WPPI GreenMax 2 Evaluation

1. Project Overview:

CARB is partnering with WPPI Energy on a research effort referred to as the GreenMax Net Zero Home Grant projects. These demonstration homes provide a wealth of information for the building community in terms of the science, effort, and cost of increasing the energy efficiency of our nation's housing stock. Though CARB's primary focus on these projects is to provide monitoring of home and system performance, WPPI has requested that CARB provide recommendations and comments on the strategies that are proposed for these homes.

The first GreenMax project was located in Black River Falls, WI. CARB has been monitoring this demonstration home since late May 2009. Key features of this home include 2x8 wall construction, a 3-mode GSHP (heating, cooling, hot water), exterior rigid insulation (R-5 above grade and R-10 below grade), and a 5.76 kW dual tracking solar PV system. For monitoring data and addition information, Click here

The second project, GreenMax 2, is located in Stoughton, WI. CARB provided recommendations based on hourly energy simulations and a review of the building specifications and drawings. The focus was on developing a cost-effective technology package that would achieve 50+% source-energy (The sum of the energy consumed at a residence and the energy required to extract, convert, and transmit that energy to the residence) savings over typical mid-1990's construction. Key features of this home include 2x6 wall construction, two GSHPs (a water-to-air for space conditioning and a water-to-water for domestic water heating), exterior rigid insulation (R-5 above grade and R-10 below grade), R-10 rigid insulation under slab, and a 5.76 kW dual tracking solar PV system. Construction was completed in December 2009. Monitoring of the home's systems has been going on since May 2010.

For more details on the building specifications of the Green Max 2, refer to CARB's Attachment NN: WPPI GreenMax 2 Evaluation Report from CARB's 2009 End of Year submittal to the National Energy Technologies Laboratory (NETL). For up-to-date monthly monitoring updates, Click here

2. Project Information Summary Sheet

PROJECT SUMMARY	
Company	Shaw Builders, Inc.
Company Profile	In 1994, this husband and wife duo, founded Shaw Building & Design, Inc. They are a design-build company that specializes in custom-built homes.
Contact Information	3185 Deer Point Drive Stoughton, WI 53589 Ph:608-873-3008 www.shawbuilders.com
Company Type	Semi-custom single-family residential
Prototype Name	GreenMax 2
City, State	Stoughton, WI

CLIMATE INFORMATION	
Climate Region	Cold (Climate Zone 6A)
Cooling Degree Days	305 (70^{o}F base)
Heating Degree Days	7,772 (65^{o}F base)
Rainfall	35 – 40 inches/year

SPECIFICATIONS	
Municipal Address	1102 Lake Kegonsa Road Stoughton, WI 53589
House Style(s)	colonial
Number of Stories	2 stories
Number of Bedrooms	3
Floor Area	3,072 square feet
Energy Sources	Electricity and Propane
Estimated Energy Reduction	60.5% over BA Benchmark (81.7% with PV)
Estimated Energy Savings	$2,109
Estimated Cost	N/A
Construction Start	July 2009
Construction Completion	Dec 2009

3. Estimated Whole House Energy Use Summary

The building specifications for this prototype are summarized in the Table 3.1. The majority of BA recommendations (which were implemented) were geared towards durability and comfort.

