phil Childs, and Jerry Atchley. 2006a. "Small House With Construction Cost of $100K, Total Energy Cost of $0.88 a Day." To Be Presented at 2006 ASHRAE Winter Meeting; Published in *ASHRAE Transactions*, 112 (1).

Christian, Jeffrey E., Lauren Richards, Phil Childs, Jerry Atchley, and Hyeun Moon. 2006b. "Energy Efficiency, SIPS, Geothermal, and Solar PV Team Up to Near-Zero-Energy House." To Be Presented at 2006 ASHRAE Winter Meeting; Published in *ASHRAE Transactions*, 2006-2.

Christian, Jeffrey E. 2006c. "Energy Savings from Small Near-Zero-Energy Houses Integration." *FEMP Tech Alert*. April 2006.

[DOE] U.S. Department of Energy. 2004. "Typical Appliance Usage." *2004 Buildings Energy Databook*, Table 7.2. Washington, D.C.: U.S. Department of Energy.

Hendron, Robert. 2005. "Building America Research Benchmark Definition, Version 4," Updated July 14, 2004. [Current version.] NREL/TP-550-36429, www.nrel.gov/docs/fy05osti/36429.pdf. Golden, Colo.: National Renewable Energy Laboratory.

Hendron, R., et al. 2004. "Building America Performance Analysis Procedures, Rev. 1." NREL/TP-550-35567. Golden, Colo.: National Renewable Energy Laboratory.

Parker, D. S., J. E. R. McIlvaine, S. F. Barkaszi, and D. J. Beal. 1993. "Laboratory Testing of Reflectance Properties of Roofing Materials," Report No. FSEC-CR-670-93. Cape Canaveral, Fla.: Florida Solar Energy Center.

[RESNET] Residential Energy Services Network. 2002. http://www.natresnet.org/standards/standards.pdf.

a. Vineyard, E. A., et al. 2003. "Measured Performance of Conventional and High-Velocity Distribution Systems in Attic and Space Locations." *ASHRAE Transactions*, 109 (2). June.

FSEC, Florida Solar Energy Center, Energygage, 2006