Zero Energy Ready Out of the Box

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ABSTRACT HEADING

For millennia, house building was a one-house-at-a-time, site-built process. Since the early 1900s, off-site-produced homes have been appreciated for their affordability but not necessarily known for their high performance or energy efficiency. This paper shares key metrics for companies that are combining off-site construction techniques with certification to the U.S. Department of Energy's Zero Energy Ready Home program to create homes that are both cost effective to construct and high performance to live in. Key performance metrics and measures for modular, panelized, and SIP homes are compared against all homes in the DOE Zero Energy Ready Home program and against new homes built to code. These metrics show that off-site construction homes achieve energy performance similar to or better than site-built homes, and in the case of modular and panelized construction, at considerably lower average cost. The paper also highlights the experiences of two DOE Zero Energy Ready Home builders who employ off-site construction methods. One builder constructs production homes using pre-assembled panels. The other builder designs and ships kit homes all over the United States. The paper will focus on the optimum value engineering aspects of the panelized construction processes used by each builder to identify management and production practices employed by the builders to operate profitably while meeting high energy performance goals, despite a year marked by skyrocketing materials costs and supply chain and labor shortages. Cost and labor savings methods will be discussed in the context of these two unique business models.

INTRODUCTION

Background

Although comprising only 3% of current new home starts in the United States, off-site construction has been around for centuries. In the United States, prefabricated homes first became popular during the 1840s when house kits of precut wood were sold to Gold Rush prospectors in California. Kit homes were popularized for families around 1906 when several companies began producing and selling kits of precut wood, roofing, doors and windows, flooring, trim, hardware, nails, and paint – everything but plumbing and electrical - through mail order catalogs. Sears, Roebuck and Company sold over 500,000 kit homes in over 300 designs through its Modern Homes department from 1908 to 1940 before closing its doors due to supply shortages and construction restrictions caused by World War II (Hunter 2012). Frank Lloyd Wright designed hundreds of precut and prefabricated wood and concrete panel homes through his American System Built homes project between 1911 and the 1950s. The popularity of kit homes waned with the rise of production homes after World War II, which applied assembly line construction methods to site-built homes to meet the post-war demand for low-cost housing (Chavez 2011).

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Modular and panelized homes differ from manufactured homes (or mobile homes) which are built to the Manufactured Home Construction and Safety Standards ("HUD Code," 24 CFR 3280, Revd April 6, 1979). Manufactured homes are constructed in a factory in one or more sections and transported to the site on a permanent chassis (Hart, Rhodes, and Morgan 2002). In contrast, modular and panelized homes are built to local building codes and are constructed on a permanent foundation (Lopez and Froese 2016). Modular homes consist of sections of a home that are constructed and assembled in a factory and include framing, drywall, wiring, insulation, house wrap, siding and windows, and sometimes floors. The sections are shipped to the site and set in place, typically by crane (Perry 2022, Lopez and Froese 2016). Panelized homes are homes built of wall panels constructed in a manufacturing plant and assembled on site (Schinde and Darade 2018). The panels could consist of 2x4 or 2x6 framing members, plywood or OSB structural insulated panels, concrete panels, or other materials. One form of commercially available panels is structural insulated panels (SIPs), which were first developed using plywood panels in the 1930s at the Forest Products Laboratory in Madison, Wisconsin, and further developed by Alden B. Dow, a student of Wright and son of the founder of The Dow Chemical Company (SIPA 2022). SIPs consist of a layer of rigid insulation board, typically expanded polystyrene (EPS) sandwiched between two layers of OSB. The insulation layer can vary in thickness depending on the insulation R value desired. The panels can be 4x8 ft or smaller or larger and are precut in the factory to fit the house plans. They are attached with "splines" consisting of either dimensional lumber or I-joist-like structures with insulation adhered to each side to form an insulated connector, so the panels can form a nearly continuous thermal break on the walls or roof of the home.

