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Northwest Energy Efficient Manufactured Housing Program: High Performance Manufactured Home Prototyping and Construction Development

Tom Hewes and Brady Peeks
BA-PIRC

November 2013

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Definitions

ACH	Air changes per hour
BA-PIRC	Building America Partnership for Improved Residential Construction
BPA	Bonneville Power Administration
CFL	Compact fluorescent lamp
cfm_{50}	cubic feet per minute at 50 Pascals
DAPIA	Design Approval Primary Inspection Agency
DHP	Ductless heat pump
DHW	Domestic hot water
EF	Energy factor
ft^2	Square foot
GE	General Electric
gpd	Gallons per day
gpm	Gallons per minute
HPMH	High performance manufactured home
HPWH	Heat pump water heater
HVAC	Heating, ventilation, and air conditioning
kW	Kilowatt
kWh	Kilowatt-hours
LED	Light-emitting diode
MH	Manufactured housing
NEEA	Northwest Energy Efficiency Alliance
NEEM	Northwest Energy Efficiency Manufactured Housing Program
NEW	Northwest Energy Works
PNNL	Pacific Northwest National Laboratory
RTF	Regional Technical Forum
SEEM	Seasonal Energy and Enthalpy Model
UES	Unit Energy Savings
Uo	U overall
W	Watt
WSEP	Washington State University Extension Energy Program

Acknowledgments

We want to thank Eric Martin and the staff of the Florida Solar Energy Center's (FSEC) Building America Partnership for Improved Residential Construction team who supported this project and who performed BEopt analysis for this project phase (especially David Beal of FSEC). Thanks also to Graham Parker and Sarah Widder at the Pacific Northwest National Laboratory, in addition to all the other project partners. The region's manufactured housing (MH) industry is a key partner in this project. Northwest Energy Works (NEW) worked with many of the factories' engineering, production, and quality management personnel to develop and test each measure proposed for inclusion in the new High Performance Manufactured Housing (HPMH) specifications. The majority of the DHP prototyping was done at Fleetwood of Oregon and Kit Homebuilders West. Industry partners included the following:

Champion Home Builders, Weiser, Idaho

Fleetwood Homes of Oregon, Woodburn, Oregon

Fleetwood Homes of Idaho, Nampa, Idaho

Golden West Homes, Albany, Oregon

Kit Homebuilders West, Caldwell, Idaho

Marlette Homes, Hermiston, Oregon

Nashua Homes of Idaho, Inc., Boise, Idaho

Palm Harbor Homes, Millersburg, Oregon

Skyline Corporation, McMinnville, Oregon

Valley Manufactured Housing, Sunnyside, Washington.

Special thanks go to Mark Johnson and Sarah Moore at Bonneville Power Administration (BPA), and other regional utility partners in this project. BPA is an active partner in developing the new specifications and helping to bring other regional utilities to the table with the intent to develop a regional HPMH program. If and when the HPMH package begins to be included in new manufactured home construction, utility incentive funds will leverage this project's efforts by bolstering consumer demand (or lowering manufacturer costs) for higher efficiency homes.

Special thanks to Jeff Pratt, president of The Heat Pump Store. The Heat Pump Store specializes in ductless heat pumps (DHPs), and its staff trained the factory personnel to install DHP zonal heating and cooling systems.

Executive Summary

The Building America Partnership for Improved Residential Construction, BPA, and NEW, the current Northwest Energy Efficient Manufactured Housing Program (NEEM) administrator, have been collaborating to conduct research on new specifications that would improve on the energy requirements of a NEEM home. In its role as administrator, NEW administers the technical specs, performs research and engineering analysis, implements ongoing construction quality management procedures, and maintains a central database with home tracking.

This project is the second phase of a larger effort to develop a package of readily deployable measures able to reduce energy used for space conditioning, water heating and lighting by 50% over typical manufactured homes produced in the Northwest. The project's first phase worked directly with the MH industry to develop the measure specifications and perform energy modeling to confirm that the 50% energy savings target had been met. The modeling results were peer reviewed by the Northwest Power and Conservation Council's Regional Technical Forum. The project, conducted with support from the Building America team, Partnership for Improved Residential Construction, produced a peer-reviewed Short Term Results report that describes the HPMH specification and energy modeling in detail. This project phase built upon that work by prototyping and assessing the performances of the HPMH-specified high performance building assemblies and mechanical systems that are not commonly deployed in the MH setting.

