

DOE's Zero Energy Ready Home Program: Getting Builders from Code to Net Zero and Beyond

*Jaime Van Mourik, U.S. Department of Energy
Theresa L Gilbride, Pacific Northwest National Laboratory*

ABSTRACT

The U.S. Department of Energy's Zero Energy Ready Home Program has helped over 700 home builders go beyond code to construct more than 10,000 zero energy ready homes. Several states have recently adopted zero energy ready home requirements as a mandatory or stretch residential code (Berg, Cooper, and DiMascio 2022; Carbonnier 2021). For builders looking to navigate their way through this unfamiliar territory, DOE's Zero Energy Ready Home (ZERH) Program offers both map and compass. This paper describes the requirements of the DOE ZERH program and provides a comparison between the original program requirements of version 1 of the program and those of version 2 (DOE 2022b), which is likely to be released in late 2022. Case studies provide examples of builders in each Building America climate region across the country who are successfully building ZERH residences of all types and budgetary constraints that already meet the requirements of version 2 of the DOE program. These case studies lend transparency to how the zero energy ready requirements can be achieved, including choices in energy-efficiency measures implemented at various cost premiums, as well as energy savings that might be anticipated from certification in the DOE ZERH program. The visionary early adopters of DOE's ZERH program can serve as valuable role models to educate a broader national building community on how to design zero energy ready homes for diverse project types and climates and provide transparency on the economics of ZERH projects.

Introduction

The DOE Zero Energy Ready Home (ZERH) program is the U.S. Department of Energy's (DOE's) rigorous high-performance home program (Werling et al. 2021). These homes combine an energy-efficient envelope and equipment with deliberate site selection, building orientation, and roof design so that a solar photovoltaic (PV) system can generate all or most of the electricity the home uses in a year. More than 10,000 homes have been certified through the program since its inception in 2013, based on program data (DOE 2022a). This paper describes current requirements of the DOE ZERH version 1 and proposed requirements of version 2. Case study examples are provided of homes built by participating builders that would already meet the requirements of version 2 to illustrate choices that could be made by builders in terms of wall type, HVAC, and mechanical systems to meet the new DOE program requirements. These case studies reflect a variety of climate zones, construction types, and categories (including production, affordable, multi-family, and custom).

BACKGROUND

The DOE Zero Energy Ready Home Program is a high-performance home labeling program that provides a certification for homes that meet certain requirements enabling them to be zero energy ready. These homes are constructed to be so energy efficient that a small amount of renewable energy resources (typically solar PV panels) will enable the home to achieve net zero energy – a home that produces as much energy as it consumes over the course of the year (Carbonnier 2021). DOE provides one definition for a zero energy building (ZEB) as “an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy” (NIBS 2015).

The program does not require that PV panels be installed at the time the home is turned over to the home owner but the home must be constructed to be solar energy ready, with conduit installed from the roof to the electric panel and space next to the electric panel for the installation of solar power inverters. To certify a home as DOE ZERH, the builder must have the home assessed by an independent third-party verifier (such as a RESNET-certified rater) who will test whole-house air leakage and confirm that other program requirements have been met. The rater will also perform energy modelling (using a software such as REM/Rate or Ekotrope’s RATER) to determine a target Home Energy Rating System (HERS) score for the home. The ZERH program does not specify a maximum HERS score for all homes. Rather, the rater models a “target home” that is geometrically identical to the home to be built, but with an envelope assembly and mechanicals that match the program’s target home prescriptive requirements (DOE 2019) then determines a target HERS score for that home which the builder must meet with the actual home.

The requirements of the DOE Zero Energy Ready Home program were first put forth in 2013 and have undergone slight revisions since that time. The current version, revision 07, was issued May 1, 2019. To keep pace with increasingly stringent energy codes and advanced building technologies, and to continue to boost efficiency and reduce greenhouse gas emissions from new U.S. homes, DOE is in the process of developing ZERH Version 2. DOE released version 2 of the DOE ZERH Zero Energy Ready Home National Program Requirements for Single Family Homes for stakeholder feedback in November 2021. The public comment period concluded in spring of 2022 and DOE is now reviewing all submitted feedback, addressing comments, and editing requirements as needed (DOE 2022b).