In 2020, modular and panelized homes combined to make up 3% of all single-family home completions. This actually represents a decline from the pre-Great Recession peak in 1998 when 7% of single-family completions were modular (4%) or panelized (3%). Out of a total of 912,000 total single-family homes completed in 2020, 11,000 homes were built using modular construction and 17,000 were built with panelized/pre-cut construction methods. Approximately 1% of multifamily buildings (properties, not units) were built using modular and panelized methods, down from a 2011 peak of 5% of multifamily buildings constructed with modular (1%) or panelized (4%) construction methods. With supply chain issues including materials shortages and skyrocketing costs as well as labor shortages, the time for modular or panelized construction, which requires less labor, may have arrived (Schibline 2021).

There are pros and cons to both panelized and modular construction. Panels are easier to transport. They lay flat and can be stacked so they are less likely than modules to be damaged during shipping. They also require less heavy equipment to set up on site (Lopez and Froese 2016). Modular homes are built in a controlled environment, which can improve accuracy and save time and money from inclement weather delays (Schinde and Darade 2018). The assembly time on site is much faster for modular and requires fewer skilled trades, resulting in lower labor costs (Lopez and Froese 2016). In one case study, modular homes were found to be cheaper to construct than panelized homes at \$106/ft^2 (\$9.85/m^2) versus \$116/ft^2 (\$10.78/m^2) (Lopez and Froese 2016). Modern construction management design methods like building-integrated modeling have further increased the efficiency of both modular and panelized design and construction.

DOE Zero Energy Ready Home Program

The DOE ZERH program is a voluntary high-performance home labeling program designed to help builders achieve net zero or zero energy ready home construction (defined as a home that is so energy efficient a small number of photovoltaic panels can help the home achieve net zero energy bills over the course of a year) (Carbonnier 2021). The program includes several mandatory requirements, as well as prescriptive requirements the builder can use to design a target home. An energy modeling software is used to model the designed target home to determine a target Home Energy Rating System (HERS) score for the home. The builder can construct the actual home to that list of prescriptive requirements or make tradeoffs to achieve the target HERS score (DOE 2019). Requirements of the DOE ZERH program are summarized in Figure 1 and described below. Among the mandatory requirements: the home must be certified to ENERGY STAR and EPA Indoor airPLUS. Windows, appliances, bath exhaust fans, ceiling fans, and 80% of the lighting must be ENERGY STAR labeled. Envelope insulation must meet or exceed the 2015 IECC levels. The HVAC air handler and ducts must be located within conditioned space. Also, the home must be assessed by an independent third-party verifier who will test whole-house air leakage and confirm that other requirements have been met. The performance path allows tradeoffs in above-minimum HVAC, insulation, window, and water heating requirements to meet the target HERS score. Installation of solar panels at construction is not mandatory; however, builders are required to construct the homes to be "renewable ready" with conduit in place to install wiring to the roof and space near the electric panel for inverters for a future solar photovoltaic power system when and if the homeowner decides to install one (DOE 2019).