This project explores in detail the technical feasibility of building the primary measures of the HPMH. The following basic technologies were prototyped in partnership with the industry:

- Shell modifications, including increasing insulation quantities in attics, floors, and walls and upgrading the efficiency of windows
- New wall assemblies with reduced thermal bridging (e.g., exterior rigid foam sheathing)
- New roofline designs and insulation strategies that allow for more insulation
- Heating, ventilation, and air conditioning system modifications built around the use of a DHP with zoned supplemental heating in secondary zones
- Domestic hot water modifications, primarily reliance on a heat pump water heater (HPWH) instead of traditional electric tank water heating.

These technologies and their applications are discussed at some length within the report, along with descriptions of prototyping with the industry and progress in securing design approvals for the proposed changes. The key lessons learned are:

1. The technologies being recommended for the HPMH are available and can be readily deployed in the factory setting. An HPWH capable of ducting in its process air from outside and exhausting it to outside is not available yet for the domestic market.
2. Electric energy savings ranging from about 8,000 kWh/yr up to nearly 11,000 kWh/yr over today's regional baseline home can be expected from using the HPMH specification.

3. A prototype model home should be built at each of the nine manufacturing plants in the region. Prototyping a HPMH home with each manufacturer will encourage them and their retailers to take ownership throughout the process of formulating new specifications.
4. Prototyping whole HPMH homes will be necessary to accurately price the HPMH option.

The project’s research findings are proving useful to regional stakeholders, because they make possible discussions between regional utilities and the industry. The goal for those discussions will be to develop a workable model for regional utility collaboration that targets incentives upstream to home manufacturers in support of the HPMH.

1 Introduction and Background

This project represents the second phase of an effort supported by the Building America Partnership for Improved Residential Construction (BA-PIRC) to develop a new High Performance Manufactured Home (HPMH) specification, prove its feasibility through prototyping of individual measures, and support its adoption in the marketplace. The project team consists of Northwest Energy Works (NEW), working with the manufactured housing (MH) industry, the relevant in-plant primary inspection agencies, the plants' design approval primary inspection agencies (DAPIA), retailers, industry associations, Florida Solar Energy Center, the Northwest Energy Efficiency Alliance's (NEEA) NW Ductless Heat Pump Project, Pacific Northwest National Laboratory (PNNL), the Northwest Power and Conservation Council, Washington State University Extension Energy Program (WSEP), and regional utilities.

The project's first phase progress report (Hewes and Peeks 2013) covered the project team's work with the MH industry in the Pacific Northwest region (Idaho, Montana, Oregon, and Washington) to develop the HPMH specification and obtain approval for its use as a measure in utility energy efficiency programs. The project's overall goal is to help the industry build homes that incorporate a package of readily available and proven energy efficiency measures not currently being used in the MH industry. The potential annual savings for the HPMH are about 8,000–10,000 kWh for each home produced and sited, depending upon siting location. This represents potential annual energy savings of 50% over a typical baseline manufactured home produced today in the Pacific Northwest region.

In this project's specification development phase, the HPMH energy modeling, package cost and benefit/cost analysis was presented to the Regional Technical Forum (RTF) at its April 2012 and May 2012 meetings. The HPMH specifications and energy use modeling were reviewed by the RTF, and the body concurred with the project team's findings. As analyzed using the RTF's methodology, the HPMH constitutes a cost-effective measure package with benefit/cost ratios ranging from 1.8 to 2.5, depending upon climate zone. Consequently, the HPMH specification received Provisional Unit Energy Savings (UES) approval, with the requirement that research be performed to confirm that the heat pump water heater (HPWH)-crawlspace interaction modeling results hold up in real-world applications, especially in cold climates. Provisional UES approval makes it possible for Northwest utilities to develop incentives in support of the HPMH specification. The full presentations made by NEW and Ecotope can be found at the following links:

www.nwcouncil.org/energy/rtf/meetings/2012/04/HPMH_Proposal_v4.ppt

www.nwcouncil.org/energy/rtf/meetings/2012/05/HPMH_Proposal_20120515_v2a.ppt

The current prototyping project phase focused on building and installing five of the individual measures called for by the HPMH specification. Research involved assisting the plants with obtaining engineering approvals for the new construction methods. Before each measure was built, it had to be accepted by the plant's DAPIA. Except for the exterior foam sheathing, it was the first time most of the construction methods or equipment were included online in the plants.

