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PNNL-37080

DOE Zero Energy Ready Home Building Assemblies in U.S Climate Zones

December 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 United States of America extends from the equator, through the Northern Hemisphere, and up into the subarctic. So, U.S. climate zones, as specified in the International Energy Conservation Code (IECC), range from 1A Very Hot Humid in places like Southern Florida and Hawaii, to 5A Cool Humid which stretches from Pennsylvania to Nebraska, and all the way up to 8 Subarctic in Northern Alaska. Residential construction adapts to each climate zone to meet the region's building codes and ideally to perform effectively and efficiently. Builders participating in the U.S. Department of Energy's Zero Energy Ready Home (ZERH) program follow specific above-code guidelines to construct houses that are so energy efficient they can easily offset their energy consumption with solar power production from photovoltaic panels located on site. Using data collected from homes participating in the DOE ZERH program's Housing Innovation Awards (HIA) as a representative sample, we identified the most common energy-efficient building assemblies constructed in each climate zone These results will be used to develop drawings showing building envelope construction details for homes that can meet the prescriptive requirements of the 2021 IECC in every U.S. climate zone. These drawings will be added to the "2021 IECC Climate-Specific Building Assemblies Tool" in the Building America Solution Center, where they will serve as a resource for builders, architects, and engineers who are designing and constructing homes to meet the latest building codes and the program requirements of the DOE Zero Energy Ready Home Program, ENERGY STAR V3.2, and the 45L Federal Tax Credit. Out of 382 projects, 20% of projects were in IECC Climate Zone 5A Cool Humid, 17% of projects were in 4A Mixed Humid, and 15% were in 4C Mixed Marine. The most common ZERH HIA building assemblies for each of these climate zones is detailed in Tables 1.1, 1.2, and 1.3. Overall, the most common wall assembly was 2x6 24 inch on center; the most common cavity insulation was blown fiberglass, the most common continuous insulation was polyiso, and the most common exterior cladding was fiber cement. The overall average R value was 26 for cavity insulation and R-7 for continuous insulation. The most common building assemblies and corresponding R values for each climate zone are detailed in the Climate Zone Data Points in this research paper.

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 and fall. I have learned a lot this summer and fall 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.

This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internships Program (SULI).

Acronyms and Abbreviations

BASC	-	Building America Solution Center
DOE	-	Department of Energy
GHG	-	Greenhouse Gas
HIA	-	Housing Innovation Awards
HVAC	-	Heating, Ventilation, & Air Conditioning
ICF	-	Insulated Concrete Form
IECC	-	International Energy Conservation Code
PNNL	-	Pacific Northwest National Laboratory
SIP	-	Structural Insulated Panels
ZERH	-	Zero Energy Ready Home

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1.0 Introduction

This research paper presents findings of an evaluation of 382 homes that were constructed in the United States between 2013 and 2024 and certified to the high-performance criteria of the U.S. Department of Energy Zero Energy Ready Home Program. While more than 20,000 homes have been certified through the program since its inception in 2013, this subset of 382 homes were all submitted to DOE by their builders for consideration for Housing Innovation Awards (HIAs).

While all the homes met the criteria of the DOE ZERH program, they vary considerably in size, shape, market segment (including production, custom, affordable, and multifamily homes) and geographical location. The homes were dispersed across the country and nearly every climate zone found in the United States from hot-humid (Climate Zone 1A) to very cold (Climate Zone 6, based on the climate zones specified in the 2021 International Energy Conservation Code (IECC).

Specifications for each project's building envelope and efficiency measures were collected and uploaded into a master spreadsheet. With that information, we sought to find the most common wall, roof, foundation, and window assemblies for each climate zone.

This information will be used to inform the development of new construction detail drawings. These drawings will be added to the *2021 IECC Climate-Specific Building Assemblies Tool*, a tool housed in the Building America Solution Center (BASC), which is an online resource for the home building industry developed and maintained by the Pacific Northwest National Laboratory for the U.S. Department of Energy. These detailed cross-sectional views and specifications will give builders clear options for meeting the prescriptive requirements of the 2021 IECC, a building energy efficiency code that is currently in the process of being adopted by several U.S. states. The 2021 code serves as the basis for the insulation requirements in the DOE ZERH Single-Family Version 2 (SF V2) home certification program. The DOE ZERH SF V2 certification in turn serves as the requirement for builders to earn the 45L tax credit, which is a $5,000/home tax credit paid to the builder for each home they certify as a ZERH home.

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.) Every DOE ZERH certified single-family home is required to meet the insulation requirements of the 2021 IECC, to be certified to ENERGY STAR and EPA's Indoor air PLUS program and to meet other mandatory requirements. DOE 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 for future installation of solar panels.