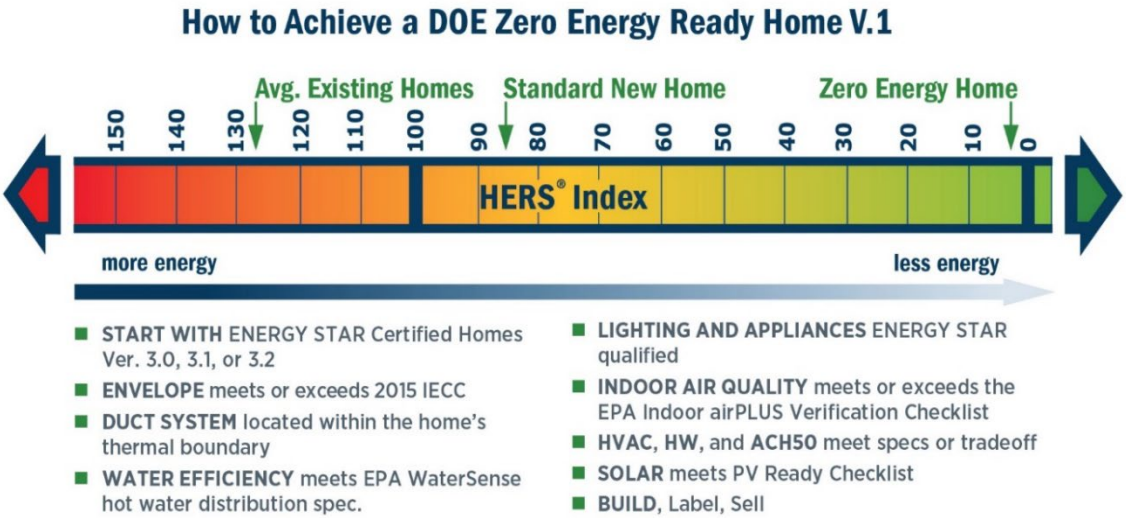

Figure 1. Requirements to Certify a Home in the DOE Zero Energy Ready Home Program (DOE 2019).

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 to the program criteria. 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 (DOE 2022a). These 100 builders are among the most active builders in the program, having constructed nearly 60% of certified homes (DOE 2022b). 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 and materials, insulation types, and R-values; HVAC and water heating types and efficiency levels; window types with 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 kilowatt hours 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 are 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 (based on project records).

Information for the two case study examples is provided from the direct on-the-job experience of two of the co-authors as well as from data collected through the DOE Zero Energy Ready Home program.

RESULTS

Builder Choices in Energy Efficiency Measures

Data collected from builders participating in the DOE ZERH program were used to compare builder choices in wall types and HVAC. More than 10,000 homes have been certified through the DOE ZERH (DOE 2022b). Data were collected from a sampling of 290 DOE ZERH certified homes as described in the Methods section above. Of this set, 43 homes were constructed with structural insulated panels (SIPs), 14 used other panelized construction methods, and 4 used modular construction. This subset includes builders of a variety of types of housing (single-family custom and production, affordable, and multi-family) across every U.S. climate zone. Figure 2 shows all of the wall types used by builders in the DOE ZERH program and compares this with wall type choices by builders of new to-code homes, based on data obtained by the authors directly from the National Association of Home Builders 2019 survey of new home builders which was conducted for NAHB

by Home Innovation Research Labs, identified in the chart as "HI." These data show nearly 18% of DOE ZERH projects used SIPs or other panelized or modular construction methods versus about 7% of new homes built to code. DOE ZERH modular, panel, and SIPs builders are also much more likely to use a heat pump for space conditioning, as shown in Figure 3. This correlates with the finding that two-thirds of DOE ZERHs are all-electric homes.