The experiences of building the prototype measures into homes assisted the project team in developing the initial construction processes plants used to incorporate the measures in future homes.

Construction methods developed through this project might well be readily adopted as best practices in new and retrofit work. The measures developed for the HPMH specification also have appreciable applicability to existing manufactured homes, especially measures that affect a home's structure and heating system.

The project team worked with manufacturers, DAPIAs, and in-plant primary inspection agencies to develop the specific details of how various measures included in the HPMH specification could be implemented. The details worked through included how to meet structural and other code requirements, optimize cost efficiency in implementing measures, and ensure consistent outcomes when installing the measures.

The project team asked for volunteers from the MH industry to build prototypes of some of the equipment (e.g., ductless heat pump—DHP, and heat pump water heater—HPWH) and building materials such as foam sheathing and windows in a few of its new NEEM homes to ensure correct operation. NEW purchased materials or equipment in some cases, and the homebuyers purchased equipment such as the DHP. Prototyping shell and mechanical innovations in the plants included drawing new details or floor plans and working with suppliers to gain access to new equipment and materials.

To gauge the reaction of the industry, NEW staff met regularly with key groups, such as state MH associations, to bring the industry up-to-date on measure development and prototyping progress with the different shell and mechanical systems measures. Positioning the HPMH concept in Northwest markets was discussed with financial institutions, building code officials, and industry leaders at their quarterly association meetings.

The resultant HPMH specification was then analyzed using Seasonal Energy and Enthalpy Model (SEEM) for its energy savings and cost-effectiveness potential, and the energy modeling results were presented to the Northwest Power Conservation Council's RTF. Electric energy savings ranging from about 8,000 kWh/yr up to nearly 11,000 kWh/yr over today's regional baseline home are possible using the HPMH specification. Gaining RTF concurrence with cost-effective energy savings attributable to the new specifications was a necessary step to permit the Bonneville Power Administration (BPA) and the region's utilities to consider moving forward with developing a program around the HPMH.

The list of HPMH measures developed in the prior phase of this BA-PIRC project is included in Table 1, below. Table 1 compares current NEEM program requirements and the HPMH measures.

Table 1. Detailed HPMH Specifications

Component	NEEM (Base)	HPMH
Ceiling	R-40	R-49 (R-45 net)
Floor	R-33	R-38
Wall	R-21	R-26 (with R-5 foam)
Window	U = 0.35	U = 0.22
Door	R-5	R-5
Duct Leakage	6% of supply	No ducts
Target Uo	0.054	0.040
Heating System	Electric forced air furnace	DHP/electric residential hybrid zonal
Lighting	1.4 W/ft^2	0.7 W/ft^2 (almost all are CFL or LED)
Infiltration	0.25 ACH (natural) and cfm$_{50}$ targets	0.21 ACH (natural)
Ventilation	Whole-house fan, 32 W continuous (0.1 ACH added)	HPWH (0.14 ACH added)
DHW (EF)	0.93	2.0 (HPWH)
Appliances and Miscellaneous	Standard refrigerator, ENERGY STAR® dishwasher	ENERGY STAR refrigerator and dishwasher/low-flow showerheads and faucet aerators

Notes: Uo, U overall (average hourly conductive heat loss for the building envelope on a ft^2 basis); CFL, compact fluorescent lamp; LED, light-emitting diode; ACH, air changes per hour; cfm$_{50}$, cubic feet per minute at 50 Pa; DHW, domestic hot water; EF, energy factor

1.1 Mathematical Modeling—BEopt

BEopt V2.0 was used to model energy savings of a two-section home, which is the most commonly built product in the region, including the HPMH specification energy features. Modeling was performed in accordance with the December 2012 Addendum to the Building America House Simulation Protocols of October 2010. The HPMH specification resulted in just under 29% savings over the Building America Benchmark in a western Washington state marine climate location. Figure 1 illustrates the BEopt-modeled energy consumption by end use.