To recognize outstanding DOE Zero Energy Ready Homes, DOE conducts the annual Housing Innovation Awards. Award winners are rewarded with a page on DOE's Tour of Zero website and a poster detailing important project details. PNNL supports the ZERH program by gathering energy costs and savings data on each winning home along with details on the building envelope assemblies (attics, walls, foundations), and the mechanical, electrical, and plumbing (MEP) systems. This data is collected 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. DOE has recently added separate program certifications for multifamily buildings and manufactured homes.

2.0 2021 IECC Climate Zones

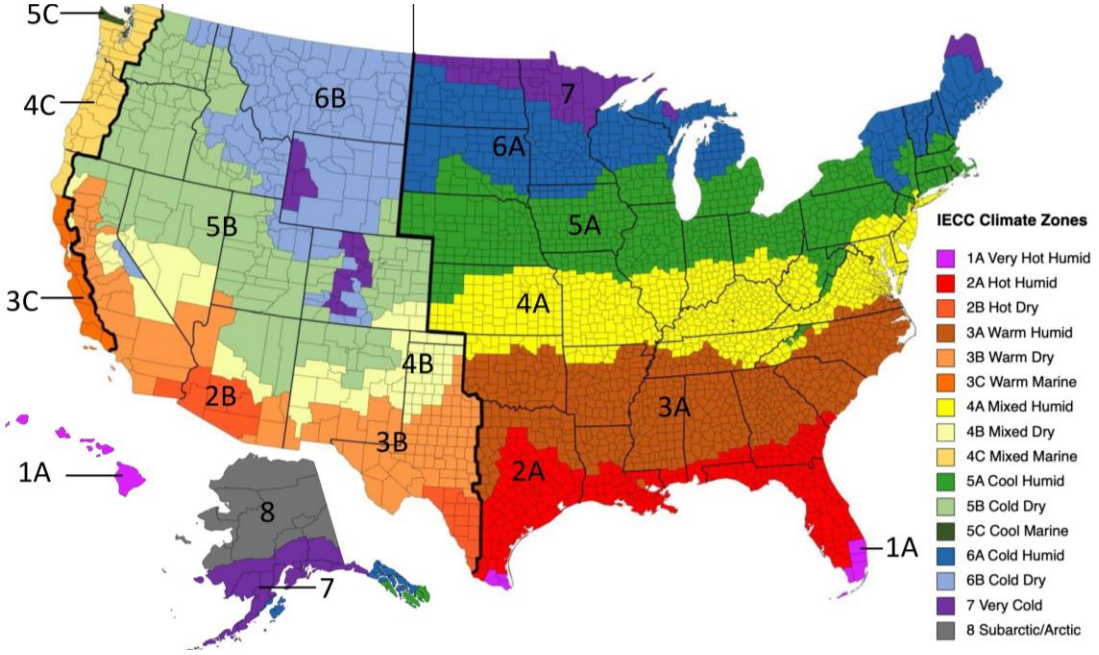


Figure 1: Building America Solution Center. n.d. (a) "2021 IECC Climate-Specific Building Assemblies" https://basc.pnnl.gov/building-assemblies.

