NEW CONSTRUCTION NEIGHBORS: A COMPARISON OF ZERO ENERGY READY VS. STANDARD RESIDENTIAL DESIGN

December 2024

BACKGROUND

The Wisconsin FOCUS ON ENERGY® ratepayer-funded energy efficiency portfolio includes a new home certification program which piloted U.S. Department of Energy Zero Energy Ready Home (ZERH) certification and support for builders pursuing certification for their customers. Two homeowners enrolled in the program in 2022 and agreed to participate in a study comparing energy performance of design and operation of their similar-sized, neighboring homes: one home built to the standard program specifications (referred to as "2812") and the other to ZERH specifications. According to the U.S. Department of Energy, a ZERH is a highly efficient home whose annual energy use could be fully offset by a renewable energy system.

The homeowners and Focus on Energy were interested in comparing energy, utility costs, and carbon emissions between the two homes, which were occupied in late 2022. Additionally, the study examined whether the ZERH is performing as expected based on simulation of the proposed designs over 365 days under applicable weather conditions. The ZERH owners also wanted to know if their home was achieving net zero energy on an annual basis. The results of the study would inform recommendations for any changes to the Focus on Energy ZERH certification initiative and shared with homebuilder participants.

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

FEATURE	ZERH	2812
Total Square Footage	3,522	4,008
Total Cubic Volume	32,993	37,504
Conditioned Stories	2	2
Unconditioned Stories	1	1
Bedrooms	4	4
Heating System	9 HSPF1 ASHP	96 AFUE Furnace
Cooling System	16 SEER1 ASHP	14 SEER1 Central AC
Water Heating	3.63 EF Heat Pump	.70 EF Gas Storage
Attic Insulation R-Value	50	50
Above Ground Wall Insulation R-Value (cavity insulation + continuous exterior insulation)	23+5	23+5
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
Joist Insulation R-Value	14+5	14+5
Window U-value	0.27	0.31
Window SHGC	0.26	0.32

FEATURE	ZERH	2812
Door R-Value	7.5	7.5
Infiltration (Air Changes per Hour @ 50pa)	1.44	1.43
Ventilation	ERV	ERV
Refrigerator kWh/year	640	775
Dishwasher kWh/year	265	467
Range / Oven	Electric Induction	Electric
Clothes Washer kWh/year	105	400
Clothes Dryer CEF	3.94	2.62
Lighting	LED	LED
Ceiling Fans	None	1
PV Peak Power Watts	14,700	N/A
Electrical Service (amperage)	325	200
Home Energy Rating System (HERS) Score[1]	-8	47

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

The two homes differ in several key areas:

1. **Size and Volume**: The ZERH is slightly smaller in square footage (3,522 sq ft) compared to 2812 (4,008 sq ft). The ZERH also has a lower cubic volume (32,993 cu ft) compared to 2812 (37,504 cu ft). Smaller homes tend to use less energy.
2. **Heating Systems**: The ZERH uses a 9 HSPF1 Air Source Heat Pump (ASHP), while 2812 relies on a 96 AFUE gas furnace.
3. **Cooling Systems**: The ZERH features a 16 SEER1 ASHP for cooling, whereas 2812 has a 14 SEER1 central air conditioner.
4. **Water Heating**: The ZERH uses a heat pump water heater with a 3.63 EF, in contrast to 2812's gas storage water heater with a 0.70 EF.
5. **Insulation**: Both homes have R-50 attic insulation. The ZERH has higher foundation and slab perimeter insulation (R-10), compared to 2812's R-7.5.
6. **Windows**: The ZERH's windows have a lower U-value (0.27) and a lower Solar Heat Gain Coefficient (SHGC) of 0.26, compared to 2812's higher U-value (0.31) and SHGC of 0.32. Lower U- and SHGC values indicate higher performance windows.
7. **Air Infiltration**: The ZERH and 2812 have nearly identical air leakage rates, with the ZERH achieving 1.44 Air Changes per Hour at 50Pa (ACH50), compared to 2812's 1.43 ACH50.
8. **Appliance Energy Use**: The ZERH has more energy efficient appliances overall, with lower annual energy consumption for appliances such as refrigerators, dishwashers, and clothes washers, and a higher clothes dryer Combined Energy Factor (CEF) of 3.94 compared to 2812's 2.62.

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

9. **Photovoltaic (PV) Power**: The ZERH includes a photovoltaic system with a peak power of 14,700 watts, which is not present in 2812.
10. **Electric Vehicle**: The ZERH began charging a plug-in EV in December 2022.

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

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 windows, and efficient heating and cooling and water heating systems to minimize energy use.
- **Renewable Energy Ready**: The design must facilitate the easy installation of renewable energy systems, such as solar panels, to achieve net zero energy status. Homes must also be sited to maximize the roof area oriented to the south to ensure optimum solar

generation. 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 proper ventilation, filtration, and moisture control. Indoor air quality standards are confirmed to have been met by earning ENERGY STAR® Indoor AirPlus certification.
- **Performance Testing**: Homes are subject to rigorous performance testing performed by a third party to ensure they meet efficiency and safety standards.
- **Durability and Sustainability**: The requirements encourage the use of durable materials and construction practices that contribute to the home's longevity and reduce environmental impact.

UTILITY DATA COMPARISON

The homeowners have collected utility data at the ZERH for 613 days (from 10/17/2022-6/20/2024) and at 2812 for 558 days (11/10/2022-5/21/2024). The ZERH usage, solar production, and billing totals were adjusted to match the comparison's house timeframe. Both homes' utility data was normalized to a 365-day basis and converted to million Btu (MMBtu) equivalent energy units (Figure 2).

With annualized metered electricity usage of 54 MMBtu, the ZERH consumed less than half of the comparison home's 120 annual MMBtu of purchased electric and natural gas energy use. However, the ZERH produced 64 MMBtu (18,800 kWh) in annualized solar generation on site, with 48 MMBtu (14,000 kWh) of that available to the grid, according to utility data. The remainder was produced and consumed simultaneously by the ZERH and therefore not accounted for in utility meter data. After accounting for this output, the ZERH annualized net utility energy consumption represented just 5% of the comparison home's utility energy consumption. Energy supplied to the grid was accounted for based on the net metering requirements in the state of Wisconsin, which changed during the project, affecting the ZERH owner's return on investment.

As shown in Figure 2, when accounting for gross solar generation on site, the ZERH consumed 130 MMBtu less than the comparison home.