Further investigation into how BEopt models the DHP hybrid heating system and the HPWH unit drawing air from the crawlspace is warranted, and future work on this project will explore the subject further. Also worthy of note is that the Building America Benchmark includes gas-fueled space and water heating, which diminishes the apparent value of HPMH reductions in electricity use for these end uses in the home on a source fuel basis. The assumption that gas is available as the baseline fuel choice is not valid for many locations where manufactured homes typically are sited in the Pacific Northwest region. Smaller communities and rural areas—where manufactured homes constitute a larger percentage of the housing stock—often do not have natural gas infrastructure in place. Many homes being sited in existing manufactured home communities in larger towns also do not have gas available to them, as many communities predate the arrival of gas to the area, and the cost to install gas is prohibitive to the community owners.

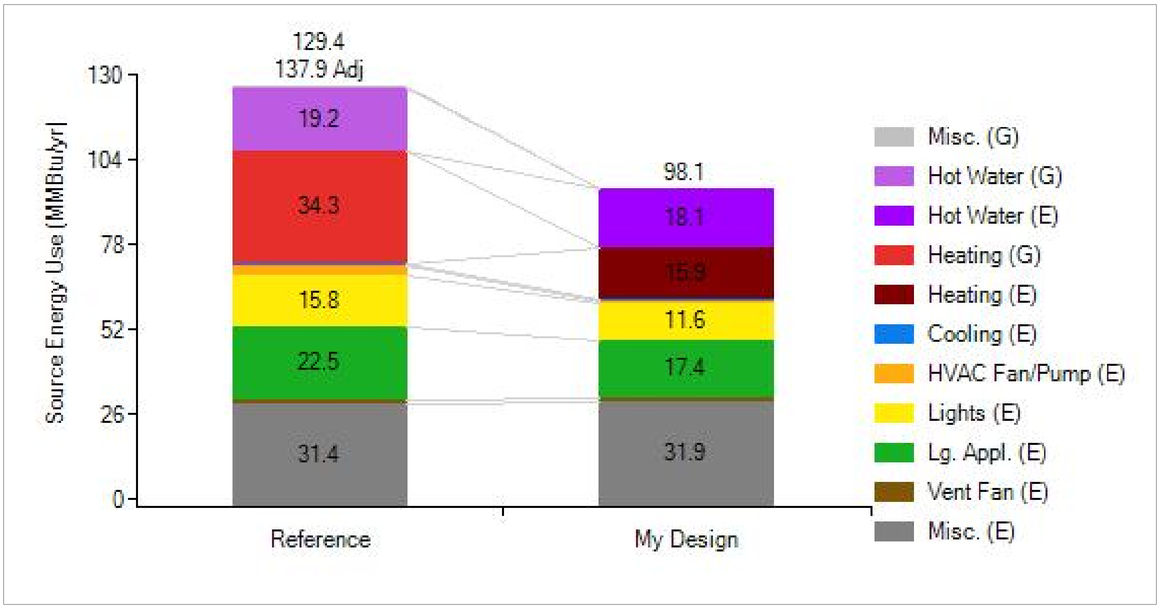

Figure 1. BEopt V2.0 modeled annual consumption by end use

2 Results of Prototyping the Measures

All of the shell improvements and energy-efficient mechanical technologies proposed for inclusion in the HPMH package are buildable with readily available equipment and materials, but they may require revisions to floor plans and/or factory construction processes. The project team focused its efforts on prototyping the five measures that involve the most significant changes to current practices in the plants. The following sections describe the measures, the construction processes developed by the project team, and the plants to implement the measures, the challenges faced during the prototyping process and the outcomes from the efforts. The research questions posed by the project team and the individual measures were prototyped and put through the design approval process for this project phase. Appendix A contains the full construction processes developed by the project team.

2.1 Continuous Exterior Rigid Foam Wall Insulation

<u>New wall assemblies with reduced thermal bridging</u> (e.g., exterior rigid foam sheathing, structural insulated panel construction, etc.) – Research questions: shear implications? Transport issues with lap siding being held off from sheathing? Would there be DAPIA engineering approval difficulties?

Through discussions with plant personnel, the project team determined that an improved wall assembly with exterior rigid foam sheathing added to reduce thermal bridging could be implemented with modest impact on plant production processes, provided that siding would be able to be installed directly over the foam using a nail gun. The project team worked with the Kit Homebuilders plant in Idaho to prototype this wall assembly. The project team assisted with any technical information needed to secure DAPIA engineering approvals before the prototype home was built (which did not prove to be an issue, as all materials were installed in accordance with manufacturer specifications), participated in the installation in the plant to develop appropriate job processes, and observed the home on site to assess any discernible problems that transport may have caused.

