Advanced Manufactured Home Case Study:

A Collaboration for High-Efficiency, Affordable Housing

An Advanced Manufactured Home progressing along the Titan Homes assembly line. *Photo from Peter Schneider, VEIC.*

A manufactured home plant has delivered seven manufactured homes as part of a pilot project to prepare the plant for certification with the U.S. Department of Energy's (DOE's) Zero Energy Ready Home Manufactured Homes (ZERH MH) Program.

The Advanced Manufactured Home (AMH) project is a collaboration between a nonprofit affordable housing developer (Shires Housing), an energy efficiency utility (Efficiency Vermont, administered by VEIC), and the home manufacturer (Skyline Champion Titan Homes).

VEIC provided technical assistance for this AMH project through DOE's Building America program. The homes resulting from this case study will serve families experiencing housing insecurity and will fill vacant lots in a Shires Housing community in Vermont.

This fact sheet provides background information on the ZERH MH program, presents best practices learned by the home manufacturer, and details the breakdown of tasks performed in-plant versus on-site so that future efforts can achieve AMH designs and streamline manufacturing processes.

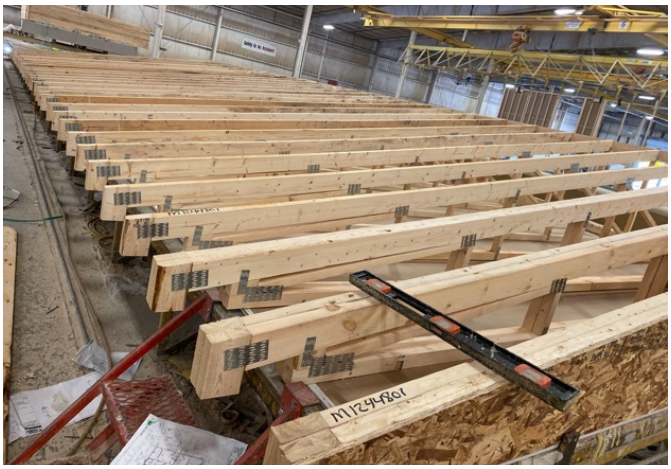
DOE's Zero Energy Ready Home Manufactured Homes Program

Meeting the ZERH MH Performance Requirements

DOE's ZERH MH program requires energy efficiency measures beyond the U.S. Environmental Protection Agency's ENERGY STAR® Manufactured New Homes program. The ZERH MH requirements double the homes' 45L tax credit eligibility through the Inflation Reduction Act. The AMH homes incorporate an improved thermal envelope, cold climate ducted heat pump (CCHP) for heating and cooling, balanced ventilation with energy recovery, heat pump water heating, solar photovoltaic (PV)-ready status with a roof-mounted system site-installed, and ENERGY STAR lighting and appliances.

DOE supports research and innovations for achieving ZERH MH certification and provides resources for manufactured home builders and stakeholders.

To be certified, a ZERH MH must achieve mandatory building science and efficiency requirements for insulation, glazing, ductwork, and other building elements. Efficiency requirements vary by climate zone, and can be found in **DOE's ZERH MH program requirements publication**. Titan Homes, the home manufacturer for this project, was able to obtain certification as a ZERH MH plant partner after completing these initial seven homes and standardizing the changes to design and assembly line practices.



2 x 4 top chord 16oc to accommodate field-installed, standard rack-mounted solar PV system. *Photo from Peter Schneider, VEIC.*

Integrating house wrap and window flashing prior to window installation. *Photo from Peter Schneider, VEIC.*

Process Improvements and Best Practices

The AMH design will use approximately 65% less energy than the 2015 U.S. Department of Housing and Urban Development (HUD) Manufactured Home baseline code, as determined through energy modeling using Open Studio®/HPXML.

