Proving Net Zero: Results from a Zero Energy Ready Home in Wisconsin

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ABSTRACT

This paper presents the results of a field study comparing two neighboring Wisconsin homes: one built to U.S. Department of Energy Zero Energy Ready Home (ZERH) standards and the other to ENERGY STAR® specifications. Using utility bills, solar data, and energy monitoring, the study evaluated the homes' energy use, costs, and carbon emissions in a cold-climate setting.

The ZERH home used less than half of the comparison home's annual energy before accounting for on-site solar generation. With a 14.7 kW photovoltaic system, it achieved net zero energy performance annually. Solar credits reduced utility bills by approximately $2,300 and avoided nearly 10,000 kg of CO_2 emissions each year. However, a shift by the utility provider from annual to monthly net metering reduced the financial value of solar overproduction. These findings underscore the importance of aligning energy loads with generation and the role of policy in supporting ZERH adoption.

The study also assessed the accuracy of a selection of energy modeling software tools. Some models underestimated baseload energy consumption and overstated heat pump efficiency during moderate winter conditions, while others more closely matched actual performance. This highlights the need for calibrated modeling inputs and better heat pump selection for cold climates.

Overall, the results provide insights into how technology, modeling, and policy design influence the performance, economics, and scalability of ZERH new construction relative to current new construction practice in residential markets.

Background

The Wisconsin Focus on Energy ratepayer-funded energy efficiency portfolio includes a new home certification program, which piloted the then- ZERH certification[1] and support for builders pursuing that certification for their customers. Two homes were enrolled in the program in 2022, and the homeowners agreed to participate in a study comparing the energy performance of the design and operation of their similar-sized, neighboring homes, built by the same builder: one home built to ENERGY STAR certification specifications (referred to as "2812") and the other to ZERH specifications with on-site photovoltaic generation. According to the U.S. Department of Energy, a ZERH is a highly efficient home whose annual energy use could be fully offset by on-site renewable energy generation.

The homeowners and Focus on Energy program implementors were interested in comparing energy, utility costs, and carbon emissions between the two homes, which were occupied in late 2022. This study analyzed these comparisons and examined whether the ZERH is performing as expected based on simulation of the proposed designs over 365 days under applicable weather conditions and on energy consumption data collected via an energy

[1] Now known as DOE Efficient New Homes at https://www.energy.gov/cmei/buildings/doe-efficient-new-homes-program

monitoring device. The ZERH owners also wanted to know if their home was achieving net-zero energy on an annual basis. The results of the study will inform recommendations for potential changes to the Focus on Energy ZERH certification initiative and will be shared with homebuilder participants.

A summary of the differing features of the ZERH and the comparison house, as documented in their respective models are detailed in Table 1.

Table 1. Comparison of Zero Energy Ready and Efficient New Construction Home Configurations

Feature	ZERH	2812
Total Square Footage	3,522	4,008
Total Cubic Volume	32,993	37,504
Conditioned Stories	2	2
Heating System & Efficiency	9 HSPF1 ASHP	96 AFUE Furnace
Cooling System & Efficiency	16 Seasonal Energy Efficiency Ratio (SEER)1 ASHP	14 SEER1 Central AC
Water Heating System & Efficiency	3.63 EF Heat Pump	.70 EF Gas Storage
Foundation Wall Insulation R-Value	10	7.5
Slab Perimeter Insulation R-Value	10	7.5
Floor Above Garage Insulation R-Value	N/A	47
Window U-Value	0.27	0.31
Window SHGC	0.26	0.32
Refrigerator rated kWh/year	640	775
Dishwasher rated kWh/year	265	467
Range / Oven	Electric Induction	Electric
Clothes Washer rated kWh/year	105	400
Electric Clothes Dryer rated CEF	3.94	2.62
Ceiling Fans	None	1
PV DC rating, Watts	14,700	N/A
Electrical Service (amperage)	325	200
Home Energy Rating System (HERS) Score [2]	-8	47

Overall, the ZERH is designed with higher energy efficiency and better thermal performance characteristics compared to 2812. A visual of the homes' exteriors is shown in Figure 1.

[2] Home Energy Rating System Index for assessing a home’s energy performance. The lower the score, the more energy efficient is the home.

Figure 1. Photo of Neighboring Zero Energy Ready Home (left) and Efficient New Residential Construction (right) (provided by homeowners).

Department of Energy Zero Energy Ready Home Requirements

The Department of Energy's ZERH requirements focus on building highly efficient homes that can achieve net zero energy consumption when paired with on-site generation, such as solar panels. Key aspects of these requirements include:

- Energy Efficiency: Homes must incorporate advanced insulation, high-performance fenestration, efficient heating and cooling, and efficient water heating systems to minimize energy use. All appliances in the home must be ENERGY STAR Certified.
- Renewable Energy Readiness: The design includes specifications for an on-site solar array, including array square footage, orientation, and inclination; roof load analysis; and electrical panel and wiring preparation unless exceptions apply. Importantly, ZERHs do not need to include on-site generation to earn the ZERH certification.
- Indoor Air Quality: Emphasis is placed on enhancing indoor air quality through the requirement of EPA Indoor AirPlus certification. Indoor AirPlus has design targets including mechanical ventilation CFM and outdoor venting, HVAC system filtration, moisture control on exterior materials and interior foundations, as well as Radon mitigation based on the region. ZERH requires that ductwork must use hard ducting and be located entirely within conditioned space.
- Performance Testing: Homes are subject to rigorous inspection and performance testing performed by a third party to verify they meet the ZERH efficiency and safety specifications. According to the Wisconsin Uniform Dwelling Code, homes must test less than 7ACH50 or pass a visual inspection. Total Duct Leakage testing is never required, and Leakage to Outside Testing is only required when ductwork is located outside conditioned space. ZERHs requires infiltration testing of 3ACH50 or lower and requires both Total Leakage and Leakage to Outside, regardless of duct location.