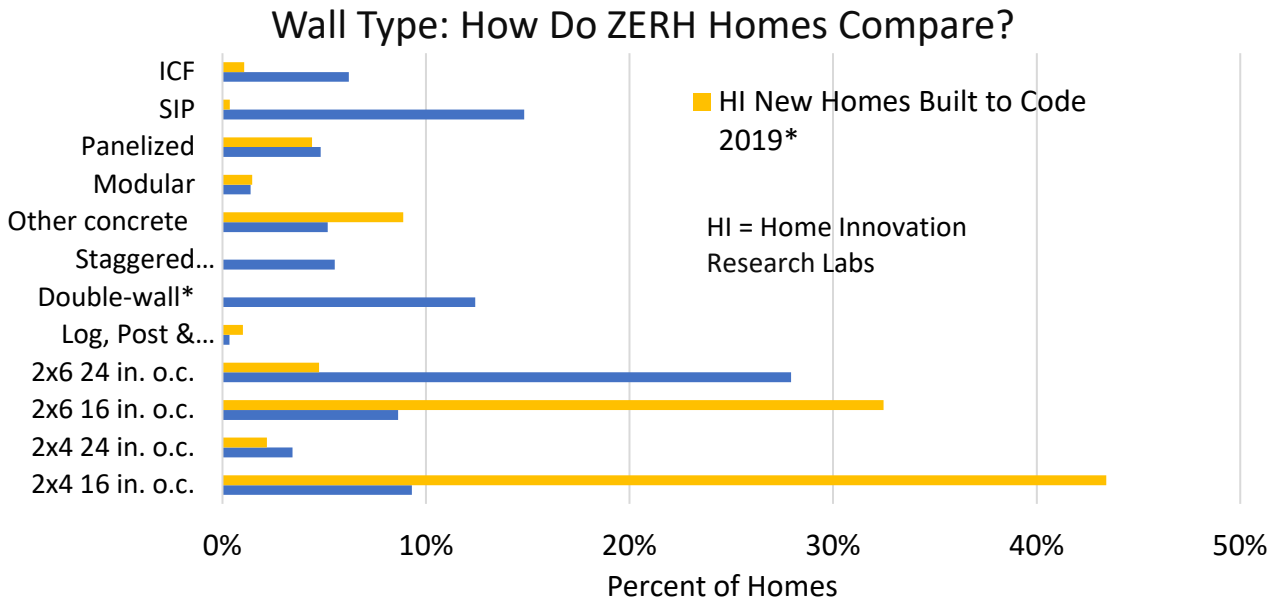

Figure 2. Comparison of Wall Types including Modular, Panelized, and SIPs Used in New Homes Built by DOE ZERH Home Builders and Homes Built by Builders of To-Code Homes.

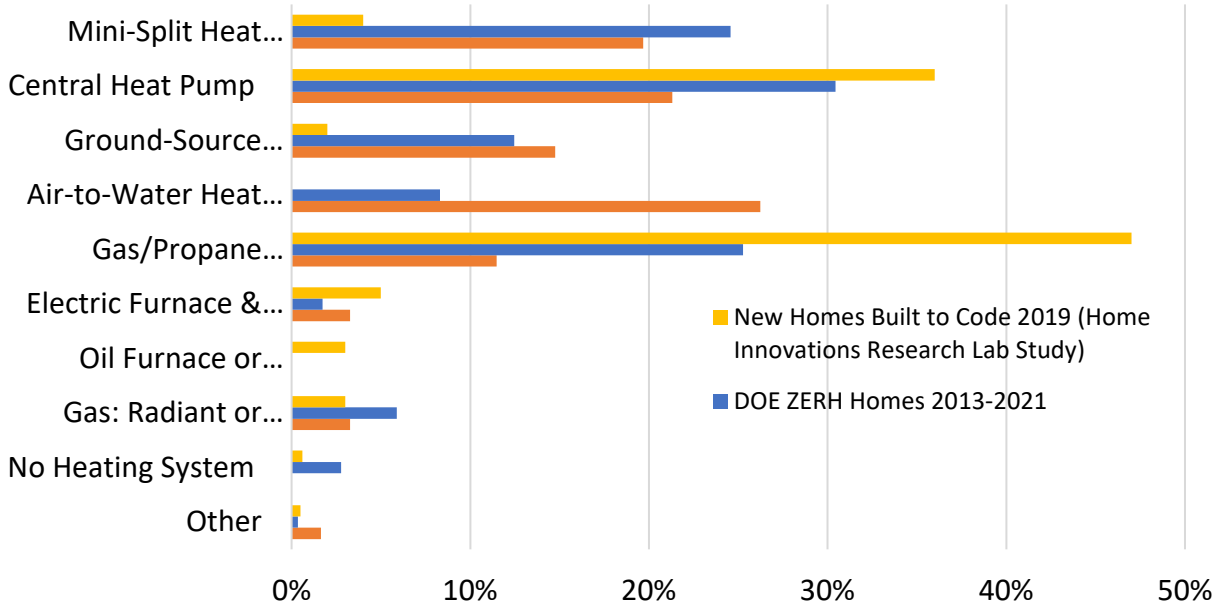

Figure 3. Comparison of HVAC Equipment Used in Modular, Panelized, and SIPs Homes in the DOE ZERH program compared to all DOE ZERH Homes and New Homes Built to Code.