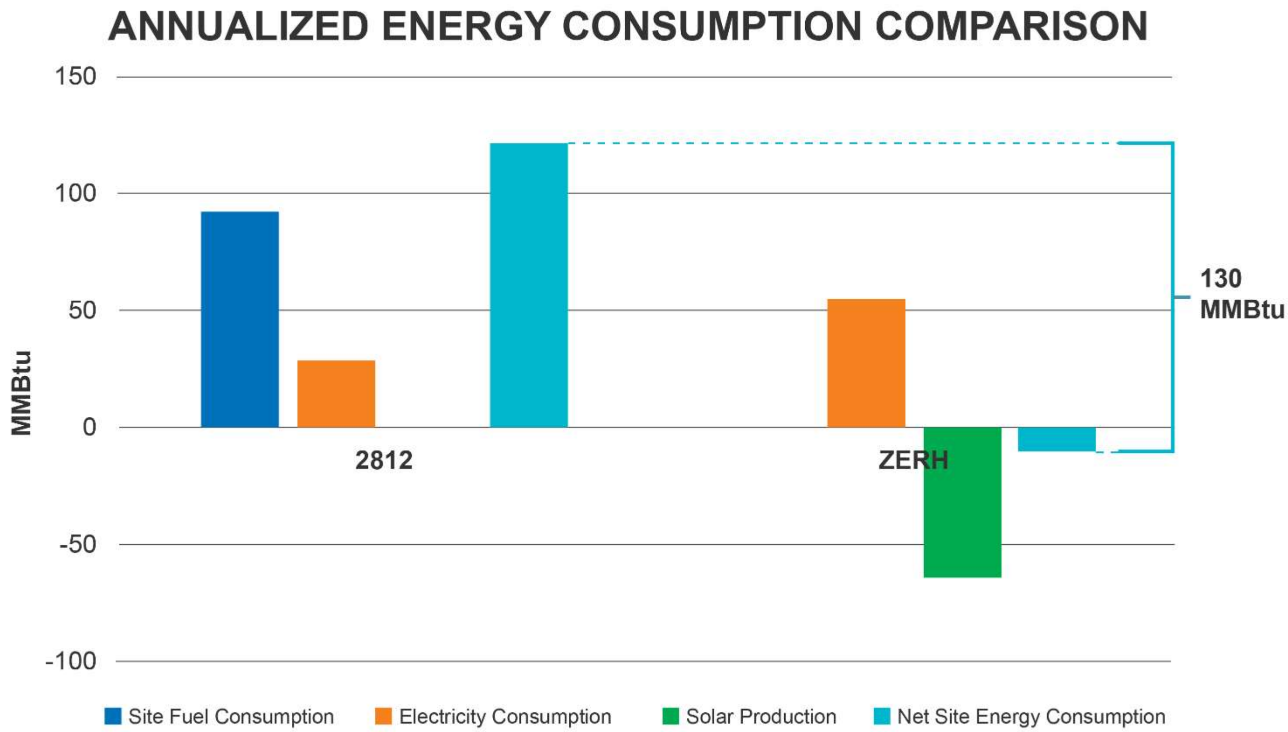

Figure 2. Comparing Annualized Energy Consumption of Two Homes. Since there are different heating fuels being used by the two homes the comparison of the two homes is made using net site energy consumption.

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

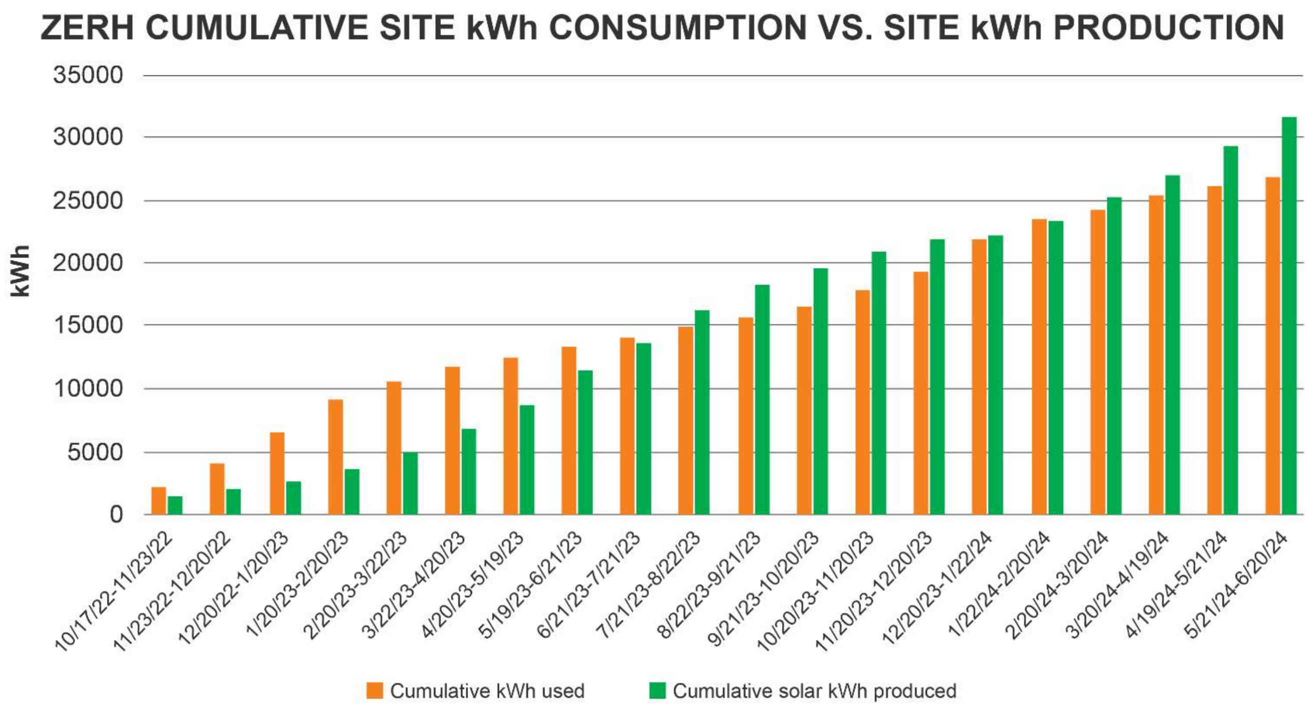

Figure 3. "Proving" Net Zero: ZERH Cumulative Site Electricity Consumption vs. Cumulative Site PV Production Reported by SolarEdge.

The 2812 home's natural gas and electric distribution costs were billed separately but combined in the homeowner's collected data. Fees for natural gas or electric service, grid or system connection, and other miscellaneous charges were reported by fuel type.