The project team supplied R-5 foam sheathing (¾-in.-thick polyisocyanurate) for installation on the exterior walls of a single-section home. Members of the project team were on hand to monitor both the time implications for the added process and any potential impacts on building durability or insulation effectiveness. The team used the experience gained from the prototyping exercise to develop initial work processes to guide installation of this measure.

The prototype home wall assembly consisted of ½-in. gypsum board on the interior, 2 × 6 stud walls on 16-in. centers, ½-in. oriented strand board sheathing, building wrap, ¾-in. foam board sheathing, and ⅜-in. lapped siding. See Figure 2 for wall cladding detail. The Northwest plants' home designs typically do not count upon the exterior cladding for shear strength, so adding exterior foam sheathing did not prove to alter the home's structural design. 0.092-in. diameter by 2½-in. siding nails were used to fasten the siding to the framing through the foam. This is the longest fastener the plant was able to locate that was not also of a heavier gauge than its typical siding nail. Larger diameter fasteners are reported to cause unacceptable levels of damage to the siding during installation. The thicker 5/4-in. trim pieces were attached with larger fasteners, as this material is not adversely affected by thicker fasteners. Windows were installed outboard of the foam sheathing and sealed to the foam. Following this plant's process, windows would be installed outboard of sheet good siding products and sealed to the siding, as currently is done by all plants with their conventional wall systems.

Figure 2. Wall cladding with exterior foam sheathing

The home selected for the prototyping exercise arguably constitutes a "worst case" test for how this insulation detail might impact the production line. First, a single-section home (most homes built in the Pacific Northwest region are multi-section) has the most exterior wall to be treated per floor section, and any additional work required at this stage of construction has the potential to hold up the production line. Second, the prototype home was of a modern design with tall sidewalls, and it had multiple changes in the wall plane for architectural detailing (see Figure 3).

Figure 3. Exterior foam installed

The task of installing the rigid foam sheathing took about 6 person-hours for the entire home. The workers became significantly more proficient as the work progressed, and the project team estimates that the same work might be done in about 4 person-hours. Each section of a simple two-section home might be done in less than 2 hours, once workers become familiar with the process. The installation rate appears to vary directly in response to workers' being allowed to waste some of the foam material. In the beginning of the installation process, the workers very carefully trimmed each piece of foam and utilized most of each sheet of material by carefully laying out cuts on the foam sheets. Each cut involved carrying foam over to a table saw, marking the cuts, sawing the foam, and returning to the home to install the cut piece. Later in the exercise, workers were instructed to install whole sheets of foam on the wall and trim it around window cutouts, which caused the installation rate to increase significantly. Waste increased, but the total amount of wasted material appeared to be acceptable, and there likely are opportunities to utilize some of the foam elsewhere in the production process. Simpler home designs with fewer window openings very likely would result in less waste as well. The prototype home required 48, 4 × 8 ft. foam sheets.

Plant staff members expressed concerns about how the home would travel with foam between the siding and the wall framing. The prototype home traveled from Caldwell, Idaho to Eugene, Oregon—a trip of more than 400 miles. The project team went to see the home on site as it was being installed, and no sign of siding shifting or window movement was evident. Figure 4 shows the home being installed on site.

Figure 4. Exterior foam-sheathed home after transport

The project team also worked with another plant to explore how foam sheathing might be incorporated into its construction processes. The second plant found that the 2½-in. length limitation for siding nails left insufficient nail penetration into the wall framing for the wall assembly to meet the siding manufacturer's warranty requirements. The fastener supplier confirmed that longer nails were available only in heavier gauge fasteners. The solution for this plant may be to use ⅝-in. thick R-4 polyisocyanurate foam sheathing and look at other tradeoff opportunities in the home's thermal package.

2.2 Triple-Glazed Windows

High performance windows – Research questions: gas-filled dual pane versus triple pane. Transport implications for heavier units? What's the best cost to performance point?

Triple-pane R-5 vinyl windows are available in the Pacific Northwest. The company that currently supplies the majority of the region's MH window market is not building R-5 windows. Two window manufacturers supplying a minority of the region's MH industry are producing R-5 windows, though not in product lines currently purchased by the industry. Members of the MH industry expressed general concern about the increased cost and weight associated with triple-pane windows, fearing that the heavier units might have a greater tendency to shift and get torqued out of square during transport and that the additional weight could push homes to where they require an additional axle to carry the home.