DOE ZERH Version 2 (V2) was developed in coordination with updates to the U.S. Environmental Protection Agency (EPA)’s ENERGY STAR Residential New Construction and Indoor airPLUS programs. DOE ZERH V2 will build upon ENERGY STAR’s most stringent version (V3.2), which is also in draft stage and was released for stakeholder comment October 18, 2021. DOE ZERH V2 is also based on EPA’s Indoor airPLUS requirements, which are also undergoing revision. The new DOE ZERH V2 is anticipated to be released in fall 2022. DOE will provide a transition period from V1 to V2 of at least 9 months, during which V2 may be used by builders on an optional basis (DOE 2022b).

The mandatory requirements of version 1 and proposed for version 2 of the DOE ZERH National Program Requirements are shown in Table 1. A summary of significant changes is provided in Table 2. Significant enhancements in ZERH V2 include boosting minimum insulation levels to align with the 2021 International Energy Conservation Code (IECC), including thermal breaks in above-grade walls in mixed and cold climates, achieving a more

stringent efficiency threshold (ERI targets in the 40s), expanding the use of PV-Ready features, and integrating properly designed MERV 13 filtration consistent with U.S. Centers for Disease Control and Prevention (CDC) and ASHRAE guidance (DOE 2022b).

Table 1. DOE ZERH Mandatory Requirements Version 1 and Draft Version 2 (DOE 2019, 2022b)

Version	Version 1 (current)	Version 2 (Draft)
Mandatory Requirements		
ENERGY STAR for Homes	► Certified under ES V 3, 3.1, or 3.2 or ES Multifamily V 1.0 or 1.1, depending on state	► Certified under ES New Homes V 3.2
Envelope	► Meet 2015 IECC insulation levels. ► Install ENERGY STAR windows.	► Install ENERGY STAR windows (update to ES V7 when its issued) ► Meet 2021 IECC insulation R, U, or UA levels ► Provide thermal breaks in above-grade walls in mixed and cold climates
Ducts	► Locate ducts and air handler within air and thermal boundary	► Locate ducts and air handler within air and thermal boundary
Water Heating	► Hot water delivery meets efficient design requirements ► Or, water heater and fixtures meet efficiency criteria	► Hot water delivery meets efficient design requirements ► Or, water heater and fixtures meet efficiency criteria
Lighting and appliances	► ENERGY STAR qualified refrigerators, dishwashers, clothes washers, and bath fans, and ceiling fans. ► 80% of lighting fixtures are ENERGY STAR qualified or ENERGY STAR lamps (bulbs) in ≥80% of sockets	► ENERGY STAR qualified refrigerators, dishwashers, clothes washers, clothes dryers, and bath fans, and ceiling fans. ► 80% of lighting fixtures are ENERGY STAR qualified or ENERGY STAR lamps (bulbs) in ≥80% of sockets
Indoor Air Quality	► Certified under EPA Indoor airPLUS	► Certified under EPA Indoor airPLUS
Renewable Ready	► Meet DOE Zero Energy Ready Home PV-Ready Checklist.	► Meet DOE Zero Energy Ready Home PV-Ready Checklist.
Target Home		
HVAC		
AFUE	CZ 1,2 = 80% CZ 3,4-marine = 90% CZ 4M,5,6,7,8 = 94%	CZ 1,2 = 80% CZ 3 = 92%, 4-marine = 95% CZ 4M,5,6,7,8 = 95%
SEER	CZ 1,2 = 18 CZ 3,4-marine = 15 CZ 4M,5,6,7,8 = 13	CZ 1,2 = 18 CZ 3,4-marine = 16 CZ 4M,5,6,7,8 = 16 (ASHP), 14 (A/C)
HSPF	CZ 1,2 = 8.2 CZ 3,4-marine = 9 CZ 4M,5,6,7,8 = 10	CZ 1,2 = 9.2 CZ 3,4-marine = 9.2 CZ 4M,5,6,7,8 = 9.5
Geothermal Heat Pump	ENERGY STAR EER and COP	none
Boiler AFUE	none	CZ 1,2 = 80% CZ 3 = 92%, 4-marine = 95% CZ 4M,5,6,7,8 = 95%
Ventilation	CZ 1,2 = 2.8 cfm/W no heat exchange CZ 3,4-marine = 2.8 cfm/W no heat exchange CZ 5,6,7,8 = 1.2 cfm/W; heat exchange with 60% SRE	CZ 1,2 = 2.9 cfm/W no heat exchange CZ 3,4-marine = 2.9 cfm/W no heat exchange CZ 5,6,7,8 = 1.2 cfm/W; balanced with heat exchange 65% ASRE