Performance Metric Comparison

Table 1 compares modular, panelized, and SIPs homes with all homes in the DOE ZERH program. The comparison includes average HERS scores for construction type, when the home is modeled with and without PV, as well as the average annual energy costs and energy cost savings (versus an energy code-minimum home built in that state). Data were provided by builders based on HERS modeling software. All homes certified through the DOE ZERH program must be blower door tested and average air sealing data is provided here as air changes per hour at 50 Pascals pressure difference (ACH50). Also shown are the average incremental or additional construction costs estimated by the builders to achieve the ZERH requirements compared to the cost of constructing the same home to the state's current code. These averages are based on numbers self-reported by the builders, who were instructed not to include non-ZERH upgrades such as premium countertops; they were also asked to not include energy efficiency or PV tax credits, or incentives or rebates offered by utilities in their estimates of incremental costs.

Table 1. Comparison of Key Performance Metrics for Modular, Panelized, SIPs, and All DOE ZER Homes

Metric	Without and with PV	Modular	Panelized	SIPs	All DOE ZERH
Avg House Size, ft2		1,433	2,703	2,551	3,080
Air Sealing, ACH 50		1.55	1.75	1.29	1.41
Avg. HERS	Without PV	42	48	42	43
	With PV	-5	6	0	4
Avg. Annual Energy Cost Savings over Code, $	Without PV	$1,560	$1,930	$1,430**	$1,460
	With PV	$4,670	$2,845	$2,535	$2,885
Avg. Annual Energy Costs, $	Without PV	$1,395	$1,725	$1,100	$1,515
	With PV	$84	$380	$95	$300
Avg. Incremental Costs, $*	Without PV	$15,000	$10,415	$32,855	$21,390
	With PV	N/A	$21,445	$66,645	$44,435

* Does not include tax rebates and incentives which will reduce incremental costs and increase net monthly return to homeowners.
**Most SIP homes in the program are located in the Northwest which already has stringent energy codes so the lower savings above code may reflect that.

CASE STUDIES

Two examples of builders who employ off-site construction methods are provided below. Both builders participate in the DOE ZERH program and employ factory construction techniques to meet the high energy-efficiency and durability requirements of the program. One builder is a production home builder based in Delaware, who constructs approximately 300 homes per year. The other is a kit home manufacturer who ships home kits to buyers across the United States but especially in the southeast. Their experiences are described, including implementation, benefits, costs, savings, and challenges.

Panel Production Builder

The production home builder constructs about 300 homes per year in the U.S. Mid-Atlantic region, which is in the mixed-humid IECC climate zone 4A. This builder constructs primarily single-family detached as well as some multi-family rental units. The production builder started building homes in 2009. In 2018 they built their first home to the DOE ZERH specifications and later that year committed to building all of their homes to DOE ZERH certification. The builder noted that panelized construction enables them to cost-effectively achieve energy-efficiency goals.

This builder employs a panelized wall system consisting of 2x6 framing at 24-inch (61 cm) on-center stud spacing and other advanced framing techniques like insulated headers and two- and three-stud corners (Figure 4). Every panel is made in a climate-controlled indoor environment where materials are protected from the elements as they are precision cut and attached with laser-guided pneumatic nailers and self-squaring roller tables so every panel is constructed with an accuracy within 1/16th of an inch (0.16 cm). The wall panels have a coated OSB exterior sheathing, which saves time and money by serving as the structural sheathing and primary weather barrier when all seams between panels are taped. The wall cavities

are insulated with R-23 of netted and blown fiberglass. No plumbing or HVAC is installed in the exterior walls. The walls are clad with vinyl siding. The exterior walls sit on an unvented conditioned crawl space and the homes have vented attics.

Figure 4. This production builder uses panelized construction and volume purchasing of standardized equipment packages to realize profits on cost-effectively produced DOE Zero Energy Ready Homes (photos courtesy of Insight Homes).

Home panels are delivered to the site and the builder achieves dry-in in four days. Dry-in includes setting up the panels, taping the seams, and installing the roof and windows. A typical home achieves an air tightness of 1.9 air changes per hour at 50 Pascals (ACH50). Air sealing occurs in two stages at the site. The first stage occurs before drywall is installed and after mechanical rough-in when all penetrations through the subfloor to the crawl space, through the top plates and chases to the attic, and through the exterior walls are sealed using expanding foam sealant and rough openings around the windows and door frames are sealed with low-expansion foam sealant. The second stage occurs after drywall is installed when spray foam is used to seal seams and penetrations from the attic side of the ceiling drywall, including the top plates of all interior partition walls, and around light fixtures, exhaust fans, plumbing stacks, etc.