Table 3.1 GreenMax 2 Building Specifications

Green Max 2	Proposed Building Specifications	BA Recommended Modifications
Above-Grade Wall Assembly	2x6 wood framing @ 24" o.c. w/ hybrid cavity insulation (1" R-5 spray foam + R-19 fiberglass BIBs system + 4 mil visqueen) & 1" R-5 XPS on exterior	2x6 wood framing @ 24" o.c. w/ hybrid cavity insulation (~1.1" R-6.5 closed cell spray foam + R-19 fiberglass BIBs system) & 1" R-5 XPS on exterior
Foundation Assembly	poured concrete foundation, 1" R-5 rigid insulation on exterior with 1" R-5 Tuff-n-Dry, 2x4 wood framing w/ R-13 FGB, 2" of rigid foam under slab with 6-mil vapor barrier	poured concrete foundation, 1" R-5 rigid insulation on exterior with 1" R-5 Tuff-n-Dry, 2x4 wood framing w/ R-13 unfaced FGB, 2" of rigid foam under slab with 6-mil vapor barrier, capillary break for footing
Ceiling Assembly	R-50 loose fill blown fiberglass with 4 mil ceiling visqueen, energy heel truss	-
Air-sealing	air sealing package: spray foam rim/band, caulk framing, foam penetrations to exterior and through top and bottom plates	-
Garage Walls	R-13 FGB	Interzonal wall (between garage and living space): R-21 fiberglass BIBs system with continuous air barrier
Garage Ceiling	R-19 FGB	-
Building Infiltration	assume 0.15 $ACH_{natural}$ based on sealing efforts	-
Window Glazing	Loewen Heat-Smart Plus 2 triple glazed, low-e^2, argon (U-0.19 / SHGC-0.21)	-
Cooling System	WaterFurnace Envision Dual NDV038 GSHP (20.1 EER/4.2 COP)	-
Heating System	WaterFurnace Envision Dual NDV038 GSHP (20.1 EER/4.2 COP)	-
HVAC Controls	3-zone control, programmable thermostat	-
Ductwork	???	designed to accommodate zoning, mastic seal all ductwork, hard-ducted returns
Whole-House Ventilation	RenewAire 90cfm ERV connected to kitchen and bathrooms	RenewAire 90cfm ERV with dedicated ductwork
Point-Source Ventilation	???	Panasonic WhisperGreen FV-05(08)VK1 for all bathrooms, kitchen exhaust hood ducted to outside (no recirc kitchen exhaust fans)
Domestic Water Heating	Water-to-water GSHP	-
Photovoltaics	5.76 kW with dual axis tracking	-
Lighting	100% flourescent or LED lighting	-
Appliances	Energy Star refrigerator, dishwasher, clothes washer	-

CARB conducted building energy analysis to compare the energy use of this house with the Building America Research Benchmark (Definition 12/19/2008). The Building America Research Benchmark Definition is consistent with mid-1990s standard building practice for a particular climate zone. EnergyGauge USA v2.8.03 (EGUSA), an hourly energy simulation tool, was used to perform a cost-benefit analysis and generate the optimal package of measures to improve the energy performance. CARB developed specifications that would meet the Building America goal of 50+% whole house source-energy (the sum of the energy consumed at a residence and the energy required to extract, convert, and

transmit that energy to the residence) savings. Stoughton, WI falls in the cold climate zone (DOE's climate zone 6A). Based upon the design specifications, this prototype home is estimated to achieve 60.5% less source energy to operate than a typical mid-1990s home. With PV generation included, the source-energy savings would increase to 81.7%.