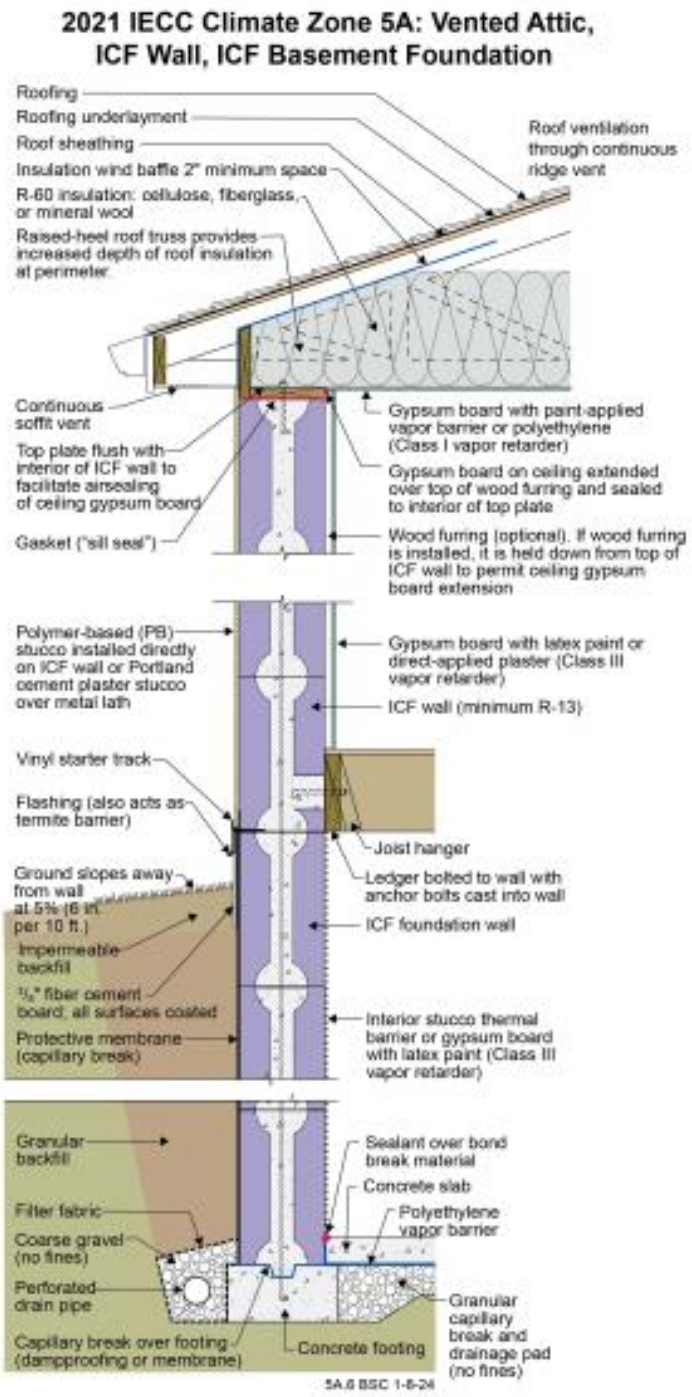
The International Energy Conservation Code identifies the minimum requirements for energy efficiency for residential construction. "The IECC addresses energy efficiency on several fronts including cost savings, reduced energy usage, conservation of natural resources and the impact of energy usage on the environment" (International Code Council). Over time, the IECC is updated to clarify, create, and remove requirements to improve standards.

The code identifies minimum insulation levels for various components of the building envelope and these minimum criteria vary by climate zone, becoming increasingly stringent in colder climates. Like most codes developed by the International Code Council (IECC), the IECC is on a three-year cycle of development and publication. Recent versions of the IECC have been published in 2009, 12, 15, 18, and 2021, and most recently 2024. U.S. states are free to adopt and amend the codes as they see fit and in accordance with each state's own code adoption cycle.

The 2021 IECC made some key changes in the requirements for the building envelope, mechanical systems, electrical power, and additional efficiency options. Providing resources for home builders is crucial for them to stay up to date with new performance expectations.

Tracking climate zones reveal regions that change in temperature over time. Based on past and current GHG emissions, ecological destruction, sea level rising, increasing average global temperature, and intensifying natural disasters, we can expect to see further adaptations overtime. To combat those issues, sustainable energy production and consumption becomes a matter of national security.

2.1 Climate-Specific Building Assemblies



The Building America Solution Center (BASC) provides a tool titled "2021 IECC Climate-Specific Building Assemblies". Each climate zone has its own webpage with examples of cross-sectional building assemblies, specifications for those building assemblies, and a list of HIA case studies that represent the best practices for the corresponding climate zone.

The image to the left is a cross-sectional detailed view of an insulated concrete form (ICF) foundation and wall assembly with a vented attic for climate zone 5A. There are eight other suggested building assemblies for climate zone 5A. While these suggested assemblies would function well, they don't necessarily reflect the conventional construction methods and materials that are most commonly used by builders in that climate zone. Best judgement was used to create those suggestions. So, using the ZERH data to find out what building assemblies have been most used by ZERH builders in each climate zone is an effective way to evaluate the current suggestions and include any additional building assemblies that are common but not previously suggested.

Figure 2: Building America Solution Center. n.d. (b) "2021 IECC Climate Zone 5A Building Assembly: Vented Attic, ICF Wall, ICF Basement Foundation" https://basc.pnnl.gov/building-assemblies/5a/vented-attic-icf-wall-icf-basement-foundation.

2.2 ZERH HIA 2013 – 2024 Data

From 2013 to 2024, PNNL with the DOE, has kept building specifications in a compiled master spreadsheet for the Housing Innovation Award winners. Overall, there are 382 projects with detailed descriptions of exterior walls, roof, attic, foundation, windows, air sealing, HVAC, lighting, appliances, and renewable energy. There is also data relating to energy consumption and expenses. Projects that have solar panels provide information about power production and battery storage. This spreadsheet has served as a resource for reporting on project features and metrics in the DOE Tour of Zero where each HIA winner is presented.