Utility Data Comparison

The homeowners collected utility data in monthly bills at the ZERH for 613 days (from October 17, 2022, to June 20, 2024) and at 2812 for 558 days (November 10, 2022, to May 21, 2024). Both homes' utility data were normalized to a 365-day basis and converted to million Btu (MMBtu) equivalent site energy units, shown in Figure 2.

With annualized metered electricity usage of 16,000 kWh (54 MMBtu), the ZERH consumed less than half of the comparison home's 120 annual MMBtu of purchased combined electric and natural gas energy use. The ZERH also produced 18,800 kWh (64 MMBtu) in annualized solar generation on-site[3], and exported 14,000 kWh (48 MMBtu) to the grid, according to utility and other data records. The remainder was produced and consumed simultaneously by the ZERH and therefore not accounted for in utility meter data. After accounting for the solar generation, the ZERH annualized net utility energy consumption was equivalent to just 5% of the comparison home's utility energy consumption.

As shown in Figure 2, when accounting for gross solar generation on site, the ZERH had a net negative annualized energy consumption representing 130 MMBtu of savings over the comparison home.

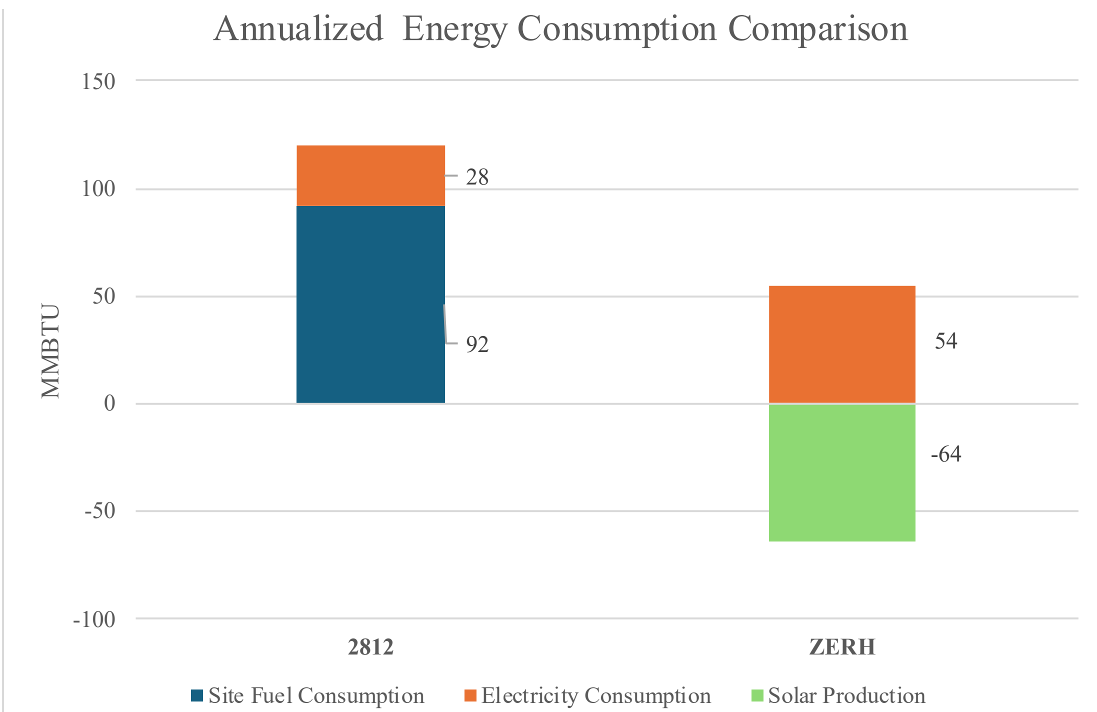

Figure 2. Comparing Annualized Energy Consumption of Two Homes.[4]

The ZERH achieved its net zero energy goal, with the one-year (October 2022-September 2023) total gross solar production exceeding total site consumption, including EV charging (Figure 3). Solar generation on site has met or exceeded consumption (on a cumulative basis) nearly every month since then.

[3] Gross electricity generation data was compiled by the homeowner using a SolarEdge monitoring device.
[4] Since the two homes use different heating fuels, the comparison is based on net site energy consumption.

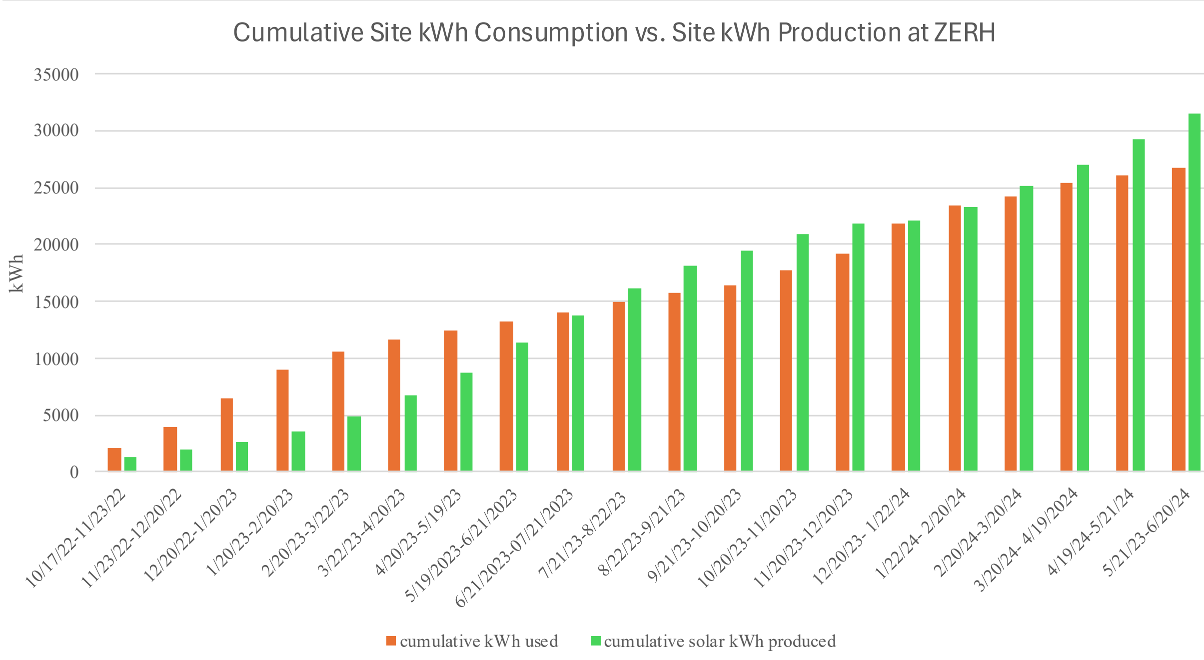

Figure 3. "Proving" Net Zero: Cumulative Site Electricity Consumption vs. Cumulative Site PV Production, reported by SolarEdge[5].

