Pacific Northwest
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PNNL-65720

Zeroing in on Key Features of DOE Zero Energy Ready Homes

July 2024

Miles C. Weatherman

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Abstract

The U.S. Department of Energy (DOE) conducts the DOE Zero Energy Ready Home (ZERH) Program to encourage U.S. home builders to construct above-code homes that are so energy-efficient, that they can offset all the energy they use over the course of a year with just a few solar panels. To recognize outstanding Zero Energy Ready Homes, DOE conducts the annual Housing Innovation Awards (HIA). Pacific Northwest National Laboratory (PNNL) supports the program by gathering energy costs and savings data on each winning home, along with details on the energy-efficient aspects of the assembly (foundation, floors, wall, openings, attic, and roof), heating, cooling, electrical, and plumbing systems, as well as appliances and lighting. These details of each HIA winner are collected and assessed in a tracking spreadsheet. The program has expanded over time, growing from 131 homes certified in 2013, to 2,562 homes certified in 2023, and a total of 23,837 projects certified over the life of the program, including production, custom, affordable, and multifamily homes. PNNL's data collection and reporting efforts are encouraging more builders to try out the DOE Zero Energy Ready Home program and are supporting the adoption of higher performance energy codes across the country. As climate change continues to affect our shared environments, reducing carbon emissions and defending against natural disasters is a necessary adaptation for our homes. The ZERH program is a step in the right direction for sustainability and self-sufficiency, and up keeping the program is important for adapting to the future. This research paper aims to define and highlight how each new key feature contributes to a zero energy ready home.

Acknowledgments

For my acknowledgments, I would like to recognize my mentor, Theresa Gilbride. She is truly an expert in the field of energy efficiency and construction, and it has been an amazing opportunity to work with her this summer. I have learned a lot this summer and have finally had the ability to pursue professional work and research in the field of building science. I will absolutely recommend the SULI internship to other students, and I hope they will have the same opportunity that I got to have here at PNNL.

Acronyms and Abbreviations

ACH50	Air Changes per Hour at 50 Pascals
CMU	Concrete Masonry Unit
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ERV	Energy Recovery Ventilator
HIA	Housing Innovation Awards
HRV	Heat Recovery Ventilator
HVAC	Heating, Ventilation, & Air Conditioning
ICF	Insulated Concrete Form
MEP	Mechanical, Electrical & Plumbing
PNNL	Pacific Northwest National Laboratory
SIP	Structural Insulated Panel
SULI	Science Undergraduate Laboratory Internship
TOZ	Tour of Zero
ZERH	Zero Energy Ready Home

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1.0 Introduction

This research paper defines all twenty-two new key features that are used to evaluate the Housing Innovation Award (HIA) winners of the U.S. Department of Energy (DOE) Zero Energy Ready Home Program (ZERH). These key features are divided into the four categories: building envelope, HVAC, electrical, and plumbing. Each one of these categories plays a crucial in role ensuring that a house is capable of consuming minimal amounts of energy while also being able to produce the same amount of energy to offset the annual consumption. Energy efficiency is the name of the game, and every step of the design and construction process must be meticulously executed so that ZERH homeowners can live comfortably and sustainably.

For the majority of my time this summer working with Pacific Northwest National Laboratory (PNNL) through the Science Undergraduate Laboratory Internship (SULI) program, I have been compiling all the details for the 354 HIA winners, from 2013 to 2023, in an excel spreadsheet that will show how many key features are included in each HIA project. The Tour of Zero (TOZ) website has been recently updated to filter HIA projects with the key features that are a part of a project. So, researching, defining, and categorizing each key feature was an important part of accurately evaluating all HIA winners.