Insulation	Meet 2015 IECC, RESNET Grade 1 install	Meet 2021 IECC, RESNET Grade 1 install
Infiltration	CZ 1,2 = 3.0 ACH50 CZ 3,4 = 2.5 CZ 5,6,7 = 2 CZ 8 = 1.5 Attached dwellings, all CZ = 3.0	CZ 1,2 = 2.75 ACH50 CZ 3,4 = 2.25 CZ 5,6,7 = 2.0 CZ 8 = 1.5 Attached dwellings, all CZ = 3.0
Windows	CZ 1,2 = U=0.4, SHGC=0.25 CZ 3,4-marine = U=0.3, SHGC=0.25 CZ 5,6,7,8 = U=0.27, SHGC=any	CZ 1,2 = U=0.40, SHGC=0.30 CZ 3 = U=0.305, SHGC=0.25 CZ 4-marine = U=0.30, SHGC=0.40 CZ 4M,5 = U=0.27, SHGC=any, CZ 6,7,8 = U=0.25, SHGC=any
Water Heating	► Gas/propane systems of ≤ 55 gallons Energy Factor (EF) = 0.67, > 55 gallons EF = 0.77 ► Electric systems in detached dwellings EF = 2.0, in attached dwellings EF = 1.5 ► For heating oil water heaters use EF = 0.60	Electric EF = 2.5, Gas/propane = 0.95,
Thermostat	Programmable thermostat (except for zones with radiant heat)	► Programmable thermostat (except for zones with radiant heat) ► All ducts and air handlers modeled within conditioned space, uninsulated, with no leakage to the outside
Lighting and Appliances	See mandatory above	See mandatory above
Benchmark Home Size Factor	Varies by size of house	none

Table 2. DOE ZERH Summary of Major Changes from Version 1, Rev.07 to Draft Version 2.0 (DOE 2019, 2022b)

Metric	DOE ZERH Version 1	DOE ZERH Version 2-Draft Requirements
Insulation	2015 IECC	2021 IECC
Windows	ENERGY STAR 6.0, in very cold climates (CZ 6-8) use ES 5.0	ES 6.0, CZ 6-8 use U=0.25
Lighting	80% high efficiency	95% high efficiency
ENERGY STAR Appliances	refrigerators, dishwashers, and clothes washers	Plus clothes dryers
Indoor air Quality	Certify to EPA Indoor airPLUS V1	Upgrade to Indoor airPLUS V2 when out. H/ERVs in very cold climates (CZ 6-8) Min MERV 13 filter on HVAC.
PV Ready	Follow ZERH PV-Ready Checklist	ZERH PV-Ready Checklist, no exception for sites with lower annual solar resources
Clean Energy Technologies (heat pumps)	none	Include ENERGY STAR Next Generation Cert.
Min. Energy-Efficiency	V1 target Home ERI in 50s	V2 target Home ERI in 40s
Prescriptive?	Allows prescriptive path.	No prescriptive path.
Multifamily?	Allowed	Multifamily will transition to a ZERH multifamily spec when issued.
Size Adjustment Factor (SAF)	Included	Removed