Based on an analysis of the 382 projects, 75 were in climate zone 5A Cool Humid. Taking up 20% of the total, 5A contained the most HIA projects. 4A Mixed Humid has 65 HIA projects at 17% of the total, 4C Mixed Marine has 58 HIA projects at 15% of the total, 5B Cool Dry has 50 HIA projects at 13% of the total, and 3A Warm Humid has 35 HIA projects at 9% of the total.

2.3 Climate Zone Data Charts

The following charts list the most common wall assemblies for each climate zone, including wall construction, cavity insulation type, continuous exterior insulation type, and exterior cladding (or siding).

2.3.1 5A Cool Humid Wall Data Table

5A Cool Humid	Wall Assembly	Cavity Insulation Type	Continuous Rigid Insulation Type	Exterior Cladding
1st Most Common	2x6 24 in. oc	Cellulose	Polyiso	Fiber-Cement
2nd Most Common	Double	Blown Fiberglass	EPS	Vinyl
3rd Most Common	ICF	Flash & Fill	Rigid	Wood Siding

Average Cavity R Value: 29

Average Continuous R Value: 10

Average Continuous Width: 2

2.3.2 4A Mixed Humid Data Table

4A Mixed Humid	Wall Assembly	Cavity Insulation Type	Continuous Rigid Insulation Type	Exterior Cladding
1st Most Common	2x6 24 in. oc	Blown Fiberglass	Polyiso	Vinyl
2nd Most Common	2x6 16 in. oc	Batt Fiberglass	Rigid	Fiber-Cement
3rd Most Common	Double	Flash & Fill	EPS	Engineer Wood

Average Cavity R Value: 24

Average Continuous R Value: 6

Average Continuous Width: 1

2.3.3 4C Mixed Marine Data Table

4C Mixed Marine	Wall Assembly	Cavity Insulation Type	Continuous Rigid Insulation Type	Exterior Cladding
1st Most Common	SIP	Cellulose	Cork	Fiber-Cement
2nd Most Common	2x6 24 in. oc	Blown Fiberglass	Mineral	Wood Siding
3rd Most Common	2x6 16 in. oc	Batt Mineral	Rigid	Metal Panels

Average Cavity R Value: 28

Average Continuous R Value: 8

Average Continuous Width: 2

2.3.4 5B Cool Dry Data Table

5B Cool Dry	Wall Assembly	Cavity Insulation Type	Continuous Rigid Insulation Type	Exterior Cladding
1st Most Common	2x6 24 in. oc	Blown Fiberglass	Polyiso	Fiber-Cement
2nd Most Common	Double	Flash & Fill	EPS	Stucco
3rd Most Common	2x6 16 in. oc	CC Spray Foam	Rigid	Engineer Wood

Average Cavity R Value: 31

Average Continuous R Value: 8

Average Continuous Width: 2

2.3.5 3A Warm Humid Data Table

3A Warm Humid	Wall Assembly	Cavity Insulation Type	Continuous Rigid Insulation Type	Exterior Cladding
1st Most Common	2x6 24 in. oc	Batt Fiberglass	XPS	Fiber-Cement
2nd Most Common	SIP	OC Spray Foam	Polyiso	Vinyl
3rd Most Common	2x4 16 in. oc	Cellulose	Rigid	Brick Veneer

Average Cavity R Value: 21

Average Continuous R Value: 5

Average Continuous Width: 1

2.3.6 Totaled Data Table

Totaled	Wall Assembly	Cavity Insulation Type	Continuous Rigid Insulation Type	Exterior Cladding
1st Most Common	2x6 24 in. oc	Blown Fiberglass	Polyiso	Fiber-Cement
2nd Most Common	2x6 16 in. oc	Cellulose	EPS	Stucco
3rd Most Common	SIP	Batt Fiberglass	Rigid	Vinyl

Average Cavity R Value: 26

Average Continuous R Value: 7

Average Continuous Width: 1

3.0 Conclusion

As the results show, the most common energy-efficient exterior wall assembly materials and methods for each 2021 IECC climate zone were found using the ZERH HIA database spreadsheet as a source. The next steps will be to write out data count shorthands for the roof, attic, foundation, and window assemblies for each of the 382 projects. Using that data, the most common building assemblies from the foundation to roof will be used to find the most common materials and methods for each climate zone. These results will then be used as a reference to update the 2021 IECC Climate-Specific Building Assemblies in the Building America Solution Center website.

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