Table 3.2 Estimated Whole House Energy Use for Prototype Home

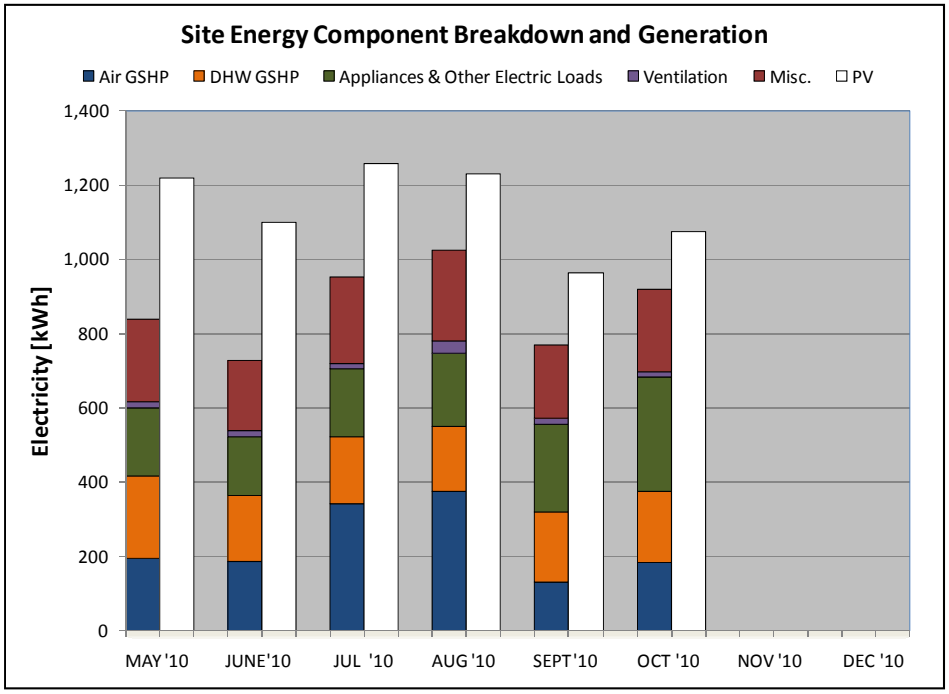
ESTIMATED WHOLE HOUSE ENERGY USE BY PLAN NUMBER					
Project	Finished Floor Area (sq. ft)	Source (MMBtu/year)	Source Energy Savings (%)	Estimated Savings Over Benchmark ($)	% Electric
GreenMax 2	3,072	196.7	60.5%	$2,109	100%

4. Monitoring

The monitoring of the GreenMax 2 project is providing additional data for the cold climate ground-source heat pump field evaluations that CARB is performing. In addition, whole-house electrical monitoring provides CARB with guidance on the appropriate miscellaneous electric loads (MELs) to focus control research in the future. The GreenMax 2 home is a better case study than the GreenMax 1 home as the occupants (two adults, one newborn child, and one in-law) better reflect a typical household.

4.1 Whole-House Energy Consumption & Generation

Over the first six months of monitored data, the homeowners are using less energy than they are consuming. This is expected during the summer, when solar PV generation is at its highest. The whole house electrical consumption over the first six months was 5,232 kWh compared to electrical generation of 6,841 kWh. Of the whole-house electrical consumption, 26.9% is attributed to the space conditioning ground-source heat pump (GSHP) and 21.7% is attributed to the domestic hot water GSHP.

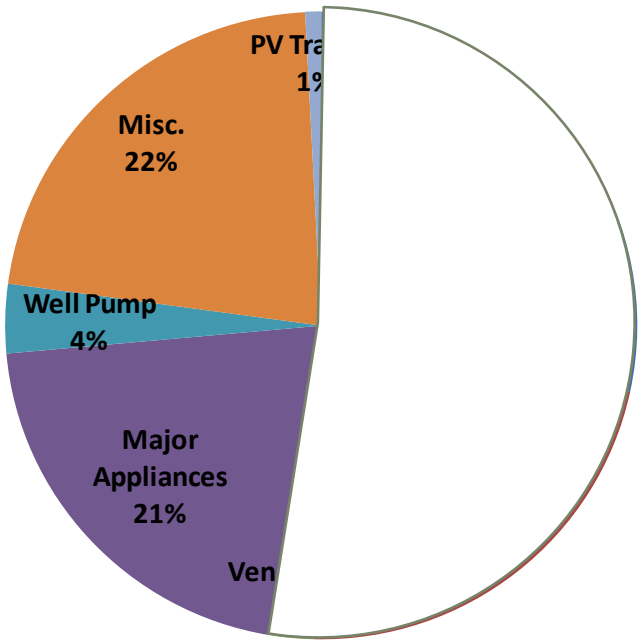


The actual PV generation tracked fairly consistent with the anticipated PV generation based on energy modeling for the first four months, but have exceeded anticipated generation for the past two months. Homeowners did confirm that October was an especially sunny month. The National Renewable Energy Laboratories' PVWatts calculator was used with Madison, WI as the representative city for Stoughton, WI (roughly 20 miles away). A DC to AC derate factor of 0.83 was utilized based on CARB-SWA's extensive PV monitoring experience for systems with limited or no shading. The results of the modeled PV generation versus actual generation are shown in the table below.