Compared to 2812, the ZERH incurred 10% higher[6] gross utility costs[7] on an annual basis (Figure 4). However, credits for solar generation at the ZERH reduced the home's net annual utility costs to $2,300 lower than those of the comparison home. The ZERH incurred a net positive annual electric utility cost associated with account fees and taxes and with the change in utility valuation of net exported kWh.

[5] The homeowner tracks on-site generation using the SolarEdge monitoring app by SolarEdge Technologies Inc. (https://monitoring.solaredge.com/mfe/auth/)

[6] The ZERH began charging an electric vehicle in December 2022, thereby adding electric load and at the site that 2812 does not also have. While this study did not track the EV usage, if this were quantified and omitted from electric usage, it is likely that the ZERH utility usage and costs would drop lower than 2812's even before solar generation was considered.

[7] Utility rates derived from bill data for the ZERH included service charges surcharges and taxes, distribution service at $0.0575 per kWh, electric service rates at $0.11497 per kWh. Exported energy values changed from an average of $0.17 per net exported kWh from 2022 through early 2024, to a $0.175 per kWh net export variable rate and a $0.043 per kWh net buy back variable rate. Utility rates derived from bill data for 2812 include service charges, surcharges and taxes; gas distribution at $0.2531 per therm, tiered gas service at $0.2734 and $0.386 per therm; electric distribution charges at $0.0575 per kWh, and electric service at $0.11497 per kWh.

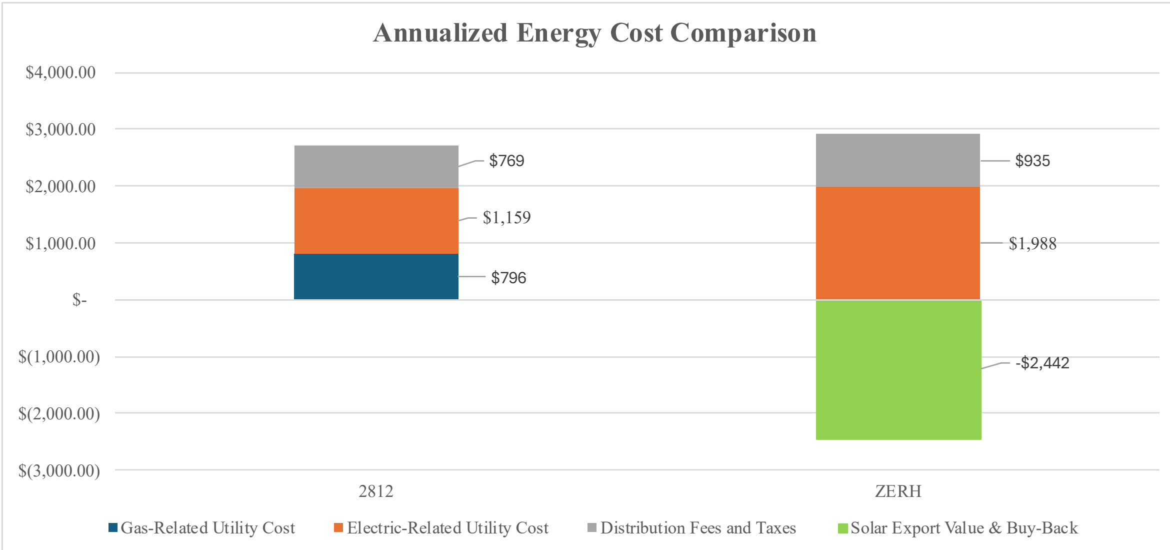

Figure 4. Comparison of Annualized Energy Costs for the Two Homes.

The annualized energy and energy cost for the ZERH relative to 2812 are summarized in Table 2.

Table 2. Annualized Home Performance Metrics Comparison

Annualized Home Performance Metrics	2812	ZERH	ZERH Net Difference
Gross Utility Energy Consumption, MMBtu	120	54	66
Net Site Energy Consumption, MMBtu	120	-10	130
Net Utility Cost, $	$2,639	$336	$2,303

Comparing End Uses via Energy Meters

Both homes installed Sense® energy monitoring systems, which collect energy data from the home's main electrical circuit and use a proprietary, undocumented algorithm to allocate portions of total energy use to specific end uses based on observed consumption patterns. Unlike utility data, energy monitoring systems allow a homeowner to assess the impact of specific end uses on their home's energy consumption, possibly enabling opportunities to reduce usage with behavior or technology changes in the future. Homeowners installed individual sensors on the heat pump circuit to measure the home's electricity usage for heating and cooling directly. Results from the Sense data should be viewed as preliminary estimates.

The energy monitoring device for 2812 allocated energy consumption to over 20 different end uses, including four "stove" loads, three unknown "heat" loads, and multiple small uses. To simplify the data for presentation here, the research team identified the top five major end uses–Air Conditioning (AC), Always On, Dishwasher, Dryer, Energy Recovery Ventilator (ERV) and Furnace Fan–and combined all other end uses into "Other."

Figure 6 represents the nine months of data collected from the 2812 home in 2023 which was annualized[8] for comparison to data collected from June 2023 to May 2024 at the ZERH. The annualized total home electric usage from the 2812 Sense data is 16% lower than the annual electric usage determined from its utility bills; differences between the two sources could be attributed to occasional loss of data connection as well as differences in monitoring periods.