Compared to 2812, the ZERH incurred 10% higher[2] gross utility costs on an annual basis (Figure 4). However, credits for solar generation at the ZERH allowed for over $2,300 annual bill savings relative to the comparison home's total utility costs. According to the ZERH homeowner's billing data, the utility credited solar generation at a variable rate averaging 17 cents for the first year. After one year of service the utility initiated variable rate buy-back of overproduction monthly, which came to 4 cents per kWh on average in the first four months of overgeneration buy-back, plus 18 cents per kWh for generation covering electric consumption. The change from annual to monthly net metering calculations significantly impacts the economics of the ZERH's PV generation.

[2] 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.

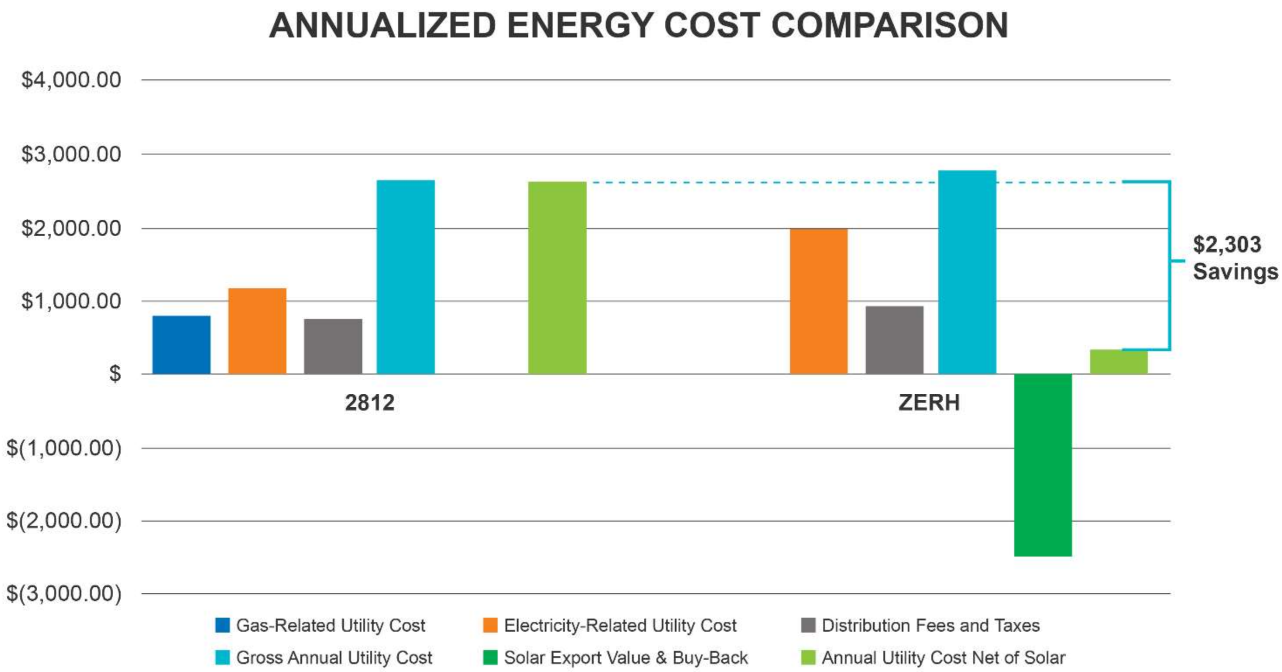

Figure 4. Comparison of Annualized Energy Costs for the Two Homes.

Carbon emissions associated with energy consumed or produced on site for these homes were estimated using the U.S. Environmental Protection Agency's Greenhouse Gas Equivalencies Calculator[3] and are summarized in Figure 5. Assuming solar generation at the ZERH site fully offsets carbon emissions of utility electric generation (one MMBtu of solar generation replaces one MMBtu of utility electricity), the ZERH home is estimated to avoid almost 10,000 kg of carbon annually relative to the comparison home, using these simplified emissions factors.

[3] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

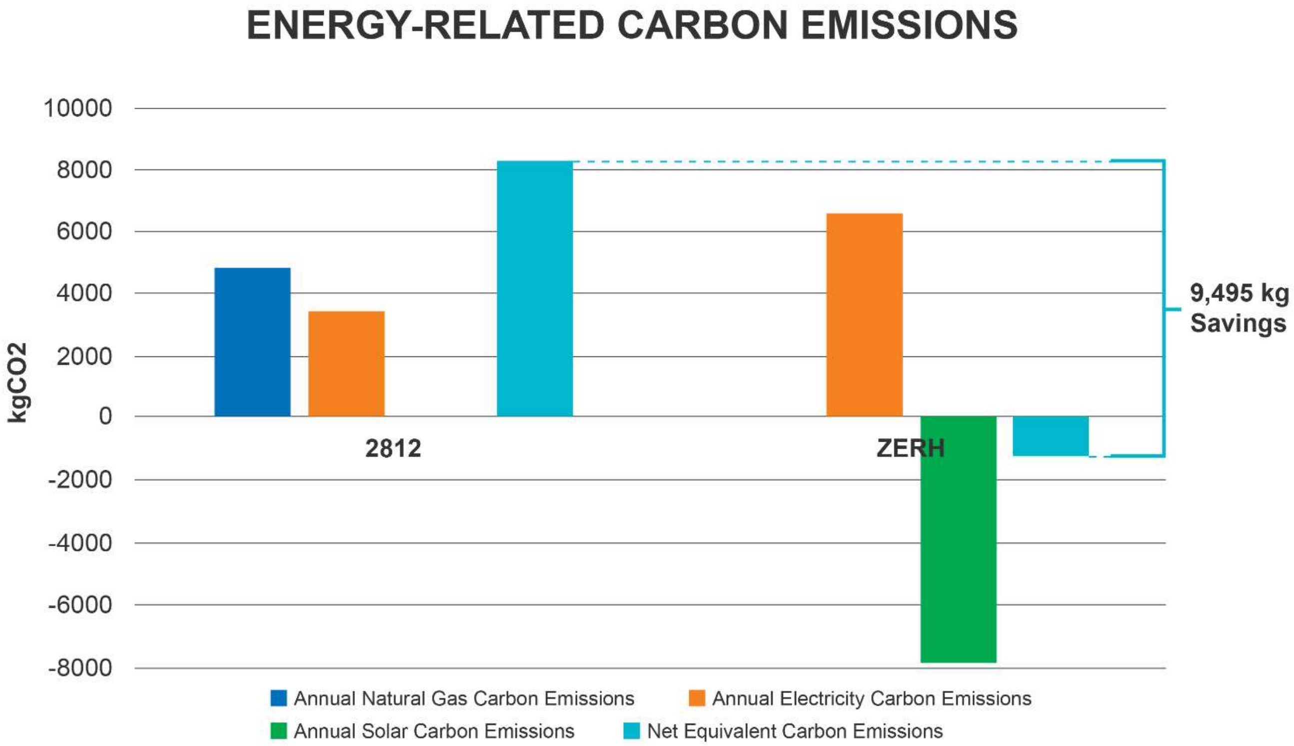

Figure 5. Comparison of Annualized Carbon Emissions Related to Site Energy Consumption.