1.1 DOE ZERH Program Overview

“A DOE Zero Energy Ready Home is a high-performance home that is so energy-efficient that a renewable energy system could offset most or all the home's annual energy use.” (DOE, n.d.) Zero Energy Ready Homes are not required to have solar panels installed before being sold or completed, but they do have to be structurally engineered and wired in for future installation of solar panels. To recognize outstanding Zero Energy Ready Homes, DOE conducts the annual Housing Innovation Awards. Every year the TOZ webpage is updated with posters for each HIA winner that includes pictures and important project details. PNNL supports the program by gathering energy costs and savings data on each winning home. Also, the details of the assembly and mechanical, electrical, and plumbing (MEP) systems of each HIA winner are collected and assessed in a tracking spreadsheet. Starting in 2013 with 131 homes certified, the program has grown to 2,562 homes certified in 2023, and a total of 23,837 projects certified over the lifetime of the program. This includes production, custom, affordable, and multifamily homes. Other programs that coincide with the ZERH program, from the U.S. Environmental Protection Agency (EPA), are the ENERGY STAR Single-Family New Homes, Indoor airPLUS, and WaterSense.

2.0 Building Envelope

The building envelope consists of the foundation, floors, walls, and roof. The design, materials, and assembly of the foundation, walls, openings, and roof is crucial for creating an effective thermal envelope that reduces energy consumption and keeps unwanted air and water out of the house. Below is a list of all key features that are associated with the building envelope.

- Insulated Concrete Forms (ICF)
- Structural Insulated Panels (SIP)
- Staggered stud
- Double wall
- Raised-heel trusses
- Triple-pane windows
- Continuous exterior rigid board insulation
- Draft-free, airtight construction (Air Changes per Hour at 50 Pascals (ACH50) < 2.5)

Figure 1: Red Tree Builders, Wandering Oaks: 2x6, 24" o.c. Wall Assembly

Utilizing insulated concrete forms, structural insulated panels, staggered studs, double walls, or a continuous exterior rigid board insulation will create a continuous layer of insulation. This is important because a break in the insulation, like studs in conventional stick framing, introduces thermal bridging, which allows heat to enter and escape the thermal envelope. The image to the right is an example of 2x6 stick framing, which provides more space for insulation in the cavities than 2x4 stick framing, but without continuous rigid board insulation, the studs are a thermal break and allow for thermal bridging. ICFs are similar to conventional concrete masonry units (CMUs), except that ICFs are blocks of two pieces of foam board held together and snapped into place with plastic attachments. Once all the ICF's are in place, rebar is installed, and concrete is poured in between the two pieces of foam mentioned before. SIP walls and roofs are made up of foam insulation sandwiched between two pieces of sheathing. Staggered stud walls use a sill plate larger than the studs so that the studs can alternate side to side of the wall. This allows insulation to fill the areas where thermal bridging occurs where studs are conventionally placed. Double walls are exactly what it sounds like, two layers of conventional stick framing are used to increase the thermal boundary. Raised-heel trusses extend the exterior walls up from the top plate, so that the entire

roof is raised and allows room for insulation. This prevents thermal bridging from breaching through the top of the wall assembly where the top plates conventionally meet the roofing assembly. Triple-pane windows are made of three panes of glass typically filled with argon gas that acts as an insulator while still allowing natural light into a home. Draft-free, airtight construction means that a home has been properly air sealed and has used a blower door test to determine the air changes per hour at 50 pascals.

2.1 HVAC (Mechanical)

HVAC is an acronym for heating, ventilation, and air conditioning. The capability and efficiency of an HVAC system is important for maintaining indoor air quality and comfort. Heating and cooling systems will typically consume the most amount of energy than any other electric systems in a home. So, installing a properly sized and energy-efficient HVAC system is a very important part of qualifying for the ZERH program. Below is a list of key features associated with HVAC.

- Air-to-water heat pump
- Cold-climate heat pump
- Ground-source heat pump (Geothermal heat pump)
- Variable-speed heat pump
- Heat pump water heater
- Energy Recovery Ventilator (ERV)
- Heat Recovery Ventilator (HRV)
- Sensor-controlled ventilation