METHODS

Data and case study information provided in this paper were collected from builders participating in the DOE ZERH program. Since its inception in 2013, more than 700 builders have participated in the program by certifying at least one home. More than 10,000 homes have been certified since 2013. Extensive data has been collected on a subset of these builders (approximately 100 builders) who have participated in the DOE ZERH program's annual Housing Innovation Awards competition, which recognizes exceptional projects and builders in the program. These 100 builders are among the most active builders in the program, having constructed nearly 60% of certified homes (DOE 2022a). The data collection instrument is a detailed on-line form that the builders are required to fill out to participate in the Housing Innovation Awards. Data collected includes energy-efficiency measures such as attic, wall, and foundation assembly details including materials, insulation types, and R-values; HVAC and water heating types and efficiency levels; window types plus U and SHGC values; which appliances are ENERGY STAR rated; what percent of lighting is high efficiency; and how much PV (if any) is installed. Builders are asked to report energy costs and savings in dollars and kWh based on energy modeling prepared by their HERS raters. Builders are also asked to report their incremental construction costs to achieve the DOE ZERH certification; this would be the difference in initial construction cost between just meeting code requirements in their state and meeting the DOE ZERH criteria. Builders were instructed to include only those extra costs needed to get to the DOE ZERH level, not the cost of any additional optional or cosmetic upgrades. For the data collection years 2013-2021, 196 of the 290 projects did report incremental costs.

RESULTS

Builders in the DOE Zero Energy Ready Home (ZERH) program have constructed and certified more than 10,000 zero energy ready homes to Version 1 of the ZERH program requirements since the program's inception in 2013, including homes in every U.S. climate zone and in every housing category (including production, affordable, custom for buyer, custom spec, multifamily and attached) (DOE 2022a), as shown in Figure 1.

Based on data on a subset of DOE ZERH builders collected through the DOE ZERH Housing Innovation Awards program, of 290 certified homes, 121 homes could be considered near net zero with a HERS score of 10 or lower; 90 are true net zero energy, with scores ranging from HERS 0 to HERS -29.