The combined annualized energy, energy cost, and carbon emissions and savings enabled in the ZERH relative to 2812 are summarized in Table 2.

Annualized Home Performance Metrics	2812	ZERH	ZERH Savings
Gross Site Energy Consumption, MMBtu	120	54	66
Net Site Energy Consumption, MMBtu	120	-10	130
Net Utility Cost, $	$2,639	$336	$2,303
Net Carbon Emissions, kg CO_2	8,303	-1,193	9,495

Table 2. Annualized Home Performance Metrics Comparison.

Key Findings

- On the basis of equivalent energy units, the ZERH consumed less than half the annual energy than the 2812 home consumed before considering on-site electric generation, suggesting the zero energy ready design principles contribute to better energy and carbon emissions performance than a typical new home built to meet or exceed the Focus on Energy New Home Certification program.
- On the basis of energy costs, 2812's total utility bills are lower than the ZERH gross electricity costs before solar net metering is taken into account, possibly making zero energy ready design less appealing to future homebuilders who might not be ready to

invest in renewable generation technology. The future values of net metering, community solar, or other renewable energy purchasing arrangements, and heating fuel costs will all be important to the future of zero energy ready building.

COMPARING END USES VIA ENERGY METERS

Both homes installed Sense® energy monitoring systems which collects energy data from the main electric circuit and allocates the data to specific end uses based on observed patterns in consumption. Unlike utility data used for the earlier analysis, energy monitoring systems allow a homeowner to assess the impact of installed equipment on their home's energy consumption, possibly enabling opportunities to reduce usage with behavior or technology changes in the future. Additional sensors can be installed to get more detailed information on specific equipment which was the case for the ZERH which had individual sensors installed on the heat pump circuit to measure the heating and cooling usage. The Sense data results should be viewed as a preliminary estimate of a home's energy use.

The Sense data for 2812 allocated measured energy consumption among over 20 different end uses, including four "stove" loads, three unknown "heat" loads, and multiple small uses. To simplify the data summary, the top five major end uses were identified – Air Conditioning (AC), Always On, Dishwasher, Dryer, Energy Recovery Ventilator (ERV) and Furnace Fan; and all others were combined into "Other." Figure 6 represents the nine months of Sense data collected from the 2812 home in 2023 which has been annualized for comparison to June 2023-May 2024 data collected for the ZERH.

The research team observed the Sense 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 captured every end use at every hour. The large "Other" (light green) end use shown in Figure 6 may be overstated because it is calculated as the difference between the reported total home consumption annualized to 6,900 kWh and the sum of the top five defined end-use annualized consumptions, which include the "Always On" channel. Some of the annual usage currently counted as "Other" in the figure below could actually be "Always On" usage not identified by the Sense meter.

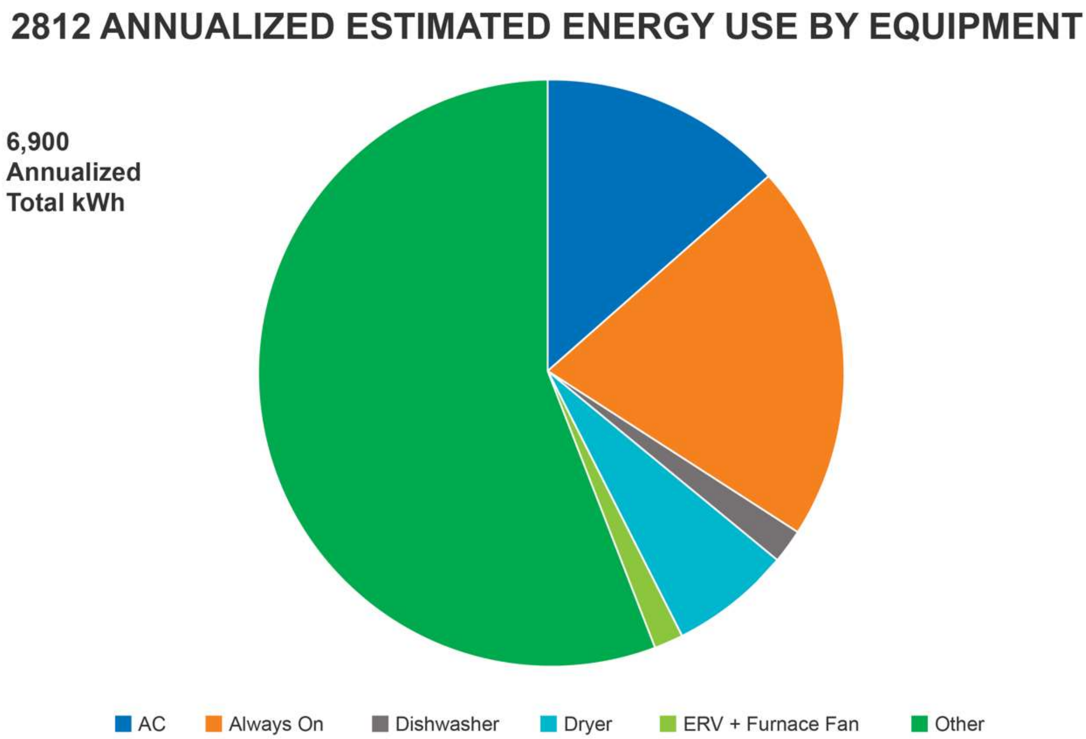

Figure 6. Annualized Energy Consumption by Major End Uses for 2812 Comparison Home.

More than 12 months of Sense data was available for the ZERH from two devices installed on the home's two panels, allocated to roughly 25 different end uses combined. As in the case of the Sense platform's allocations for 2812, the ZERH's estimated end uses included four loads defined as refrigerators, four loads defined as individual heat loads in addition to the measured heat pump, and other undefined uses. A detailed review of 2023 Sense data for ZERH, before the heat pump was separately monitored, suggests the heat pump usage was being allocated to "Always On." To isolate the heat pump over the 2023-2024 analysis period, the team annualized the 2024 heat pump consumption as measured by the newly installed sensor, and annualized the 2024 "Always On" data, excluding 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 load to 2812 energy use (Figure 7) and could benefit from further investigation by the homeowner to understand how Sense is defining this. It is not surprising the heat pump usage contribution is also significantly larger than 2812's air conditioning contribution to the home's energy use, since the ZERH is using the heat pump for heating and cooling. Interestingly, the ZERH began measuring a separate circuit for electric backup heat in January 2024 along with the heat pump – no energy use was reported on this circuit in 2024, implying the heat pump met the full heating load.