By certifying all of its homes to DOE ZERH rather than making certification an optional upgrade, the builder simplifies its messaging and the decision-making process for homeowners. This production builder found that using a consistent envelope assembly and mechanicals package and standardizing its product selections allowed it to streamline its purchasing with vendors enabling the builder to consistently achieve cost savings of 5% to 15% on higher performing products.

Using panelized production and providing training to subcontractors has helped the builder reduce costs and increase profitability in several ways: It has allowed the builder to improve first-time quality, reduce call backs, avoid back-charges, focus on profitable work, and implement continuous improvement practices.

The builder identified several specific ways in which panelized production has helped reduce materials costs: the high-performance thermal enclosure with two-stage air sealing has allowed the builder to downsize HVAC equipment and standardize the equipment size they order. This higher performance equipment includes a heat pump with a variable-capacity compressor that provides improved dehumidification allowing the builder to avoid purchasing a dedicated dehumidifier.

Along with wall panel standardization, the builder has also standardized its window sizing. Seven window sizes make up 80% of the windows used in its home models. This has allowed the builder to bulk purchase windows for reduced lead time and efficient manufacturing runs for the window maker. The builder has found that this standardization carries through to relationships with vendors, manufacturers, and distributors of HVAC and other products used in its homes, for reduced markups, better warranty coverage, and negotiated pricing based upon large production runs and guaranteed purchase orders for average savings of 3%-10% per building system and average annual rebates to the builder of $150,000, translating into average savings to the builder of $2,000 per home. This standardization has also enabled the builder to qualify for rebate programs that benefit the home owner including local programs as well as state and federal incentives and tax credits totaling an average of $3,000 to $5,000 per home.

The one weakness in relying on these relationships for negotiated prices on high-performance equipment is that it leaves the builder more vulnerable to supply chain disruptions. Recent shortages from regular suppliers have forced the builder to find alternative suppliers who charge considerably more for smaller orders of appliances with similar high performance levels.

Kit Custom Home Builder

The kit home manufacturer of custom and semi-custom kit homes is headquartered in North Carolina. The company is over 50 years old and has approximately 50 employees. The company offers pre-designed and custom floor plans and associated shell packages that aim to meet the performance specifications of the DOE Zero Energy Ready Home program. The company built its first certified DOE ZERH in 2019, added another in 2020, and currently has green building consultants working with clients to help achieve that and other certifications on more projects in the customers' local regions. Shell kits include open-stud wall panels with plywood sheathing, continuous exterior insulation, house wrap, and higher performance windows pre-installed. The kits also include roof trusses and roof sheathing, and connection hardware. Floor trusses and floor sheathing are also included if the home will be built on a raised foundation (Figure 5). In addition to energy performance, the builder's designs also incorporate high wind resistance. Some homes have been designed for net-zero and off-grid installations. The panelized shell packages can be shipped anywhere in the world. Customers hire a builder to erect the shell on-site and finish the home from the inside out.

The company began as a panelized manufacturer selling to builders and developers. Over time their business evolved to sell directly to customers. Their sales and design force grew to accommodate working with custom home clients, helping them design the home and find builders and other resources in their local area. In 2011 they added a turn-key construction team for projects within their local region, recognizing that it is their biggest source of business, and in 2020 they added shell assembly for projects throughout the southeast. They are working to expand the region in which they offer turn-key construction and shell assembly of their products, by growing and training traveling shell crews, recruiting builder partners, and growing their in-house turn-key operation.

Figure 5. The kit builder constructs panels in a factory and ships them to sites around the country with air sealing gaskets, rigid foam sheathing, house wrap, and windows already installed for quick installation (photos courtesy of Deltec Homes).