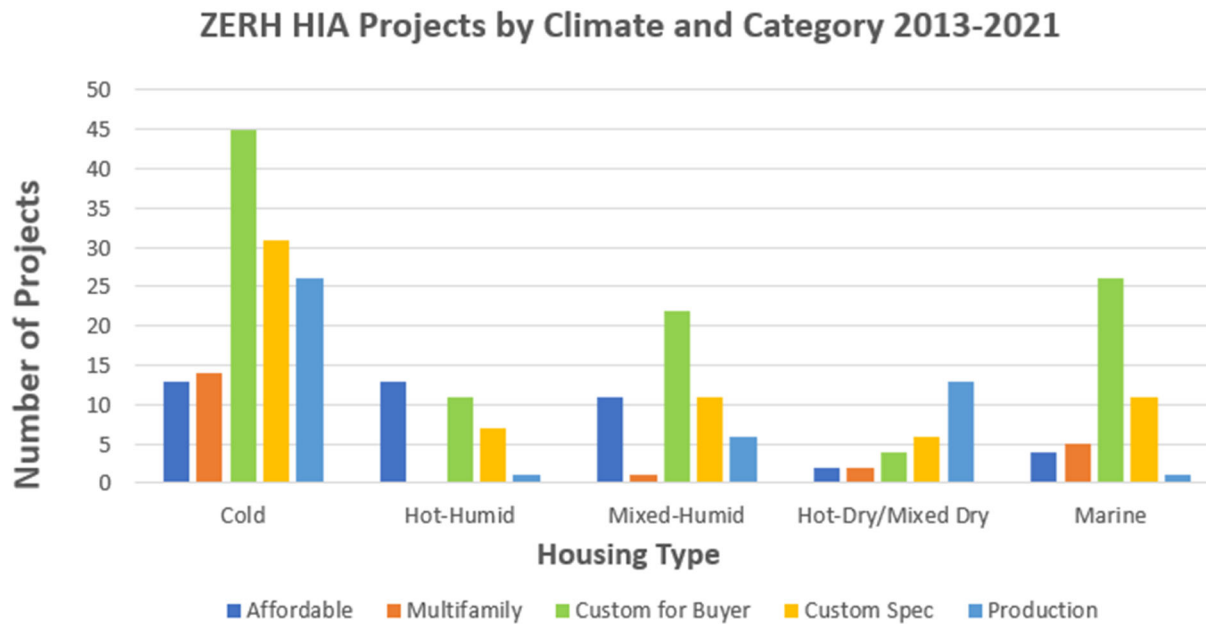


Figure 1. Number of DOE ZERH Housing Innovation Award winning homes by category and Building America climate region.

Preliminary analysis by PNNL of detailed program data on the 290 Housing Innovation Award winning projects indicates that 48 of these homes would meet the requirements of the 2021 IECC and the DOE ZERH V2. See Table 3.

Table 3. Homes Certified under DOE ZERH V1 that could meet DOE ZERH V2

Climate Zone	Projects Meeting DOE ZERH V2
Cold/Very Cold	18
Hot/Humid	4
Hot-Dry/ Mixed-Dry	3
Marine	10
Mixed-Humid	13
Total	48/290

Figure 2 gives a snapshot view of six of these homes. These include one production homes, three custom homes, and two affordable homes, in six different locations across the United States representing the hot-dry, marine, cold, mixed-humid, and hot-humid climates. Figure 2 describes these homes' envelope measures including wall assembly, attic, and foundation insulation details; HVAC and water heating types; and PV system size, and battery size, if included. Table 4 lists the HERS scores for each project, with and without PV, as well as the annual energy savings compared to the energy code in that state in terms of kWh and annual energy cost savings, the incremental or additional construction costs for the builder to achieve the ZERH requirements over the cost of constructing the same home to the state's current code,

and the net monthly cash flow to the homeowner. This amount is the dollar amount the homeowner nets each month when the amortized monthly addition to the mortgage to cover the added construction cost to achieve ZERH is balanced against the average monthly energy cost savings the homeowner can expect to see each month compared to utility bills for a home just built to code.

 Ferrier Custom Homes Lost Creek Phoenix Fort Worth, TX FerrierCustomHomes.com	 Mandalay Homes Foothills Lot 8 Prescott, AZ MandalayHomes.com
Envelope: Walls 2x6 24" o.c., advanced framed R-24, 5" spray foam. , Roof R-34 open-cell spray foam under roof deck.. Foundation Uninsulated slab on grade. HVAC: Air-source heat pump, 16 SEER, 9.0 HSPF. Water Heating: tankless electric. Solar: 8.96kW	Envelope: Walls 2x6 16" o.c., advanced framed R-21 o.c. spray foam. Attic R-30 open-cell spray foam under roof deck. Foundation slab on grade. HVAC: Air-source heat pump, 17 SEER, 9.6 HSPF. Water Heating: heat pump, 3.42 EF. Solar: 1.9 kW, 10-kW battery
 Hartford Habitat for Humanity Roosevelt Zero Energy Home Hartford, CT HartfordHabitat.org	 TC Legend Homes Everson Net Positive Bellingham, WA TCLegendHomes.com
Envelope: Walls 2x6, 24" o.c., R-31 total: 5.5" open-cell spray foam in cavity + 1.5" R-6.5 insulated coated OSB sheathing; 20" R-60 blown-in cellulose above ceiling; Insulated basement R-31 total: precast concrete panels with adhered R-10 rigid foam, R-21 fiberglass batt. HVAC: 2 ductless heat pumps, 14.2 HSPF, 33.0 SEER with In-wall transfer fans. Water Heating: Heat pump water heater, 3.42 UEF Solar: 7.75-kW rooftop panels.	Envelope: Walls 6.5" R-29 graphite SIPs, roof 12.25" R-59 graphite SIPs. Foundation 4" R-20 rigid foam under slab HVAC: Air-to-water heat pump, 3.92 COP (heat), 6.75 COP (cool), 23.02 EER. Water Heating: Combi w/Air-to-water heat pump. Solar: 12.4 kW, 40 310-W panels. Wired for future battery.