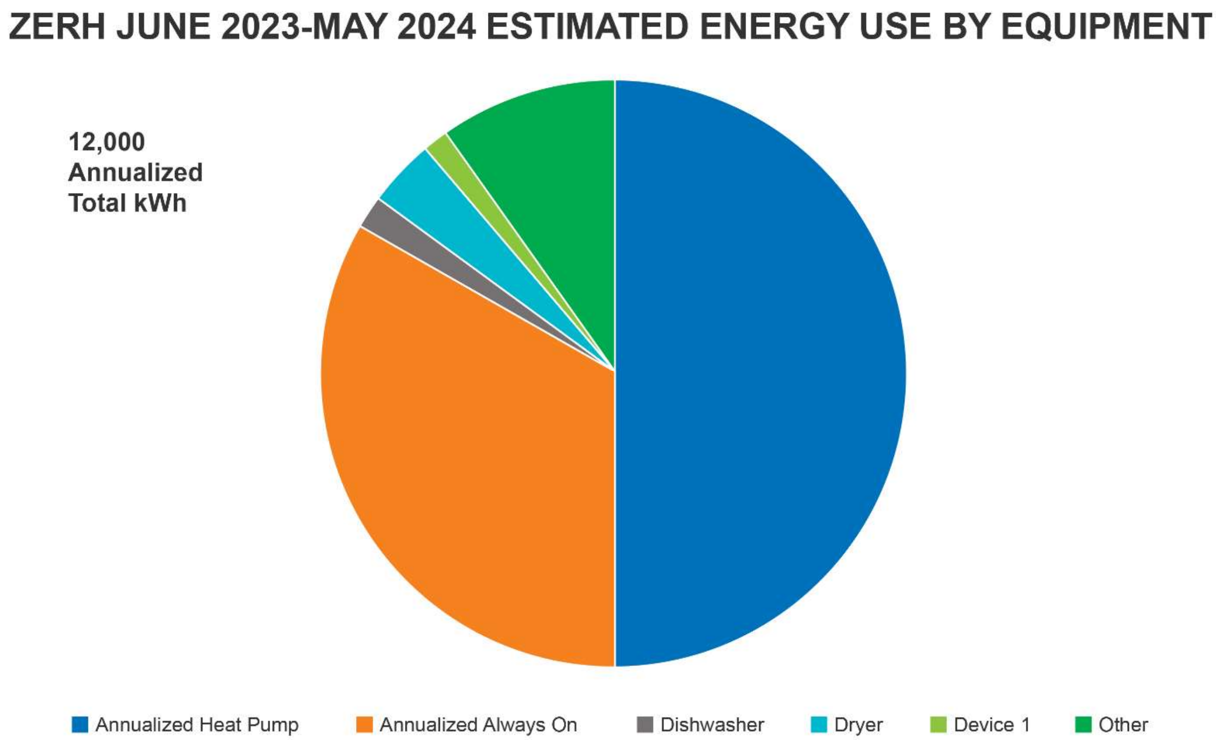

Figure 7. Electricity End Use Allocations. The ZERH "Device 1" usage was identified in the data as a furnace fan but is assumed to reflect the home's ERV.

Key Findings

Energy monitoring at an end use level, either with direct circuit measurement or with an automated analytical platform, can help a homeowner understand and investigate reasons for unexpected consumption patterns and improve their home's energy management. However, the homeowner should also be aware errors in meter set up, device outages, or automation methodologies will influence their apparent energy usage, so the data should be relied on to guide further exploration rather than trigger immediate decisions about equipment replacement or other changes.

The two largest ZERH home electrical annual kWh loads indicated by the meter are the heat pump and the "Always On" equipment. A plug-based meter could help identify and better control the "Always On" loads. Some metering manufacturers include options for adding low-cost plug-in outlet submeters to their system. These outlet meters can be moved around to find and measure "Always On" loads.

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 the original model predictions used to establish the size of on-site renewable energy systems enabling “zero energy readiness”. This comparison answers the following questions when predicting a home’s energy performance:

- 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?
- Is the building model good at predicting baseload energy use (the energy use that is not dependent on temperature or season) important to size the PV system correctly?

The answers to these questions impact the ability to cost effectively achieve zero energy ready performance using optimally sized renewable energy systems. Figures 8 and 9 illustrate the answers to these questions for this ZERH.

The original REM/Rate model of the ZERH energy usage developed for determining the size of the PV system[4] underestimated the home’s actual energy use as tracked by the Sense meter. Improvements to heat pump and baseload inputs to the original model, summarized in Table 3, resulted in an energy usage prediction more accurate for the home’s energy consumption.

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 platform. Energy monitoring data was compared to results from building energy modeling using REM/Rate home energy rating software which informed the design of the PV system, and the National Renewable Energy Laboratory’s OpenStudio building energy analysis platform with EnergyPlus™ simulation methodology. The initial REM/Rate models were subject to adjustments following a QA field audit after construction completion. The QA-adjusted inputs were then applied to the EnergyPlus methodology and additionally adjusted with default residential electric baseload energy usage calibrated to billed usage during non-heating/non-cooling periods, and detailed heat pump specifications replacing initial simplified assumptions.

[4] REM/Rate would typically be used to inform design of a PV system. However, the ZERH homeowner has advised that their solar contractor provided their own analysis and quote, which ultimately determined the PV system size.

As a result, three sets of hourly simulation results are available for comparison to the collected hourly consumption data[5] in Figure 8 for the ZERH.

Model Version	Input Data Source	Operational Conditions	Simulation Engine	Heat Pump Data
"REM Model"	REM User converted to HPXML[6]	REM	EnergyPlus	9 HSPF/16 SEER 32.8 kBtu heating capacity at 17 degrees 36 kBtu cooling capacity
"REM Model Field QA'd"	REM User Converted to HPXML with changes based on Site QA	REM	EnergyPlus	9 HSPF/16 SEER 32.8 kBtu heating capacity at 17 degrees 36 kBtu cooling capacity
"HPXML CH3 Model"	REM User Converted to HPXML with changes based on Site QA	Calibrated to Actual Loads	EnergyPlus	Equipment Specific from Air Conditioning, Heating and Refrigeration Institute (AHRI) certification directory

Table 3. Summary of the three ZERH Building Energy Models.