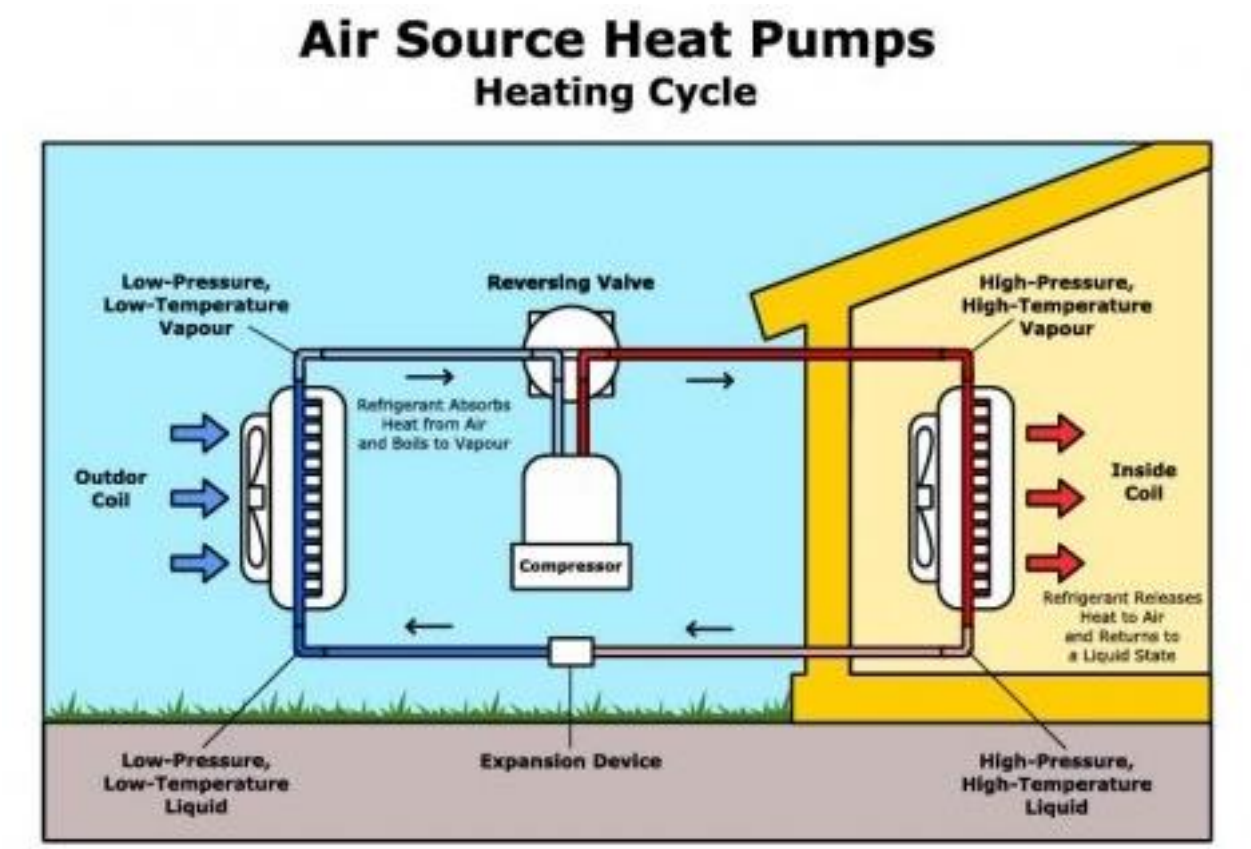

Figure 2: U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy "Air-Source Heat Pumps"
https://www.energy.gov/energysaver/air-source-heat-pumps

The Air Source Heat Pump diagram shows how refrigerants flow through a system to extract heat from the atmosphere and transferred into the house. This process can be reversed to extract heat from inside the house and into the atmosphere. An air-to-water heat pump uses the same refrigerant flow system but extracts heat from the atmosphere and transferred into hot water. Ground-source heat pumps uses water or a water and glycol mixture that cycles through an underground closed loop system to take advantage of constant temperatures ranging from 40 degrees Fahrenheit to 70 degrees Fahrenheit. A variable speed heat pump means that the heat pump can run at varying speeds and run continuously instead of just turning on and off at one speed. An energy recovery ventilator and heat recovery ventilator function similarly in that they retain heat from exhausted indoor air and transferred to incoming outdoor fresh air. The only difference is that an energy recovery ventilator doubles as a dehumidifier and a heat recovery ventilator does not. Sensor-controlled ventilation comes in many forms, whether that sensor is for carbon dioxide, carbon monoxide, humidity, particulate matter, or motion detection. Each type of sensor aims to inform a ventilation system that indoor air needs to be ventilated for comfort and safety.