	Estimated		Actual
Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)	AC Energy (kWh)
Jan	3.87	618	
Feb	5.39	761	
Mar	5.54	841	
Apr	6.14	862	
May	7.96	1,130	1,218
Jun	8.17	1,086	1,098
Jul	8.21	1,105	1,259
Aug	7.89	1,076	1,229
Sep	5.97	808	962
Oct	4.90	700	1,074
Nov	3.53	504	
Dec	3.58	557	
Total	-	5,205	6,841

Though every electrical breaker is not being monitored in this home, all major equipment beyond lighting and outlets are being monitored. Looking at just the Lighting, Appliances, and Miscellaneous Electric Loads (LAMELs), the major appliances account for 44% of the electrical consumption outside of heating, cooling, ventilation, and hot water. The major equipment (see table below) accounts for 57% of the LAMELs for this home. Those items specific to the kitchen account for 33% of the LAMELs. These major appliances are all top of the line units (Energy Star labeled, if available), so there is little that can currently be done from a technology stand-point to reduce this usage. The same is true of the lighting, which is nearly all LED lighting. Essentially, the homeowners would need to alter their behavior to see a significant reduction in their LAMEL consumption.

	Energy Totals [kWh]						
LAMELs	May	June	July	August	Sept	Total	% of LAMELs
Induction Cooktop	18.9	14.3	17.3	17.6	21.8	89.9	4%
Oven	23.8	19.2	26.2	36.1	27.2	132.5	6%
Microwave Oven	5.7	6.2	5.6	5.8	5.7	29.0	1%
Clothes Washer	3.3	3.3	3.1	2.9	2.7	15.2	1%
Wine Cooler	1.3	1.3	1.4	1.3	1.4	6.7	0%
Clothes Dryer	50.0	50.0	50.0	50.0	51.8	251.8	12%
Refrigerator & Island Outlets	68.4	65.7	72.5	73.1	72.4	352.1	17%
Garbage Disposal & Dishwasher	7.3	4.9	6.0	8.3	5.9	32.5	2%
Kitchen Outlets	8.8	9.2	9.5	9.9	9.2	46.6	2%
Septic System	2.5	1.8	2.2	2.2	2.1	10.8	1%
Well Water Pump	36.7	26.5	31.1	30.8	28.3	153.3	8%
PV System Tracking Unit	7.1	6.8	7.0	7.0	6.8	34.9	2%
Miscellaneous	172.4	138.7	182.5	194.0	199.4	887.1	43%
Total	406	348	414	439	435	2,042	100%
Kitchen Total	133	120	137	151	142	683	33%



Appliance	% of Energy Usage Not Associated with HVAC/DHW
Induction Cooktop	4%
Oven	6%
Microwave Oven	1%
Clothes Washer	1%
Clothes Dryer	12%
Refrigerator	17%
Dishwasher	2%
Total	44%

Misc. includes:

- Lighting
- Outlets
- Beer/wine fridges
- Steam Shower/Whirlpool Tub
- Water Treatment

4.2 Ground-source Heat Pump for Space Conditioning

This horizontal closed loop, pressurized slinky GSHP system consists of two 110 foot trenches at a depth of 8 feet and separated by 15 feet. Environol 1000 solution (21.4% ethanol) is circulated between the ground coils and two GSHPs located in the unfinished portion of the basement: a WaterFurnace Envision 3-ton dual speed (NDV038) heat pump for space conditioning and a WaterFurnace ESeries 2-ton (EW020H) for water heating. A desuperheater runs from the Envision to a 50 gal pre-heat storage tank. The ESeries runs to an 80 gal primary tank. There is no auxiliary water heating source.

CARB extensively monitored this GSHP system. CARB coordinated with the plumber to have thermo-wells installed at fluid temperature measurement points to ensure accuracy of these measurements. Inline flow meters were also installed.