In Figure 8, total home electric energy usage simulated or measured in each hour is associated with an hourly temperature value[7] 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 temperature bins (under 5 degrees) or 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 having very few data points.

[5] Prior to January 2024, reported Sense meter 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.
[6] The REM to HPXML model transform used allowed the REM/Rate inputs to be directly utilized in the OpenStudio simulation platform.
[7] Local average hourly temperature data were accessed using the tomorrow.io API.

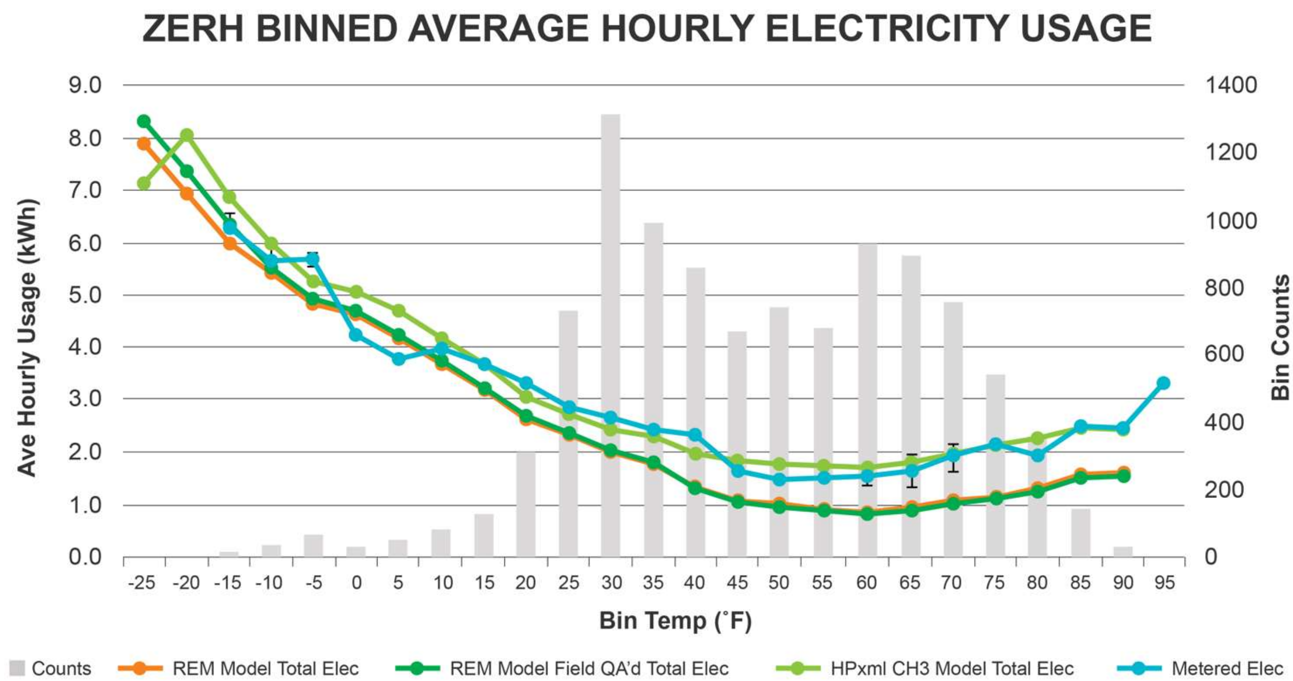

Figure 8. ZERH Average Hourly Electric Usage by Temperature Bin - Simulation Results vs. Actual Measurements

The REM/Rate models both before and after QA adjustments (orange and green lines in Figure 8) underestimate the actual home energy usage (blue line labeled Metered Elec) consistently across all temperatures. This suggests the default assumptions used in REM/Rate underestimate the real baseload energy consumption of the home. If we assume a home temperature set at 60 degrees has virtually no need for energy use in heating or cooling, we can assume the home's average hourly energy use of 1.5 kWh at that temperature represents the hourly baseload use. The REM/Rate QA model predicted an average of 0.8 kWh at 60 degrees, underestimating actual energy use by 0.7 kWh. If average hourly baseload is constant over the year, the REM/Rate model would have missed over 6,000 kWh per year – requiring the equivalent of 30 additional square meters of solar panels[8]. This represents 31% of the installed system size.

The final calibrated model results (green line labeled HPxml CH3 Model Total Elec in Figure 8) very closely fit hourly kWh measurements (blue line labeled Metered Elec) across most temperature bins shown. The more significant differences between the average hourly meter usage and the model results below 10 degrees may be a result of the small number of data

[8] According to the National Renewable Energy Laboratory's 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.

points available at those temperatures. Baseload calibration plus heat pump specification adjustments in the OpenStudio simulation resulted in a model appearing to fit the meter data well in all except rare extreme cold conditions.

The absolute error between the binned average final model kWh and the binned average meter kWh, as a percentage of the actual (metered) hourly usage, ranges from 0% to 23%. The overall average percent error between averaged hourly metered kWh and final calibrated model kWh, calculated as

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

is 4%, whereas the same calculation for the REM/Rate model with field QA results in 21% error. The final model run in OpenStudio therefore appears to represent actual usage reasonably well after calibration.

Key Findings

The original REM/Rate building energy modeling software typically used for designing on-site renewable generation systems underestimated baseload energy consumption not directly dependent on outdoor temperatures and would have resulted in a PV system not capable of serving the ZERH's actual needs. Increasing the baseload consumption in the model by calibrating to actual consumption data, and more detailed analysis of the heat pump system using National Renewable Energy Laboratory (NREL) Energy Plus energy modeling methodology resulted in predicted ZERH energy consumption aligning closely with its actual energy use across most cold climate temperatures.

ZERO ENERGY READY HOME MODEL VS. METER HEATING AND COOLING ENERGY USE

In a climate with cold winters and hot summers like Wisconsin, energy used in heating and cooling is often the biggest contributor to residential energy consumption and to peak energy loads. Understanding the ZERH electric heat pump energy use relative to design predictions is therefore important for assuring the ZERH usage will not exceed planned site generation.