The research team observed the energy monitoring data included fewer hourly kWh values for the “Always On” end use than for the total house, suggesting the system’s automated end use allocation methodology may not have accurately disaggregated and allocated every end use at every hour. The large “Other” (light green) end use shown in Figure 6 may be overstated as a result. Some of the annual usage that is currently counted as “Other” in the figure below could actually be “Always On” usage that was not identified by the energy monitoring device.

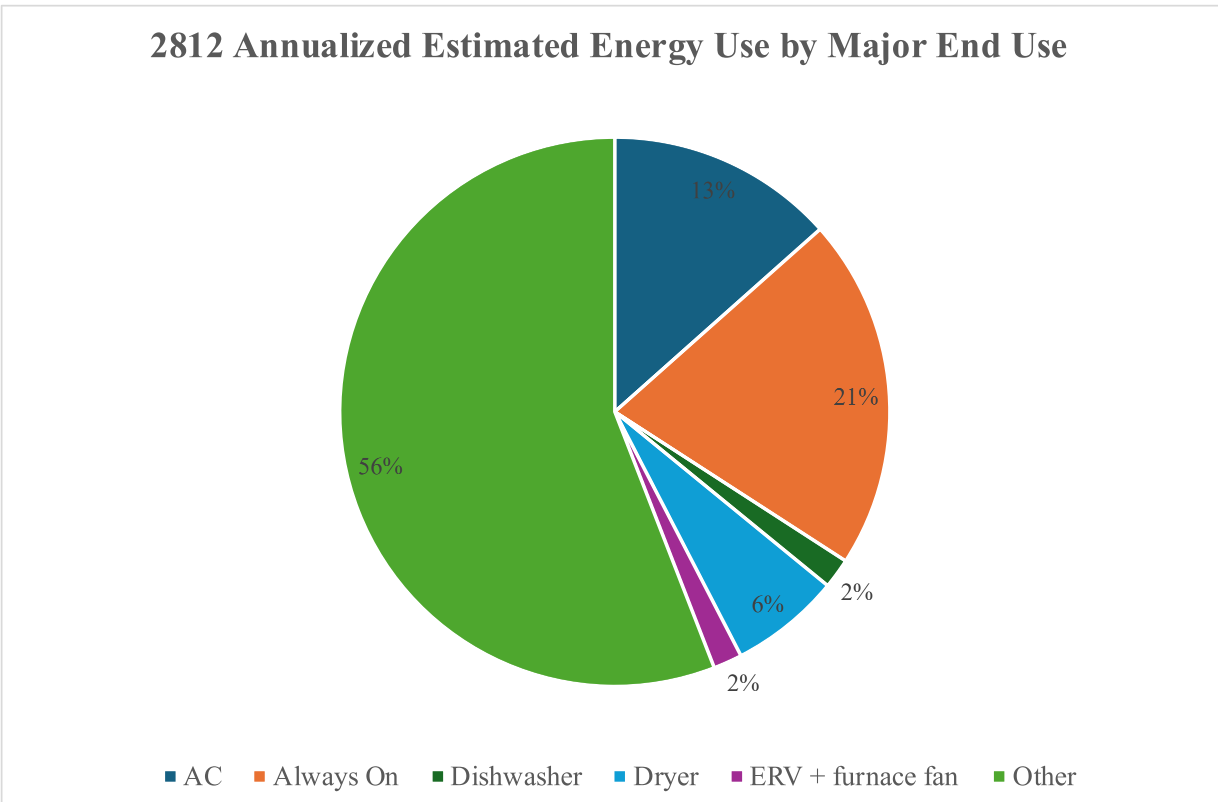

Figure 6. Annualized Energy Consumption by Major End Uses for 2812 Comparison Home.

More than 12 months of energy monitoring data was available for the ZERH from two devices installed on the home’s two independent panels[9], which together allocated energy consumption to roughly 25 different end uses. The annualized total electric usage from the Sense data represents 77% of the annual total electric usage predicted by bill data, and may differ due

[8] Interval usage data was summed for each monitored end use and month that monitoring data was available (January-September), and then the monthly usage incurred by end use in January – March was added to the nine month totals to approximate missing data for October-December. Comparing annual usage between the two homes was a project goal.

[9] ZERH panel 1 served water heating, backup electric heat, and cooking equipment; panel 2 served other electric circuits including the heat pump.

to differences in monitoring periods or lost data connections. As in the case for 2812, the Sense device(s) at ZERH's allocated uses to several unlikely duplicate end use categories in addition to an individually monitored heat pump and other undefined uses. Review of ZERH data in 2023, before the heat pump was separately monitored, suggests the heat pump usage was originally allocated to "Always On." To isolate the heat pump over the 2023-2024 analysis period, the team annualized[10] the 2024 heat pump consumption as measured by the newly installed sensor, annualized the 2024 "Always On" data, and excluded the 2023 "Always On" data from this analysis.

Even with these adjustments, the estimated contribution of "Always On" loads to the home's energy use is significantly larger than the contribution of this end use category to 2812 energy use (Figure 7) and could benefit from further homeowner investigation. It is not surprising that the heat pump energy usage contribution is also significantly larger than 2812's air conditioning contribution to the home's energy use, since the ZERH uses the heat pump for both heating and cooling. Interestingly, the ZERH began dedicated monitoring of their electric backup heat circuit in early January 2024, along with the heat pump. No appreciable energy use was reported on this circuit through June 2024, implying the heat pump met the full heating load during the coldest part of the 2023-2024 heating season.