The AMH project incorporated the following best practices in conjunction with the ZERH MH standards:

- Optimize duct length for cooling and heating air distribution and eliminate excess flex duct length.
- Install rigid insulation dams between joists at roof eaves to protect ceiling insulation.
- Improve insulation installation based on RESNET grading system.
- Perform in-plant testing, including blower door, duct blaster, and exhaust fan flows.
- Ensure balanced ventilation with energy recovery.
- Include an induction oven range.
- Install a base wall frost-protected foundation system.

- Prepare homes for future solar PV:
  - Identify site orientation and roof surface area to remain free of penetrations.
  - Relocate vent stacks and exhaust hoods.
  - Ensure adequate capacity, labels, and dedicated circuit space in electrical service panel.
  - Pre-install a conduit from the electrical service panel for future solar installation.

Table 1 presents the minimum standard requirements under DOE's ZERH MH program, as well as advanced "Tier 2" requirements implemented for Efficiency Vermont's AMH program.

Table 1: Manufactured Home Program Efficiency Requirements

Assembly	DOE ZERH MH Performance Requirements*	AMH "Tier 2" Requirements
Walls	R-21	R-24
Floor	R-33	R-33
Ceiling	R-38	R-44
Windows	U-0.30 (R-3)	U-0.25 (R-4)
Doors	U-0.30 (R-3)	
Air Leakage	Prescriptive air sealing details	3 air changes per hour @ 50 pascals
Heating	Air-source heat pump (≥7.5 HSPF2)	ENERGY STAR or NEEP cold climate air-source heat pump
Cooling	Air-source heat pump (≥14.3 SEER2)	ENERGY STAR or NEEP cold climate air-source heat pump
Ventilation	Exhaust	Efficiency Vermont H/ERV ≥70 sensible recovery efficiency
Hot Water	Tank (≥0.93 UEF)	Heat Pump Water Heater ≥3.3 UEF
Thermostat	Programmable	
Duct Leakage	4 cubic feet per minute @ 25 pascals per 100 square feet	
Duct Insulation	Floor cavity: enclosed by insulation; all other spaces: R-8	
Lighting	Federal Minimum	100% LED
Appliances	Federal Minimum	ENERGY STAR

*Heating, cooling, and hot water requirements are based on electric equipment options. Other minimum requirement options are available.

Roles and Responsibilities

Defining Measures Executed In-Plant and On-Site

This was the first ZERH MH initiative for Titan Homes. While the plant was certified to deliver ENERGY STAR Certified MH Version 2 homes, very few of their homes carried that label. ZERH MH requires ENERGY STAR MH Version 3 as a prerequisite. As a result, planning to meet and exceed the ZERH MH requirements required a number of changes to their design and assembly line practices.

Responsibilities of the Manufactured Home Plant

The improved thermal envelope with a coefficient of heat transmission (Uo) < 0.049 required the following upgrades to Titan Homes' standard HUD manufactured home package assemblies:

- R-22 to R-33 floor insulation.
- R-19 to R-24 wall insulation.
- R-30 to R-38/49 (for multi-section homes) ceiling insulation.
- U-.34 to U-.25 windows.

Window flashing, which was not standard practice in the factory, was installed using the steps outlined in the **DOE ZERH Manufactured Homes National Program Requirements Version 1**. This included proper installation and integration of the weather resistant barrier, installation of pan flashing, and caulking and flashing the window accordingly.

Measured duct leakage needed to achieve 4 cubic feet per minute per 100 square feet of conditioned floor area at a pressure differential of 0.1-inch w.g. (25

pascals). This required additional attention to duct sealing utilizing mastic, foil-faced tape, and zip ties, especially at connections across mate lines between double-wide units.

Titan Homes' typical practice was to install gas water heaters with some electric resistance units in their homes. For this effort, they had to not only set up a procurement channel to access a heat pump water heater product but also design the installation area for the unit based on ducting, pressure relief, and condensate requirements. A team from the chosen manufacturer of the heat pump water heater visited the plant to go over the design and participate in the first installation.