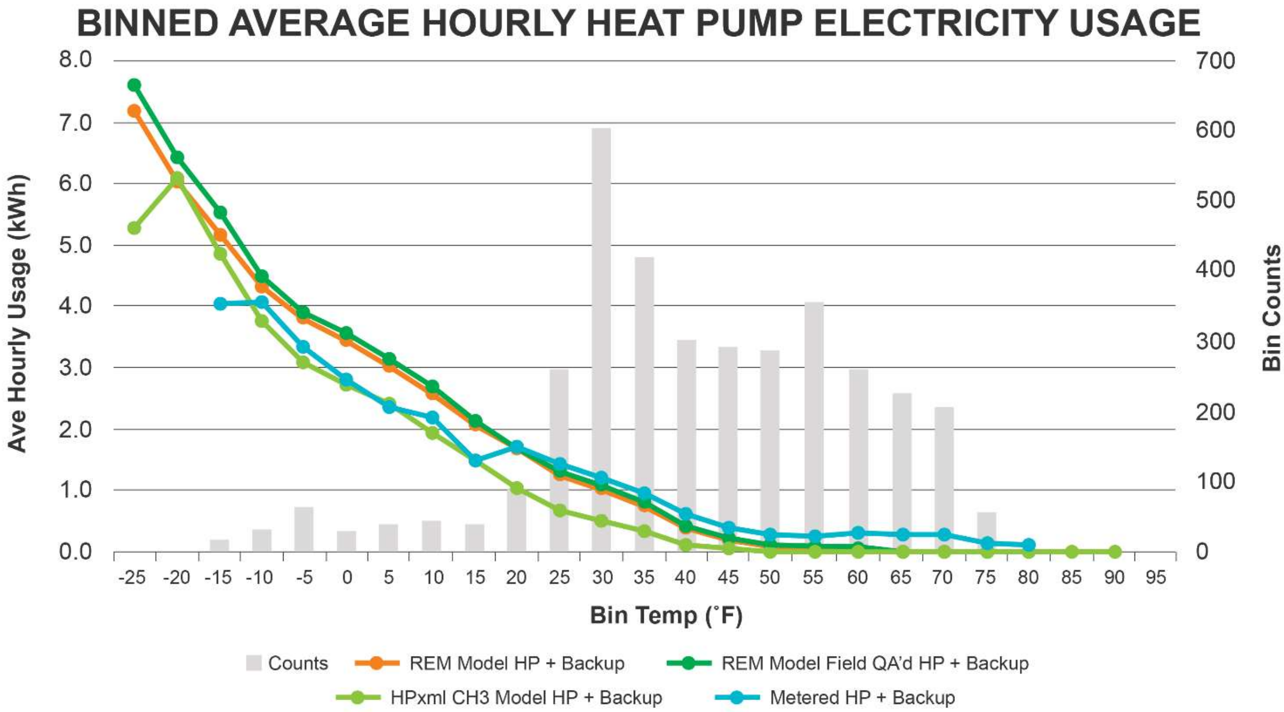

Figure 9. ZERH Average Hourly Electric Heating Usage and Coefficient of Performance by Temperature Bin.

Figure 9 compares the average energy use of the ZERH heat pump system according to different model versions or measured by the Sense sub-meter installed January 9, 2024, (blue line). The final heat pump simulation results (green line labeled HPxml CH3 Model HP + Backup in Figure 9) are lower than the actual installed heat pump energy use at moderate heating temperatures (above 20 degrees to 50 degrees). This could suggest the installed heat pump is oversized for moderate temperature operation, and perhaps another heat pump could have been selected to operate at these temperatures using less energy and therefore reducing utility costs.

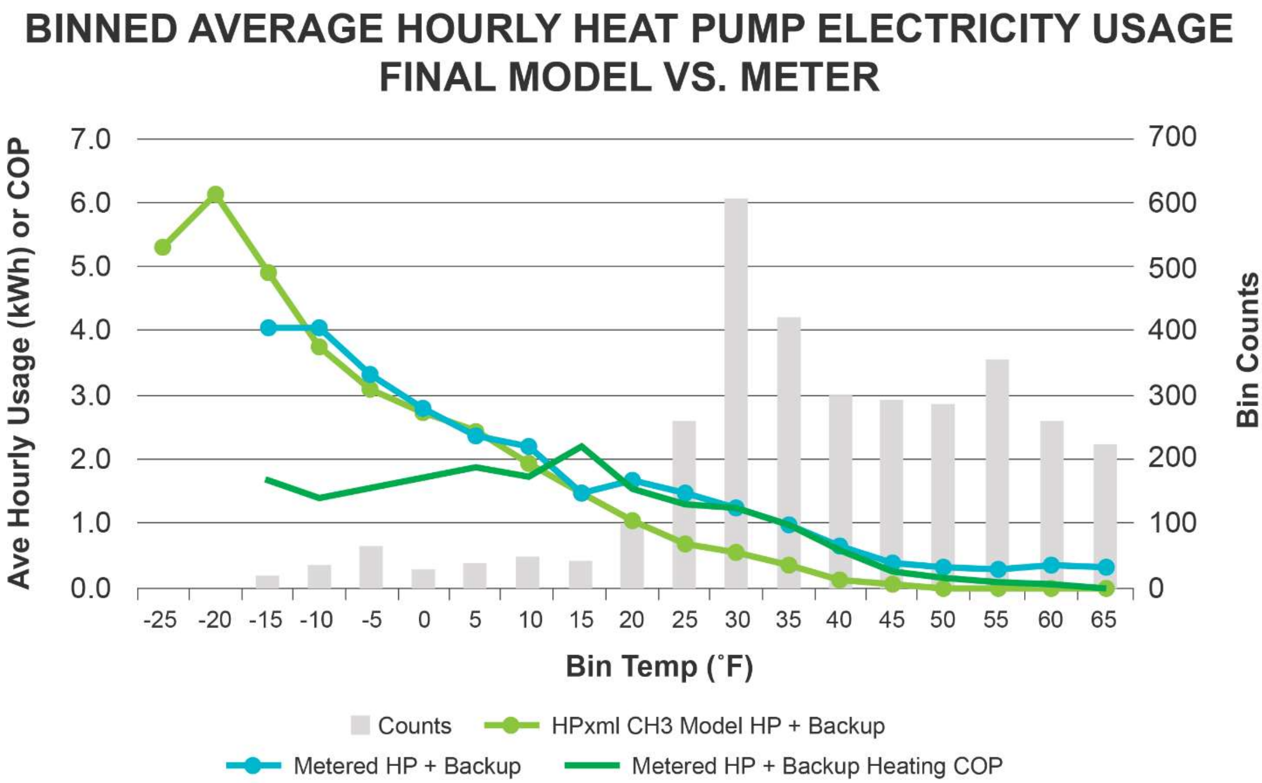

Figure 10. Heat Pump Average Hourly Electricity Usage - Final Model vs. Meter with Calculated Average Heating Coefficient of Performance (COP) per Temperature Bin.