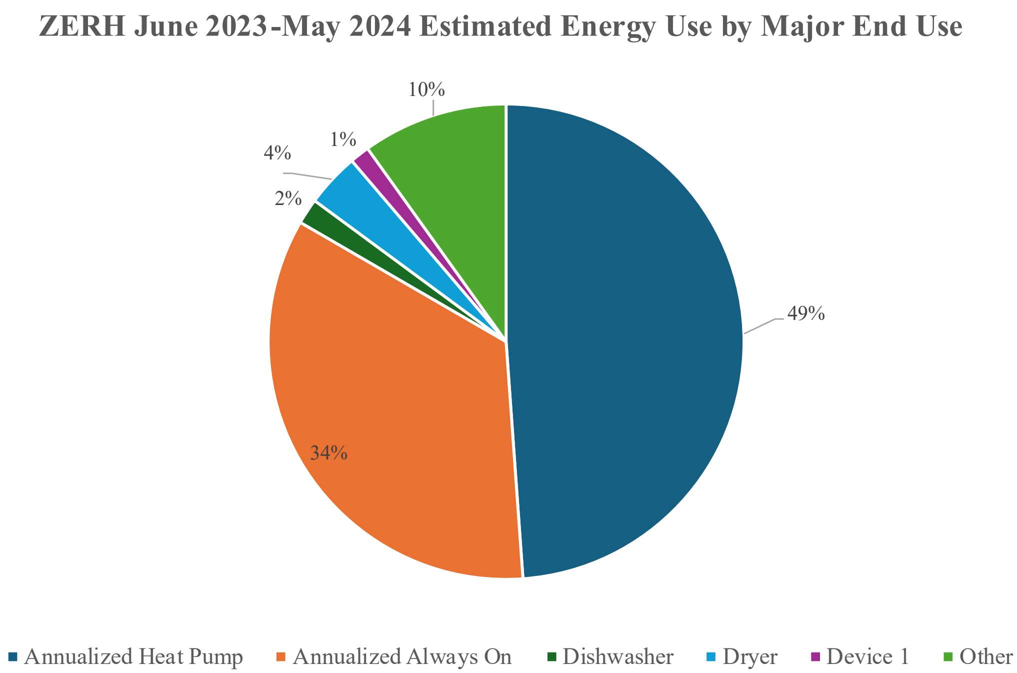

Figure 7. Electricity End Use Allocations. The ZERH "Device 1" usage was identified in the data as a furnace fan but is assumed to reflect the home's ERV.

[10] ZERH monitored energy data was summed by month. Dedicated heat pump monitoring data were available from January to June 2024. July-December 2024 heat pump usage was estimated as follows: July & August approximated by May-June average usage; September usage approximated by April-May average; October-December monthly usage approximated by January-March average. Annual "Always On" usage not attributed to heat pump was estimated with 5 months' available usage *12/5. Remaining major annual end uses were summed from 2023-2024 data.

Zero Energy Ready Home Model vs. Meter Energy Use Results

An important objective of this study was to collect actual home energy consumption data and compare it to model predictions used to analyze expected home and heating and cooling energy performance for the utility program (Table 3). Ultimately, the "HPXML CH3 Model" built with OpenStudio® software tools combined with EnergyPlus™ building energy simulation[11] was used for the comparison to collected energy monitoring data.

Table 3. Summary of the three ZERH Building Energy Models

Model Version	Input Data Source	Operational Conditions	Simulation Engine	Building Model Inputs	Heat Pump Data
"REM/Rate™ Model" (original)	REM/Rate User converted to HPXML[12]	REM	EnergyPlus	As provided by contractor	9 HSPF/16 SEER 32.8 kBtu heating capacity at 17 degrees 36 kBtu cooling capacity
"REM/Rate Model Field QA'd"	REM/Rate User Converted to HPXML with changes based on Site QA	REM	EnergyPlus	Adjustments to roof, ceiling and slab areas; ERV ventilation rate and recovery efficiencies; appliance specifications	9 HSPF/16 SEER 32.8 kBtu heating capacity at 17 degrees 36 kBtu cooling capacity
"HPXML CH3 Model"	REM/Rate User Converted to HPXML with changes based on Site QA and calibration	Calibrated to Actual Loads	EnergyPlus	As for "REM/Rate Model Field QA'd "with baseload calibrated to Sense meter data	Equipment Specific from Air Conditioning, Heating and Refrigeration Institute (AHRI) certification directory

Comparison of model results to the actual usage data intended to address the following questions:

[11] Tools originally provided by the National Renewable Energy Laboratories and US Department of Energy Building Technologies Office. OpenStudio version 1.7 was used for this study. https://openstudio-hpxml.readthedocs.io/en/v1.7.0/index.html
[12] The REM to HPXML model transform used allowed the REM/Rate inputs to be directly utilized in the OpenStudio simulation platform using the HPXML standardized data transfer protocol.

- Is the building model's predicted kWh usage accurate when using a cold climate heat pump for heating and cooling?
- What is the impact of heat pump sizing on annual heating energy use?
- Does the building model accurately predict baseload energy use (the energy use that is not dependent on temperature or season), which is important to size the PV system correctly?

The answers to these questions impact designers' ability to cost-effectively achieve zero energy ready performance using renewable energy systems sized to meet expected building electric loads without being oversized, which could add costs. Figures 8 and 9 illustrate the answers to these questions for this ZERH by comparing results of hourly, building and HVAC simulations to hourly post-construction monitoring data on a basis of predicted or actual outdoor temperatures.

On an average hourly basis, a REM/Rate model of the ZERH's energy usage [13] underestimated the home's actual average hourly energy use as tracked by the energy monitoring device. Differences per temperature bin ranged from 4% to 46%, with the largest underestimations occurring in mild temperature ranges (40 to 70 F). After improvements to heat pump and baseload assumptions in the original model, summarized in Table 3, the energy usage prediction resulting from simulating the "HPXML CH3 Model" appears to better predict the home's actual energy consumption given mild outdoor temperatures (Figure 8).

Total electricity usage in the ZERH was recorded on an hourly basis over the period of February 11, 2023 to June 7, 2024 using Sense energy monitoring equipment and combined with local average hourly outdoor temperature over the same time period from Tomorrow.io[14]. The research team compared energy monitoring data to building energy modeling results from REM/Rate home energy rating software and from simulating the same inputs in the National Laboratory of the Rockies' OpenStudio building energy analysis software with EnergyPlus simulation methodology. The initial REM/Rate model was subject to adjustments following a QA field audit and resimulated after construction completion The QA-adjusted inputs were then applied to an HPXML model input file ready for OpenStudio/EnergyPlus software simulation and adjusted further by calibrating the default residential electric baseload energy usage to billed usage during non-heating/non-cooling periods and replacing simplified heat pump assumptions with detailed heat pump specifications. As a result, three sets of hourly simulation results are available for comparison to the collected hourly consumption data[15] in Figure 8 for the ZERH by outdoor temperature.