CARB also leads the Department of Energy's Building America working group on GSHPs. Through those efforts, CARB has developed a monitoring protocol for GSHPs to effectively quantify the whole-system performance of these units that account for the ground loop pump, ductwork, and desuperheater. The following equations represent how system efficiency has been defined for this project.

Coefficient of Performance (COP): The coefficient of performance of a heat pump is the ratio of the useful heating energy outputted by the system to the net energy inputted to the system.

Heating Coefficient of Performance is:

$$COP = \frac{useful\ heating\ energy}{net\ energy\ input} = \frac{Q_h + (W_{fan} + W_{comp} + W_{DHW,pump}) \times 3.413\ Btu/Wh}{(W_{comp} + W_{fan} + W_{pump} + W_{DHW,pump}) \times 3.413\ Btu/Wh}$$

where:

COP	= coefficient of performance of the complete system [dimensionless]
Q_h	= useful heat extracted from ground loop [Btu]
W_{comp}	= energy consumed by the compressor [Wh]
W_{fan}	= energy consumed by the fan [Wh]
W_{pump}	= energy consumed by the ground-loop pump [Wh]
$W_{DHW,pump}$	= energy consumed by water heater/desuperheater pump, if appropriate [Wh]

Domestic Hot Water Coefficient of Performance is:

$$COP = \frac{useful\ heating\ energy}{net\ energy\ input} = \frac{Q_h}{(W_{comp} + W_{pump} + W_{pump-2}) \times 3.413\ Btu/Wh}$$

where:

W_{pump-2}	= energy consumed by the DHW pump [Wh]

Energy Efficiency Ratio (EER): The Energy Efficiency Ratio of a heat pump is the ratio of the useful cooling energy output by the system to the net energy input to the system.

Cooling Energy Efficiency Ratio is:

$$EER = \frac{useful\ cooling\ energy}{net\ energy\ input} = \frac{Q_c + Q_{DSH} - (W_{fan} + W_{comp}) \times 3.413\ Btu/Wh}{W_{comp} + W_{fan} + W_{pump} + W_{DSH,pump}}$$

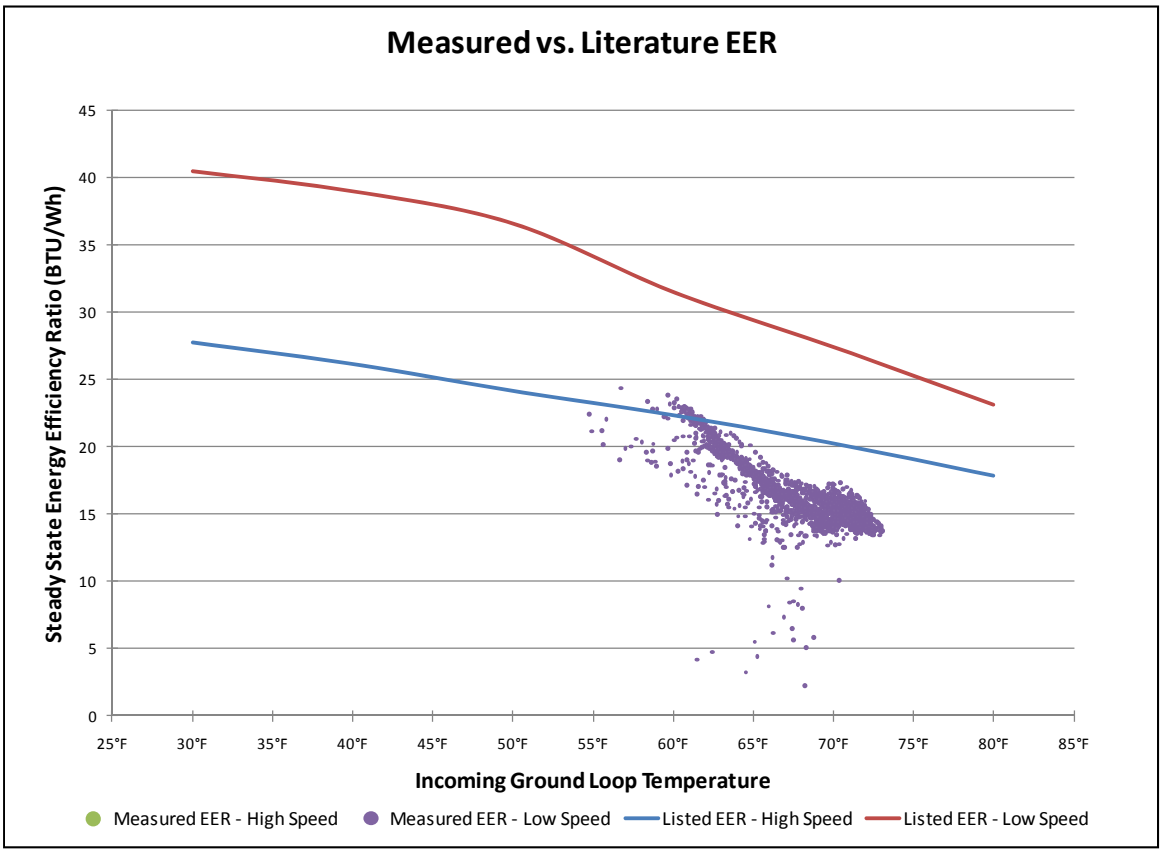
where:

EER	= energy efficiency ratio [Btu/Wh]
Q_c	= heat dumped to ground loop [Btu]
W_{comp}	= energy consumed by the compressor [Wh]
W_{fan}	= energy consumed by the fan [Wh]
W_{pump}	= energy consumed by the ground-loop pump [Wh]
Q_{DSH}	= heat transferred to DWH by desuperheater [Btu]
$W_{DSH,pump}$	= energy consumed by the desuperheater circulator [Wh]

For the initial four summer months, the overall cooling EER was 15.1. The overall heating COP has not been calculated yet as there has not been a significant heating demand since monitoring began. The overall cooling EER accounts for all energy usage of the GSHP regardless of whether the system was supplying conditioned air or not. If only looking at cooling performance at steady-state, the EER was 16.4.

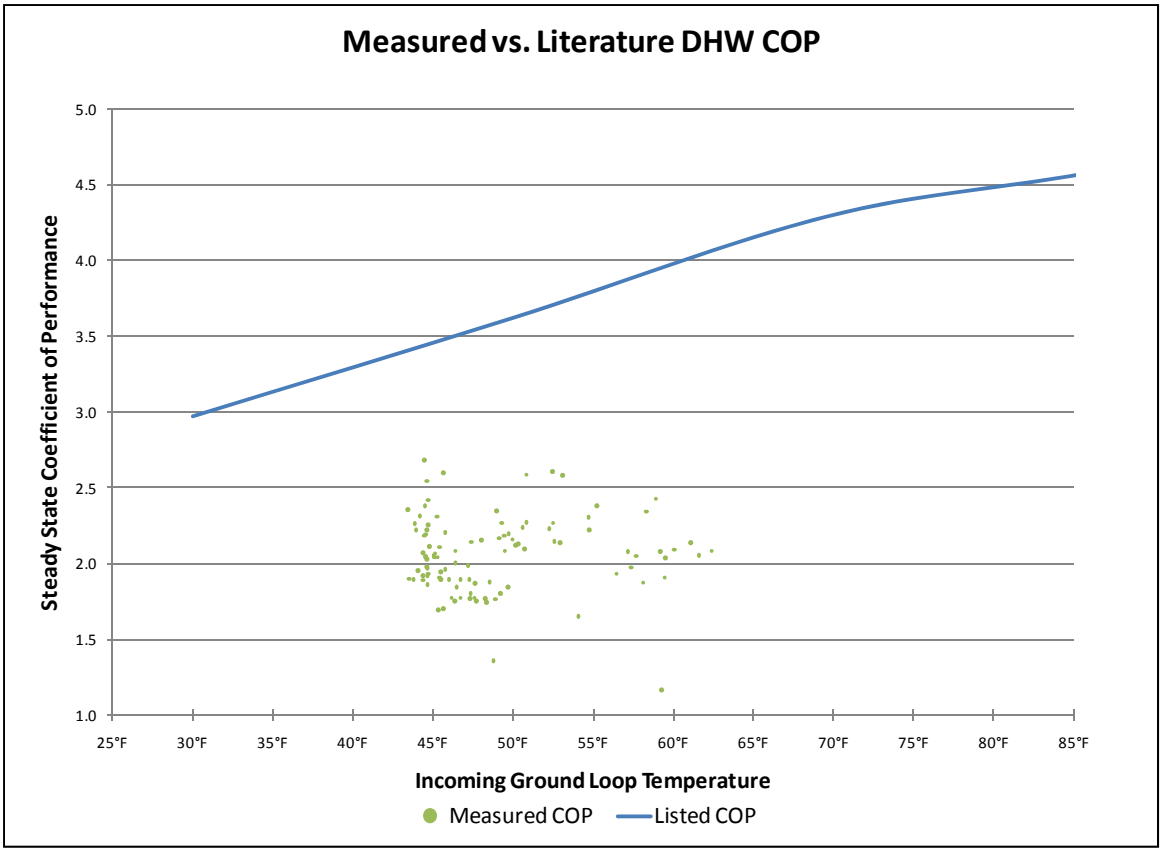
Month	Average Incoming Fluid Temp.	Overall EER
May 2010	61°F	22.1
June 2010	64°F	18.2
July 2010	67°F	15.4
August 2010	70°F	14.9
Summer Totals	65°F	15.1