2.2 Electrical

The next largest power consumers in a home are appliances and lighting. Every zero energy ready home is required to use energy star rated appliances. Below is a list of the three key features associated with electrical systems.

- Photovoltaics (solar panels)
- Battery storage
- All-electric

As mentioned before, all zero energy ready homes are designed for future installation of solar panels if they are not installed already. Battery storage is completely optional but is necessary if the buyer wants emergency energy storage, or if they want to be off the grid. To be able to use exclusively renewable energy, a house must be an all-electric home. Which means no propane, natural gas, or any kind of combustion appliances. The diagram below shows a grid connected residential photovoltaic system. The diagram does not show some essential components, like a charge controller and disconnects, but it does give a general idea of how power moves through the system.

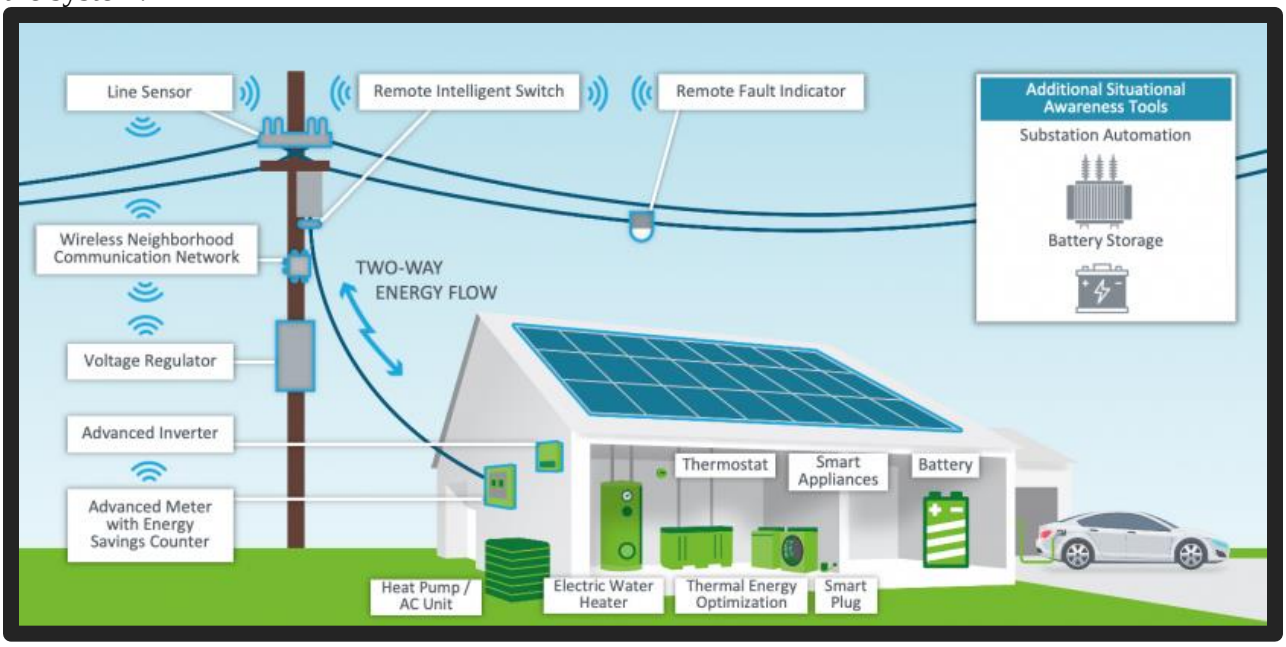

Figure 3: U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy "Solar Grid Planning and Operation Basics"
https://www.energy.gov/eere/solar/solar-grid-planning-and-operation-basics

2.3 Plumbing

Water heating is an important part of making a house energy-efficient. This is because conserving and recycling hot water reduces energy consumption. Designing a plumbing system to be as compact and centralized as possible is a great way to reduce the power consumption

required to pump hot water throughout a house. Below is a list of key features associated with plumbing.