In Figure 8, total home electric energy usage simulated or measured in each hour is associated with an hourly temperature value and averaged within 5-degree Fahrenheit temperature bins for direct comparison. The highest number of measured hourly usage data points are associated with the 30-degree bin, while very few measurements occur in very low

[13] REM/Rate is a software product hosted by REM/Rate LLC (https://www.remrate.com/), and would typically be used to inform design of a PV system and/or support participation in the Home Energy Rating System However, the ZERH homeowner has advised that their solar contractor provided their own analysis and quote, which ultimately determined the PV system size.

[14] https://www.tomorrow.io/weather-api/

[15] Prior to January 2024, reported energy monitoring data values were all non-negative. Meter data collection and reporting changed after January 2024, and negative whole-home measured usage values started appearing. These negative values account for solar generation. Negative values have been omitted from Figure 8.

temperature bins (under 5 degrees) or the highest bins (90 and 95 degrees). Therefore, average energy usage results associated with high counts of data points can be interpreted with greater confidence than results with very few data points.

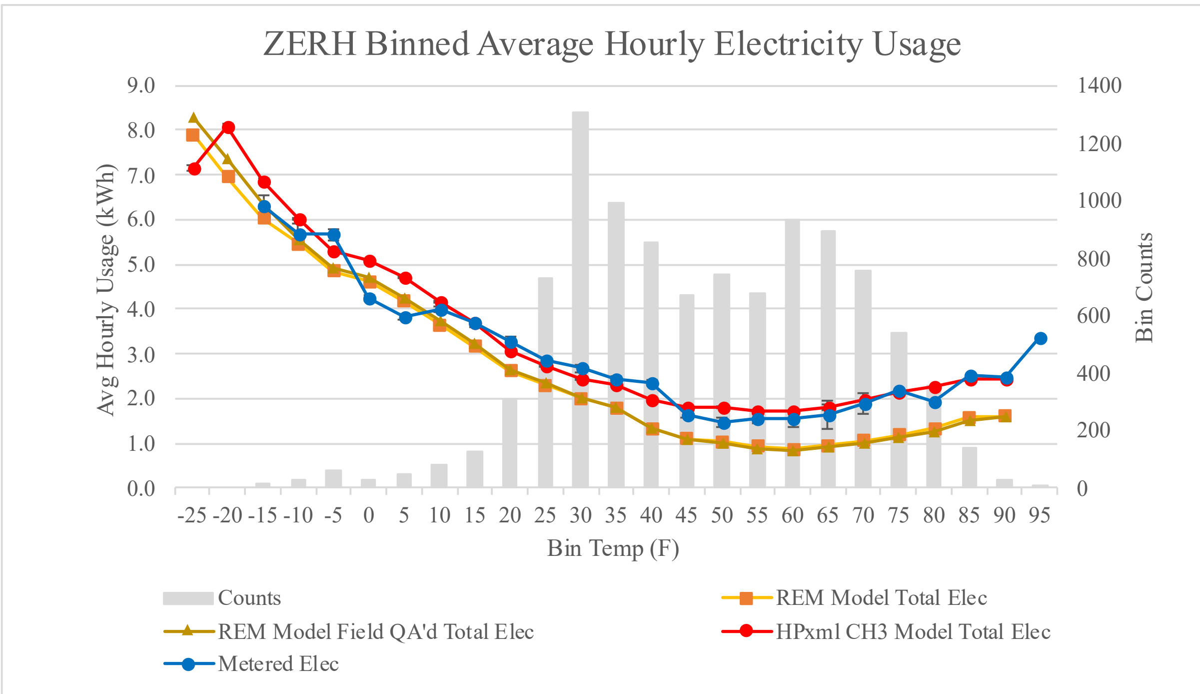

Figure 8. ZERH Average Hourly Electric Usage by Temperature Bin - Simulation Results vs. Actual Measurements

The REM/Rate models both before and after QA adjustments (the orange and green lines in Figure 8) frequently underestimate the actual home energy usage (blue line labeled Metered Elec) at most temperatures and were not calibrated to apparent metered baseload. If we assume that at 60 degrees outdoor temperature, the ZERH home has virtually no need for energy use in heating or cooling, we can assume the home's average hourly metered energy use of 1.5 kWh at that temperature represents the hourly baseload use. In contrast, the uncalibrated REM/Rate QA model predicted an average of 0.8 kWh at 60 degrees. With constant baseload over the course of the year, the REM/Rate model may have underpredicted the house usage by about 6000 kWh. Relying on the REM/Rate model results alone to design the PV system for the ZERH might have resulted in a system undersized by 4.5 kW[16].

The baseload calibration plus heat pump specification adjustments in the model run with OpenStudio software tools and EnergyPlus energy simulation framework (the red line in Figure 8) resulted in a model appearing to fit the meter data well in all except rare extreme cold conditions. The more significant differences between the average hourly meter usage and the model results at temperatures below 10 degrees may be a result of the small number of data points available at those temperatures.