 United Way of Long Island Net Positive All Electric Home Deer Park, NY UnitedWayLI.org	 Zeronetnow Sofia Court Esopus, NY Zeronetnow.com
 Envelope: 2x6, 24" o.c., R-33 total: 51-1/8" graphite EPS foam topped by 1/2" OSB. Vented attic: 14" R-50 blown-in fiberglass flat, 18" R-65 blown-in fiberglass in vaulted roof. Basement insulated with 2" graphite EPS. 1.7 ACH 50. HVAC: Ducted and ductless mini-split heat pumps, 9.6 HSPF, 15.5 SEER. Water Heating: Heat pump water heater, 3.7 UEF Solar: 9.2 kW, no battery.	 Envelope: ICF walls and walk-out basement, 11.25" R-22. Closed-cell spray foam under slab. Unvented vaulted attic, R-63 total: R-49 open-cell medium-density spray foam on under-side of the roof deck covered with 2" R-14 closed-cell spray foam. 0.14 ACH 50. HVAC: Ground source heat pump, 3.5/5.3 COP, 22 EER/37 EER. Water Heating: Ground source heat pump. Solar: 12.96 kW, no battery.

Figure 2. Six DOE Zero Energy Ready certified homes that are already meeting the 2021 IECC.

Table 4. Energy savings, additional construction costs to meet ZERH vs. just code, and monthly cash benefit to homeowners for six ZERH home builders in three home type categories and various climate zones.

		Ferrier Custom Homes, Fort Worth TX	Hartford Habitat for Humanity, Hartford CT	Mandalay Homes, Prescott AZ	TC Legend Homes, Bellingham WA	United Way of Long Island, Deer Park NY	Zeronetnow, Wallkill NY
Climate		Hot-Humid	Cold	Hot-Dry	Marine	Mixed-Humid	Cold
Category		Custom for Buyer	Affordable	Production	Custom for Buyer	Affordable	Custom for Buyer
HERS	w/o PV	52	34	45	33	37	26
	with PV	1	-7	34	-19	-2	-11
Annual Energy Savings over Code, kWh	w/o PV	9,100 kWh	10,584 kWh	8,200 kWh	11,183 kWh	11,334 kWh	25,199 kWh
	with PV	13,600 kWh	18,554 kWh	11,100 kWh	23,531 kWh	16,957 kWh	39,577 kWh
Annual Energy Cost Savings, \$	w/o PV	\$1,000	\$2,324	\$1,000	\$1,433	\$2,175	\$3,684
	with PV	\$2,500	\$3,989	\$1,400	\$2,465	\$5,227	\$5,158

Incremental Cost*	w/o PV	\$15,000	\$12,293	\$9,600	\$27,000	\$18,000	\$15,000
	with PV	\$22,800	\$23,793	\$28,800	\$65,400	\$32,000	\$32,000
Net Monthly Cash Flow to Homeowner	w/o PV	\$-30	\$135	\$43.95	\$-8	\$96	\$243
	with PV	\$-46	\$220	\$-4.72	\$-105	\$284	\$293
*Does not include tax rebates and incentives, which will reduce incremental costs and increase net monthly return to homeowners.							

As can be seen from Table 4, in half the cases the homeowner can expect to see a net gain. In several cases, that gain is more than \$200 a month, i.e., the added construction cost to live in a ZER home is more than outweighed by the monthly energy savings, and homeowners will start seeing these net gains from the first month of occupancy.