- Compact plumbing design
- Central manifold plumbing
- Recirculation pump

The image below is an ideal example of what a central manifold distribution system should look like using PEX piping. Recirculation pumps will pump back any unused hot water left behind in pipes and has a constant circulation of hot water that provides quick access to hot water. Anyone interested in water conservation and efficient water fixtures should look into WaterSense resources and labeled products. And even though water conservation may only be a concern for certain climate zones, there is also potential for energy savings sense electric water heaters

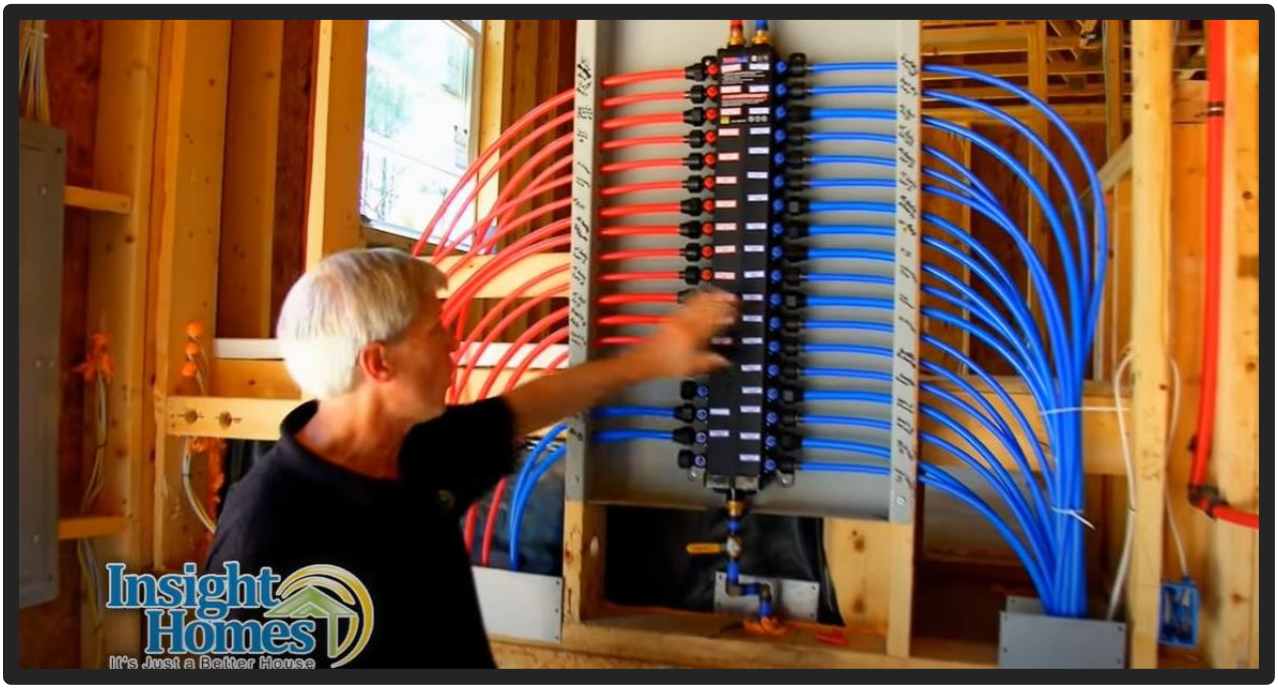

Figure 4: U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy "Core and Manifold Plumbing"
https://basc.pnnl.gov/resource-guides/core-and-manifold-plumbing#edit-group-training

consume a lot of power. Because after all, electric resistance heating is 100% efficient, but that doesn't mean that it is cost effective.

3.0 Conclusion

To conclude, all four categories are crucial parts of a whole zero energy ready home. The building envelope acts as the first line of defense for providing shelter and comfort. Also, it is important to note that a proper barrier to the outside world is crucial for all other building systems to function effectively. HVAC systems consume the most amount of energy, therefore, it is important to size your systems effectively and utilize energy-efficient systems. Solar panels are absolutely needed for a home to be able to produce the amount of energy it consumes. ENERGY STAR rated appliances will help to reduce the amount of energy consumed and subsequently the amount of energy needed to produce is also reduced. Hot water can be conserved and recycled by utilizing WaterSense labeled products and guidelines, so that the energy used to heat water is not wasted.

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