The absolute error between the binned average hourly kWh predicted by the "HPXML CH3 Model" and the binned average hourly meter kWh, as a percentage of the actual (metered)

[16] According to the National Laboratory of the Rockies' PVWatts® calculator, a 4.5 kW (DC) system would be required to deliver 6,000 kWh annually at this location, sized at 30 square meters.

hourly usage, ranges from 0% to 23%. The overall average percent error between the averaged hourly metered kWh and the final calibrated OpenStudio model kWh is 4%, whereas the same calculation for the REM/Rate model with field QA results in 21% error. Figure 9 shows the formula used to calculate the absolute error.

$$\frac{\sum ABS(averaged\ meter\ hourly\ kWh - averaged\ model\ hourly\ kWh)}{\sum averaged\ meter\ hourly\ kWh}$$

Figure 9. Absolute error formula

Zero Energy Ready Home Model vs. Meter Heating and Cooling Energy Use

In a climate with cold winters and hot summers like Wisconsin, heating and cooling energy will contribute significantly to residential energy consumption. Comparing model predictions of the installed cold climate air source heat pump[17] performance over the range of possible outdoor temperatures to actual heat pump energy data is therefore important to understanding whether the ZERH home, or other homes like it, will be able to meet electric loads with on-site generation. In addition, it is helpful to learn whether a heat pump system is performing as expected, to manage utility bills for an all-electric home. The OpenStudio/EnergyPlus modeling framework allows the heat pump to be modeled with detailed performance characteristics at differing heating and cooling season temperatures, rather than relying on an averaged capacity and efficiency value.

When heating needs were low to moderate (outdoor temperatures 50 F down to 20 F), the OpenStudio/EnergyPlus model underpredicted the actual heat pump usage (Figure 9). A possible reason for unexpectedly high actual usage could be that the heat pump's minimum capacity is greater than the house heating load in moderate conditions, causing the heat pump to cycle on and off frequently and reducing operating efficiency. In very cold conditions (15 degrees F to -15 degrees F), the actual heat pump's average hourly usage aligns well with the final OpenStudio simulation, which could indicate that the heat pump is operating within its manufacturer-reported minimum and maximum heating capacity range. The predicted heating coefficient of performance (COP) for the actual heat pump including backup heating[18] appears to be maximized at around 15 degrees F and then declines as generally expected with declining temperatures (green line in Figure 9). This COP was estimated by dividing OpenStudio-simulated hourly heating load in Btus by the heat pump's measured hourly energy use in Btu. Meanwhile, the pure model heating COP (dark blue line) declines as expected as outdoor temperature gets colder, with anomalous results around 45 degrees likely influenced by extrapolation of manufacturer-reported heating performance data at 47 degrees. The divergence of the meter and the model results below -10 degrees may be influenced by the minimal available data points[19] in those temperature bins.

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[17] Variable capacity air source heat pump meeting the Northeast Energy Efficiency Partnerships' Cold Climate Air Source Heat Pump Specification (NEEP,2023).

[18] Calculated heating COP = predicted heating output in hrly Btu/metered heating electricity consumed in hrly Btu

[19] Meter data collected from the energy monitoring device are filtered to include only directly monitored heat pump data (not inferred by device software).

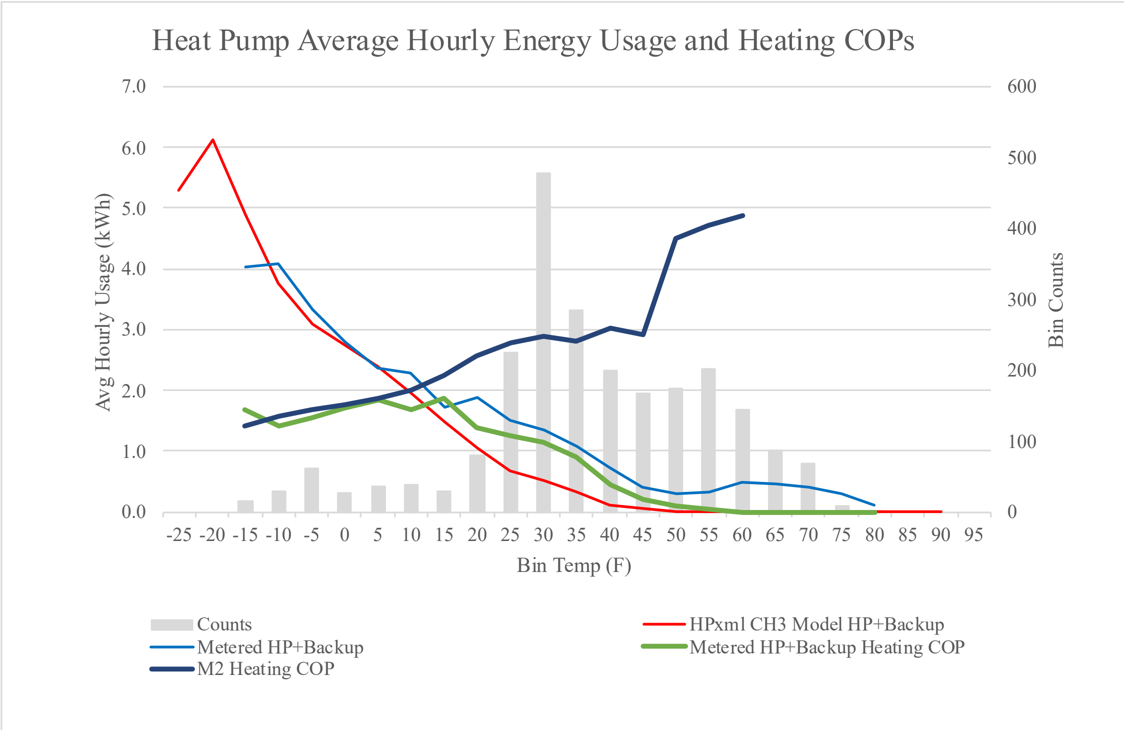

Figure 9. Heat Pump Average Hourly Electricity Usage - Final Model vs. Meter with Calculated Average Heating Coefficient of Performance (COP) per Temperature Bin.

Table 4 summarizes the design heating loads calculated near the most extreme cold historic temperatures for this home's location, according to the Air Conditioning Contractors of America Manual J Residential Load Calculation (ACCA 2016), as well as more typical (average) winter heating loads for the ZERH, predicted by the OpenStudio energy model and compared to actual expected heat pump performance.