Builders were asked to self-report incremental costs to achieve ZERH certification, above construction costs to just meet code, and 196 out of 290 builders did report incremental costs. Of these 196 builders, 188 builders reported their incremental costs not including the cost of the PV. Their reported costs are shown in Table 5. Note that because builders self-report these costs, some builders may have included additional upgrades not required to meet the ZERH specifications. Builders were also instructed to not include tax rebates and incentives in their incremental cost figures. When these are included, incremental costs could be considerably less, thus increasing the net monthly cash flow to homeowners.

Overall averages for all 290 DOE ZERH HIA projects are shown in Table 6 for comparison.

Table 5. Builders' Report Incremental Costs, Not Counting PV

Incremental Costs	\$0	\$1 - \$5,999	\$6,000- \$9,999	\$10,000- \$14,999	\$15,000- \$20,000	>\$20,001	Total
Builders Reporting this amount	13	37	24	25	29	60	188

Table 6. Average HERS, energy cost savings, and incremental costs

Key Metrics	All DOE ZERH HIA Homes 2013-2021
Avg. HERS without PV	44
Avg. HERS with PV	4
Avg. Incremental Cost without PV	\$18,719*
Avg. Incremental Cost with PV	\$39,317*
Avg. Annual Energy Cost Savings without PV	\$1,500
Avg. Annual Energy Cost Savings with PV	\$2,800
*Not counting rebates, tax credits, or incentives.	

Conclusions

The DOE Zero Energy Ready Home Program offers a path to zero that U.S. home builders constructing for a variety of markets are successfully using to achieve net zero energy home construction in every U.S. climate zone. Several of these builders are already meeting the IECC 2021 code requirements, which will become a mandatory element of version 2 of the DOE Zero Energy Ready Home criteria to be issued later this year. Brief case studies of some of those homes are provided as a package of measures builders can emulate.

References

- Berg, W., E. Cooper, and M. DiMascio. 2022. *State Energy Efficiency Scorecard: 2021 Progress Report*. Washington, DC: ACEEE. [aceee.org/research-report/u2201](https://www.aceee.org/research-report/u2201).
- Carbonnier, K. 2021. Checking in on State Energy Code Progress toward Zero Energy, New Buildings Institute, April 14, 2021, <https://newbuildings.org/checking-in-on-state-energy-code-progress-toward-zero-energy/>
- National Institute of Building Sciences (NIBS). 2015. A Common Definition for Zero Energy Buildings, U.S. Department of Energy. https://www.energy.gov/sites/default/files/2015/09/f26/bto_common_definition_zero_energy_buildings_093015.pdf
- U.S. Department of Energy. 2019. DOE Zero Energy Ready Home National Program Requirements (Rev 07). U.S. Department of Energy, <https://www.energy.gov/eere/buildings/downloads/doe-zero-energy-ready-home-national-program-requirements-rev-07>.
- U.S. Department of Energy. 2022a. DOE Zero Energy Ready Home Partner Locator. U.S. Department of Energy, <https://www5.eere.energy.gov/buildings/residential/locator/>.
- U.S. Department of Energy. 2022b. U.S. DOE Zero Energy Ready Home National Program Requirements for Single Family Homes Version 2 Draft. 2022. . U.S. Department of Energy, <https://www.energy.gov/eere/buildings/us-doe-zero-energy-ready-home-national-program-requirements-single-family-homes>.
- Werling, J. Van Mourik, J Lyons. 2021. “U.S. DOE Zero Energy Ready Home & the Year Ahead,” 2021 ENERGY STAR Residential New Construction Partner Meeting, U.S. Department of Energy, <https://www.energystar.gov/sites/default/files/tools/DOE%20ZERH%20%26%20the%20Year%20Ahead%20-%20ES%20Partner%20Meeting%202021.pdf>