The HPMH specification calls for triple-glazed low-e windows with a U-value of 0.22 or better. The leading supplier of the region's MH window market (Kinro) is not building this grade of window, so the plants do not have access to windows that meet the HPMH specification. The project team was able to gain experience with installation of triple-glazed windows through its participation in PNNL's Manufactured Home Laboratory research team. For one of the PNNL laboratory homes, Jeld-Wen built a complete set of triple-glazed low-e windows with an improved foam-filled vinyl frame design with a U-value of 0.20. The project team was on hand for the installation of the windows and worked with the Jeld-Wen representatives to develop and implement a best practice installation of the windows that would be applicable to the factory setting. The windows were able to replace the existing window packages without significant design impacts in the PNNL laboratory home.

The plants typically install sheet siding products and set the windows outboard of the siding, relying upon butyl putty or caulking to provide a weather-tight seal to the siding. Trim is installed to cover the window nail fins, and additional caulking between the trim and siding provides an additional barrier against water intrusion. The weight of the window is borne by fasteners through the nailing fins.

The key differences in the window installation process developed by the Jeld-Wen factory representatives for the triple-glazed windows, compared to typical window installation procedures used by the plants, were that flexible flashing was used to create a window sill pan, in addition to the conventional sealing at the window nailing fins (see Figure 5), and the weight of the window was supported by shims placed between the window and sill. Backer rod and caulking were used to create an interior air seal, as can be seen in Figure 6. The plants' present window installation processes rely solely upon sealing windows to the cladding at the nailing fin and supporting the weight of the window with fasteners installed into wall framing through the nailing fin. The Jeld-Wen representatives used a rigid pan flashing under sliding glass doors as a best practice that currently is not being done by the plants. Figure 7 shows the pan flashing in place, with flexible flashing being installed to create an end cap for the pan.

Figure 5. Flexible flashing window sill pan

Figure 6. Backer rod and caulking as secondary air seal

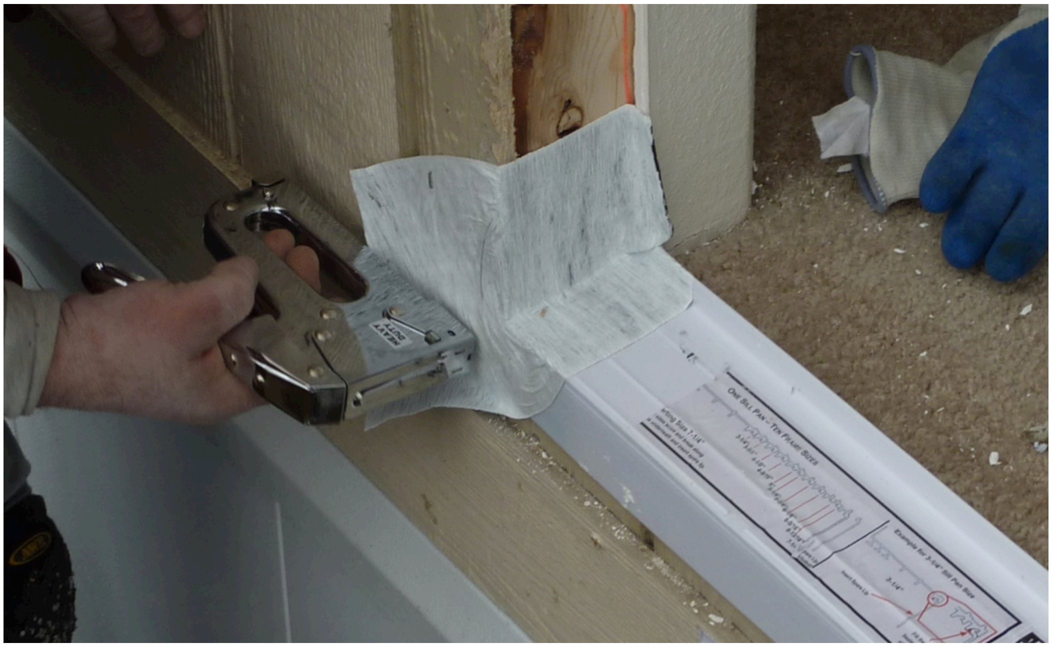

Figure 7. Sill pan for sliding glass door

2.3 Improved Ceiling Thermal Performance

Improved attic insulation strategies – Research questions: do changes to rooflines and trusses hold promise for improved ceiling insulation? Can new insulation approaches improve thermal performance with existing trusses?