In very cold conditions, the actual heat pump average hourly usage aligns well with the final simulation; Figure 10 shows a clearer view, including heating coefficient of performance (COP), a heat pump efficiency metric calculated with hourly Btu heating load divided by the heat pump measured hourly energy use in Btu (green line). The divergence of the meter and the model results below -10°F degrees is likely a result of minimal available data points in those temperature bins.

The comparison of heat pump electricity usage as modeled for equipment design and selection, and as measured following installation, is highly beneficial for any stakeholder considering participating in or supporting a ZERH certification program, especially in a cold climate where heating energy is a significant contributor to whole home energy use. Table 4 compares the design heating loads for the ZERH according to the initial REM/Rate model and the final OpenStudio model, as well as comparing the proposed initial heat pump capacity and final selected heat pump capacity. The initial REM/Rate model expected the home's heating requirements to maintain comfort at -2.92°F degrees would be over 34,000 Btu, while the final calibrated model estimated the home's heating requirements at this temperature to be slightly under 33,000 Btu. This is not a large differential, but the counts of usage measurements occurring in these very cold temperatures are low.

Model Version	Btu
REM/Rate Specified Heat Pump Capacity at 17°F	32,800
Actual Heat Pump Tested Min/Max Capacity at 17°F	9,500/37,000
REM/Rate Design Heating Load at -2.92°F	34,633
Post-calibration Final Design Heating Load at -2.92°F	32,932
Interpolated Heat Pump Max Capacity at -2.92°F	33,744

Table 4. ZERH Design Heating Load and Capacity in Two Model Versions.

It could be assumed at moderately cold temperatures, experienced more frequently in Wisconsin's heating season, the home's heating requirements would typically be lower, creating an opportunity to choose a lower-capacity heat pump with good capacity modulation. The installed heat pump as documented in the final OpenStudio calibrated simulation was manufacturer-tested to deliver 37,000 Btu at 17 degrees F – which is more capacity than needed to cover the final calibrated home design heating load. The heat pump manufacturer also provides maximum capacities of 37,000 Btu tested at 5 degrees F and 29,600 Btu at -13 degrees F; interpolating between those, the installed heat pump is expected to have a heating capacity at -2.92 degrees F exceeding the design heating load by about 2%.

However, review of the analyzed metering data relative to published heat pump performance curves indicates that the ZERH requires an average of 9,500 Btu at roughly 17 degrees F. The calculated average nighttime[9] COP per temperature bin shows the COP increases as outside temperatures decrease, up to roughly 17 degrees F. This implies the equipment is continuing to require cycling on and off to control the load at outside temperatures above 17 degrees F. The minimum capacity of the heat pump at 17 degrees F is 9,500 Btu per hour. That value can be used as roughly the average real load of the ZERH at that temperature.

Design loads are calculated without internal or solar gains. In a ZERH with significant "Always On" loads (generating heat) and a tight well insulated house, the actual loads experienced by the heat pump will be significantly less than the design loads. In this case, the average hourly internal gains calculated from the Sense meter data are 1.5 kWh or roughly 5,100 Btu per hour more than 50% of the minimum capacity of the heat pump. The Sense meter estimates more than 2/3 of these gains are always on, day and night. The meter data combined with modeling data show these internal gains, plus solar gains, significantly reduce the real load experienced by the heat pump.

Based on a design indoor temperature of 70 degrees F, and a design load of 33,000 Btu per hour at -3 degrees F, the heat pump would be expected to reach minimum capacity of 9,500 Btu per hour at an outdoor temperature of 49 degrees F. The meter data shows the house is

[9] The COP performance ratio calculated at night will not be impacted by solar gains, which can significantly reduce daytime mechanical heating inputs.

just beginning to require heat at 50 degrees F and the minimum capacity is likely reached at around 17 degrees F outdoor temperature. Most of the annual heating energy required by the ZERH is occurring in this temperature range. Because of the impact of these gains on equipment performance, ZERHs will require more careful selection of heat pumps.

Key Findings

The ZERH installed heat pump performed as predicted by the final calibrated model in cold winter temperature conditions but used more energy than predicted in more frequently experienced moderate winter temperatures. This suggests the modulating heat pump capacity at these temperatures may be oversized, frequently cycling off and on, requiring frequent bursts of high start-up energy. The Energy Plus modeling methodology used accounts for heat pump maximum and minimum capacities and tested efficiencies at varying temperatures, to correctly model equipment across the full range of cold climate operations.

Using the meter data, the installed heat pump's calculated COP peaks at 15°F degrees and drops off in more moderate or colder temperature operation. A slightly smaller heat pump with better moderate temperature performance and a lower minimum capacity (to reduce the hours when cycling on and off is required to modulate the heat pump output) would have saved more energy by increasing the COPs at milder outdoor temperatures where most heating is taking place. More accurate consideration of internal gains will also help with heat pump selection.

CONCLUSIONS AND RECOMMENDATIONS

Understanding the ZERH electric heat pump energy use relative to design predictions is therefore important for assuring the ZERH usage will not exceed planned site generation.

The study of ZERH performance relative to a standard efficient built home offers several takeaways for Focus on Energy new home certification program:

- The ZERH as built can offset its annual energy consumption with its own on-site PV generation and is consuming less than half the annual energy the comparison home is consuming. Carbon savings are also significant.
- Net metering changes from annual to monthly net calculations have a significant impact on ZERHs, especially if installed renewable energy systems are oversized. Under the current rules, oversizing of solar systems will be more penalized (pay off slower) due to lower kWh payments from the utility to the homeowner. During the winter months, electricity usage (for heating) will outpace solar generation making the home more expensive to operate if generation can't offset consumption.

- Building energy modeling software is valuable for predicting home energy usage, whether for claiming program savings, designing on-site generation or other major systems, or understanding future home energy costs. However, model inputs should be adjusted to improve accuracy of those predictions – especially to increase expected baseload energy assumptions.
- Home energy monitoring and sub-metering of major equipment such as heating equipment in a cold climate can provide confidence in energy modeling results and help identify possible performance issues.
- Extremely cold temperatures are now less common, increasing the need to more carefully consider mild temperature heat pump COP performance. Consider heat pumps offering a combination of good capacity modulation and strong mild temperature COP performance, using a detailed energy simulation of heat pump performance done during the design phase.
- When choosing the design load capacity of heat pumps, contractors should consider the significant contribution of internal gains and solar gains on the heat pump load and the role these gains play in reducing the risk of not meeting the heating load at design temperatures.
- Both prospective ZERH homebuyers and the professionals supporting them (builders, raters, and HVAC contractors) can benefit from more information on the economics and how ZERHs perform thermally in Wisconsin, with Wisconsin’s unique combination of net metering laws and weather. This analysis can provide direction for the development of more consumer-facing content.