Table 4. Cold Weather ZERH Heating Loads and Heat Pump Capacities

Expected Load/Capacity	Heating Design Conditions (-2.92 F)	Typical Winter Conditions (17 F)
Predicted Home Heating Load (Btu/hr)	32,932	10,100
Manufacturer-Reported Heat Pump Capacity (Btu/hr)	33,744 max (interpolated)	9500 min / 37,000 max

Table 4 demonstrates that the heat pump capacity should be adequate to meet the home's predicted heating needs in the most extreme temperatures of the heating season, without being substantially oversized. Meanwhile, at more frequently experienced winter temperatures around 17 F, the home's predicted average heating load is near the selected equipment's minimum capacity. This suggests that above 17 F, the heat pump could be operating below minimum capacity and subject to frequent on/off cycling, which contributes to lower operating efficiency.

Figure 10 further demonstrates the difference between the home's design heating load (blue line extrapolated from -2.92 F estimate down to zero heating need at 50 F) and heating loads predicted with OpenStudio/EnergyPlus methodology. The latter methodology estimates heat losses and gains across the range of possible temperatures rather than at a single extreme temperature, and accounts for solar and internal gains differently from the design load calculation. To remove the influence of solar gains on heating loads, the data shown in Figure 10 are filtered for nighttime hours only. If the modeled building heating load (gray line) accurately represents the ZERH home thermal performance, an HVAC design professional could assess whether a smaller heat pump with lower expected electricity consumption could meet the needs of this home.

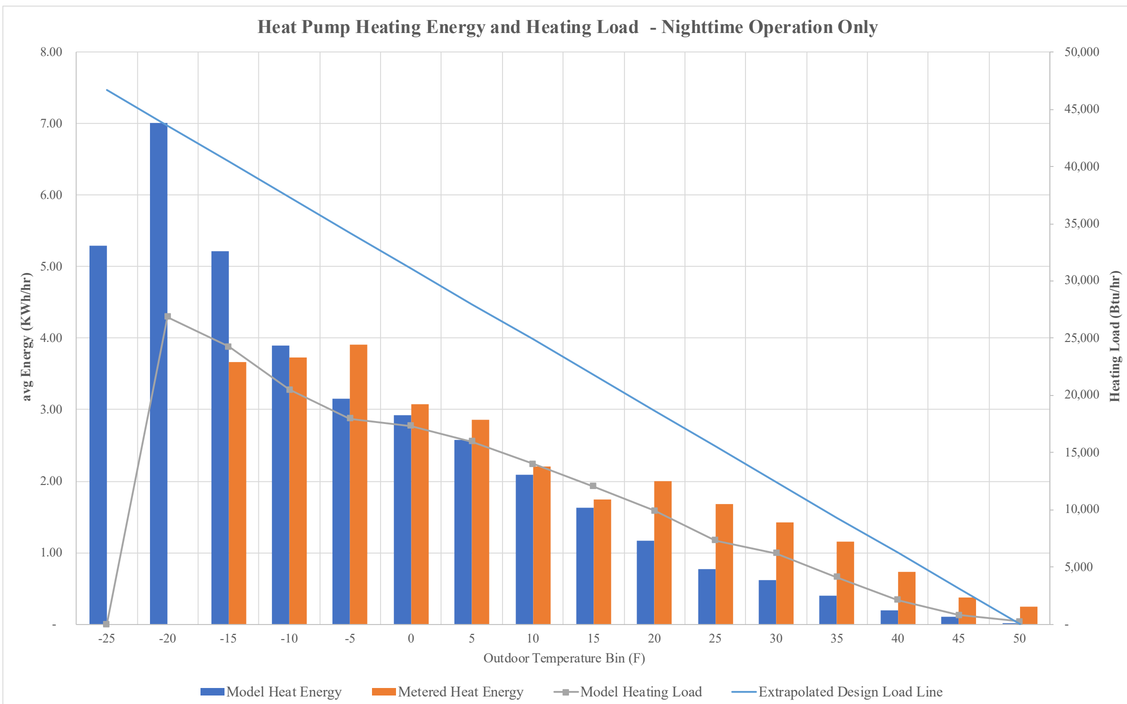

Figure 10. Comparing Average Hourly Heating and Cooling Loads to Design Loads

Conclusions and Recommendations

The study of ZERH performance relative to an energy-efficient home not pursuing ZERH guidelines offers several takeaways for the Focus on Energy new homes program:

- Utility bill and PV generation data provided by the homeowner suggest the ZERH, as built, is able to offset its annual energy consumption with its own on-site PV generation and consumes less net annual energy (after generation) than the comparison home, which was the homeowner's goal.
- Home energy monitoring and sub-metering of major equipment helped validate energy modeling results, illustrating conditions under which the modeled heat pump performance relative to outdoor temperature appeared to predict actual temperature-dependent heat pump performance well.

- The heat pump used in the ZERH used more electricity than predicted by the model at mildly cold temperatures and may serve a heating load that is typically lower than the design heating load calculated for equipment sizing. In Wisconsin, the 2023-2024 heating season was relatively mild, and extremely cold temperatures are now less common, increasing the need to more carefully consider heat pump COP performance under mild temperatures as well as under extreme cold. Consider heat pumps that offer a combination of good capacity modulation and strong, mild-temperature COP performance, based on a detailed energy simulation of heat pump performance conducted during the design phase.
- When choosing the design load capacity of heat pumps for ZERH heating and air conditioning, contractors should consider the contribution of internal gains and solar gains on the heat pump load and the role that these gains play in reducing the risk of not meeting the heating load at design temperatures. The heat pump selected for the ZERH home performed without backup heat down to very cold outdoor temperatures, which were experienced for a limited number of hours.
- Both prospective ZERH homebuyers and the professionals supporting them (builders, raters, and HVAC contractors) can benefit from more information on the economics and thermal performance of ZERHs in Wisconsin. This analysis can provide direction for developing more consumer-facing content.

References

ACCA (Air Conditioning Contractors of America). 2016. *Manual J® Residential Load Calculation:(8th ed., Version 2.50)*. Air Conditioning Contractors of America.

NEEP (Northeast Energy Efficiency Partnerships). 2023. *Cold Climate Air Source Heat Pump Specification (Version 4.0)*. neep.org/sites/default/files/media-files/cold_climate_air_source_heat_pump_specification_-_version_4.0_final_1.pdf