The builder employs a factory-applied gasket system to increase the air tightness of their homes. The average blower door test score of their kit homes is currently 1.6 air changes per hour at 50 Pascals of pressure (ACH50), as documented in their 2020 sustainability report. The panelized construction also facilitates the use of high-quality materials, reduced weather exposure due to fast dry-in times, and an opportunity for enhanced sustainability of the built product due to in-house waste reduction practices and solar generation at the factory.

CONCLUSION

These case studies and other examples among the 18% of DOE ZERH homes built using modular, panelized, or SIPs construction show that these builders achieve results comparable to or better than homes built with traditional on-site construction methods. DOE ZERH modular, panelized, and SIPs homes had HERS scores that were similar to site-built

ZERH homes. Their total air leakage scores were also similar, as were their average annual energy costs. However, their annual energy savings were higher than those of site-built homes on average. Incremental costs, which is the added amount to get a home to DOE ZERH certification above the cost of building to code, were considerably lower for panelized and modular homes, but incremental costs for SIPs homes were higher than the average incremental costs for all DOE ZERH homes. The two case study builders who have incorporated panelized construction into their home building processes have gained market success by cost-effectively achieving higher performance home construction that is verified through the DOE ZERH certification program and its third-party evaluation requirements.

REFERENCES

24 CFR 3280. 1979. Manufactured Home Construction and Safety Standards, Revised April 6, 1979, U.S. Department of Housing and Urban Development (HUD).

Briseno, A. and D. Perry. 2022. What is a Panelized Home? *NAHB – Panelized Building Systems.* https://www.nahb.org/other/consumer-resources/types-of-home-construction/panelized-building-systems.

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/

Chavez, Mark. 2011. "Prefabricated Homes," *Exceptional Places Newsletter*, Vol 6. 2011, National Park Service, Division of Cultural Resources. https://www.nps.gov/articles/prefabricated-homes.htm#:~:text=Prefabricated%20homes%20were%20produced%20during,half%20of%20the%2020th%20century.

Hart. J.F., M.J. Rhodes, and J.T. Morgan. 2002. "The Unknown World of the Mobile Home." *The Johns Hopkins University Press 307.3'36-dc21.*

Hunter, R.L. 2012. *Mail-Order Homes–Sears Homes and Other Kit Houses*. Shire Publications.

Manufactured Housing Institute. 2020. *2020 Manufactured Housing Facts – Industry Overview*.

Lopez, D. and T.M. Froese. 2016. "Analysis of Costs and Benefits of Panelized and Modular Prefabricated Homes. *Procedia Engineering 145*: 1291 – 1297.

Nanayakkara-Skillington, D. 2021. "Modular and Other Non-Site Built Housing in 2020." *Eye On Housing–National Association of Home Builders Discusses Economics and Housing Policy*. https://eyeonhousing.org/2021/07/modular-and-other-non-site-built-housing-in-2020/#:~:text=For%202020%2C%20there%20were%2028%2C000,there%20exists%20potential%20for%20expansion.

Perry, D. 2022. "What is a Modular Home?" *NAHB - Modular Building Systems.* https://www.nahb.org/other/consumer-resources/types-of-home-construction/Modular-Building-Systems.

Schibline, A. 2021. "Modular: Homes of Future's Past? How Prefabricated Residential Buildings Become the Standard in Sustainable Housing." *Technische Universitat Berlin.* 0415040.

Schinde, R. P. and M.M. Darade. 2018. "Comparison of prefabricated Modular Homes and Traditional R.C.C. Homes." *IRJET* 05-05.

SIPA. 2022. *BEST Building Education with SIPs Training*, Structural Insulated Panel Association, https://www.sips.org/documents/SIPA-BEST-1-Introduction-to-SIPs.pdf, accessed April 2022.

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 Housing Innovation Awards. U.S. Department of Energy, https://www.energy.gov/eere/buildings/housing-innovation-awards.

U.S. Department of Energy. 2022b. DOE Zero Energy Ready Home Partner Locator. U.S. Department of Energy, https://www5.eere.energy.gov/buildings/residential/locator/.