Below is a chart showing the steady-state measured EER of the *system* vs. the manufacturer listed EER for the *heat pump only*. Steady-state is defined here as system operation for the full 15 minute logging period (measurements are taken at a 10 sec execution interval). This system utilizes a single speed ground loop pump that is operating at roughly 9.1 gpm. The manufacturer's EER curves displayed are based on ground loop flow rates of 9 gpm for high stage and 8 gpm for low stage (highest flow rate manufacturer's goes to for low stage). The measured system data does follow the same trend with relation to the incoming ground loop temperature, but it is apparent that the measured system efficiency is significantly lower than the rated unit efficiency. This is due to the literature EER not accounting for the external piping resistance (the ground loop pump energy) and the equipment being rated at a blower external static pressure (ESP) of 0 in. w.c. (or no ductwork).



4.3 Ground-Source Heat Pump for Water Heating

For the initial four month period, the steady-state hot water COP was 2.04. This system utilizes a single speed ground loop pump that is operating at roughly 8.3 gpm. The manufacturer's EER curve displayed is based on ground loop flow rate of 9 gpm. With a limited quantity of steady-state operation data so far, there doesn't seem to be a trend between COP and the incoming ground loop temperature. It is anticipated that this trend will present itself once more data has been collected and analyzed.



To get a complete view of hot water heating, the pre-heat tank needs to be accounted for as well. The 50 gal pre-heat tank is feed by the main water line that runs through a drain waste heat recovery unit to capture some of the energy from hot water running down the drain. The pre-heat tank is connected to the space conditioning GSHP desuperheater via an internal heat exchanger. The table below shows the energy supplied by these additional sources and their overall contribution to the water heating. Just note that standby heat loss of the storage tanks is not accounted for.

Water Heating Source	Energy Supplied [MMBtu]	DHW Contribution
Desuperheater	969	19%
DHW GSHP	3,579	69%
Drain Waste Heat Recovery	615	12%

5. Next Steps

CARB intends to monitor this home for fifteen months. Part of the WPPI incentive to the homeowners is based on confirmation that they are a net-zero energy home based on one year of utility data. With monthly monitoring data available to the homeowners, they are able to learn how their behaviors influence their energy consumption and adjust them as needed.

CARB is also monitoring various individual loads, such as two propane fireplaces, major appliances, a steam shower, whirlpool tub, and a well water pump. It will be interesting to see how much energy these individual loads consume. Of particular interest is the steam shower, as this seems to be a fashionable item nowadays to include in homes.