As the homes were specified to include a CCHP, Titan Homes was charged with making each unit heat pump ready. This included:

- Ensuring the air distribution was properly sized.
- Accommodating the indoor heat pump unit specified in the furnace closet.
- Installing a conduit in the furnace closet for the future refrigerant lines and the specified electrical conductor.
- Installing a conduit and wiring in the furnace closet for a specified electric strip heater intended to provide supplemental heat in very low-temperature conditions.
- Setting aside breaker spaces to accommodate both the CCHP and the backup electric strip heater.
- Wiring for an electrical disconnect between the main breaker panel and the gable end of the home where the future CCHP outdoor unit would be installed.

As the homes were also specified to have a roof-mounted solar PV system installed on-site, the manufacturer was charged with making each unit solar PV ready.

A solar-ready truss that would accommodate a typical rack-mounted system required the plant to order a new truss design with a 2 x 4 top chord, in lieu of the 2 x 2 standard top chord. The new design can accommodate snow loads, load from the rack-mounted solar PV system, and the fasteners required

Fabricating duct system off assembly line and duct sealing with mastic. *Photo from Peter Schneider, VEIC.*

for the PV system. In addition, two conduits were installed from the main breaker panel to the underside of the home to accommodate future solar PV wiring.

The plant was already installing all LED permanent light fixtures, and all bathroom faucets were ≤ 1.5 gallons per minute and showerheads were ≤ 2.0 gallons per minute.

Implications for the On-Site Installer

For skirting, the base wall foundation has backfill and weight-bearing capacities that, when coupled with ≥ R-21 skirting insulation, eliminate the need for a concrete slab while meeting the manufacturer's and HUD's requirements for a permanent frost-protected foundation.

The purchase and installation of the CCHP that met ENERGY STAR MH or Northeast Energy Efficiency Partnerships (NEEP) standards became the responsibility of the installer, because Titan Homes was not able to set up a distribution channel to acquire a CCHP for this project. Detailed installation requirements for ZERH MH heating, ventilation, and air conditioning system requirements can be found in the ZERH MH program requirements.

The through-the-wall balanced ventilation unit with energy recovery was also purchased and installed by the site contractor for whole-house ventilation only. While airtightness and duct leakage tests and ventilation flows were conducted in-plant, they were also verified at completion in the field. Field results indicated that the homes met and exceeded both the desired ventilation and duct leakage standards. The envelope airtightness testing resulted in some homes meeting and exceeding the standard of 3.0 ACH50, while some had slightly higher air leakage. Additional blower door-directed air sealing was planned on-site to reduce air leakage across all homes and identify opportunities to improve the air barrier in the factory for future builds.

The kitchen and laundry appliances, which were all ENERGY STAR certified, were also installed on-site. Purchasing of appliances was completed through a single, local retailer to help ensure long-term service support. The oven/range unit was an induction model, and the clothes dryer was a ventless heat pump model.

The roof-mounted solar PV system was installed on-site prior to occupancy. The site installer was responsible for the interconnection to the home via the main electrical panel and the electric grid.

Moving Forward

With Efficiency Vermont's support, Titan Homes was able to integrate all ZERH MH and AMH measures required to meet target performance, other than missing the air leakage rate goal on a small number of the homes. Shires Housing was pleased with the results and will consider advanced housing standards when replacing homes and filling vacant lots in the future. The collaboration highlighted opportunities for manufacturing processes to better achieve AMH designs.

Costs and Incentives

The costs to implement the measures for ZERH certification are closely aligned with the 45L tax credit amounts. This incentive allows manufacturers to provide products with these measures at no increased cost. The additional costs for improved thermal envelope and equipment upgrades for the Advanced Manufactured Home are offset by efficiency and affordable housing incentives in the Vermont region.

Heat pump ready with sealed plenum, conduit for refrigerant lines, thermostat wiring, and wiring for backup strip heater. *Photo from Peter Schneider, VEIC*

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