The project team's discussions with industry personnel confirmed that improving attic thermal performance has limited opportunities without making major changes to the home construction process. Switching to trusses with greater heel heights often would result in taller home sections and cause transportation issues. New roof insulation strategies can achieve improvement to current practice without changing the roof trusses being used. The primary improvement that appears to be feasible for implementation involves increasing insulation levels in the eave area where limited attic depth prevents typical loose-fill insulation application from achieving acceptable insulation levels. Compressing full-width R-38 fiberglass batts under baffles and dense packing loose-fill insulation under baffles could prove to be two low-cost, easily implemented strategies that offer higher R-values per inch of depth than today's standard practice of using loose fill insulation exclusively. Another plant expressed interest in exploring the use of spray foam for its attic assemblies, but the change proved too expensive from both capital and product cost perspectives for them to implement at this time.

The target performance for the vaulted ceiling assembly is U = 0.026, which results from achieving an area-weighted average R-45 insulation value in the ceiling. The current standard reference assembly for the NEEM program is a nominal R-40 with a resulting U = 0.029 for vaulted ceilings insulated with loose-fill stabilized cellulose, based upon common rafter geometry that has a 5¼-in. heel height and a king post height of at least 17 in. The project team prototyped and gathered cost-related data for changing the ceiling insulation details with trusses typically used by two plants—one using a truss with a heel dimension of 5¼ in., and the other using a truss with a heel dimension of 7 in.

The new roof insulation strategies for conventional trusses included using a 24-in. wide R-38 fiberglass batt in place of blown-in loose fill insulation in the area extending from the eave above the top wall plate—where the batt is compressed using a baffle but still has a higher R-value than loose fill fiberglass insulation—and inward for 4 ft (see Figure 8), where the attic depth is sufficient to transition to blown-in insulation for the rest of the attic (see Figure 9). The full width batts effectively fill in between roof truss members to prevent insulation voids. The insulation baffles selected for this application have 1-in. wide side flanges that are stapled onto the truss top chords to create the required ventilation space, and they have a tail that is stapled onto the outer edge of the wall top plate to further stiffen the baffle against the compressed batt and prevent wind washing of the insulation. The batt and baffle installation took about 20 person-minutes to complete a 40-ft long attic, and insulation blowing used 1½ fewer bags of insulation per 10 ft of attic length. For the prototype home, this represented a 25% reduction in loose fill insulation and blowing time. Since the fiberglass batts and the baffles were purchased retail by NEW for the exercise, it is not possible to give an accurate measure of the full cost implications, but the detail likely adds about $140 to the cost to insulate a 40-ft long two-section home.

Figure 8. Compressed R-38 batts with baffles at eaves

Figure 9. Transition to blown-in insulation for deeper attic cavity area

The second attic assembly prototyped used dense-packed loose-fill insulation at the eave area. The same baffles that were used for the fiberglass batt detail proved to work effectively for this application. Dense packing insulation at the eaves can be used to improve the thermal performance of almost any attic system being insulated with loose-fill insulation where space is constrained near the eaves.

For the dense packing prototype assembly the lower half of the roof assembly was blown with insulation. Then, baffles were installed at the eaves and secured to the truss top chords and wall top plate. Insulation from the area inboard from the baffle was then raked toward the eave and compressed into the cavity formed by the ceiling and the baffle. Afterward, additional insulation was blown in to fill the ceiling's inboard area. Consistent density was obtained by pushing insulation into the cavity until the baffle bowed up in the center by nearly 1 in., after which the baffle was pushed downward until it returned to its flat position. Figure 10 shows a baffle in place. Core sampling from the dense-packed area (see Figure 11) showed the density of the fiberglass insulation to be a little more than 2.5 lb/ft^3, which yields approximately R-4.1/in. of thickness (compared to the manufacturer's listed value of R-3.5/in. at 0.9 lb/ft^3 installed density—an increase of 17%). Dense packing the eave area required approximately one extra 30-lb bag of loose fill insulation per 10 ft of attic length.

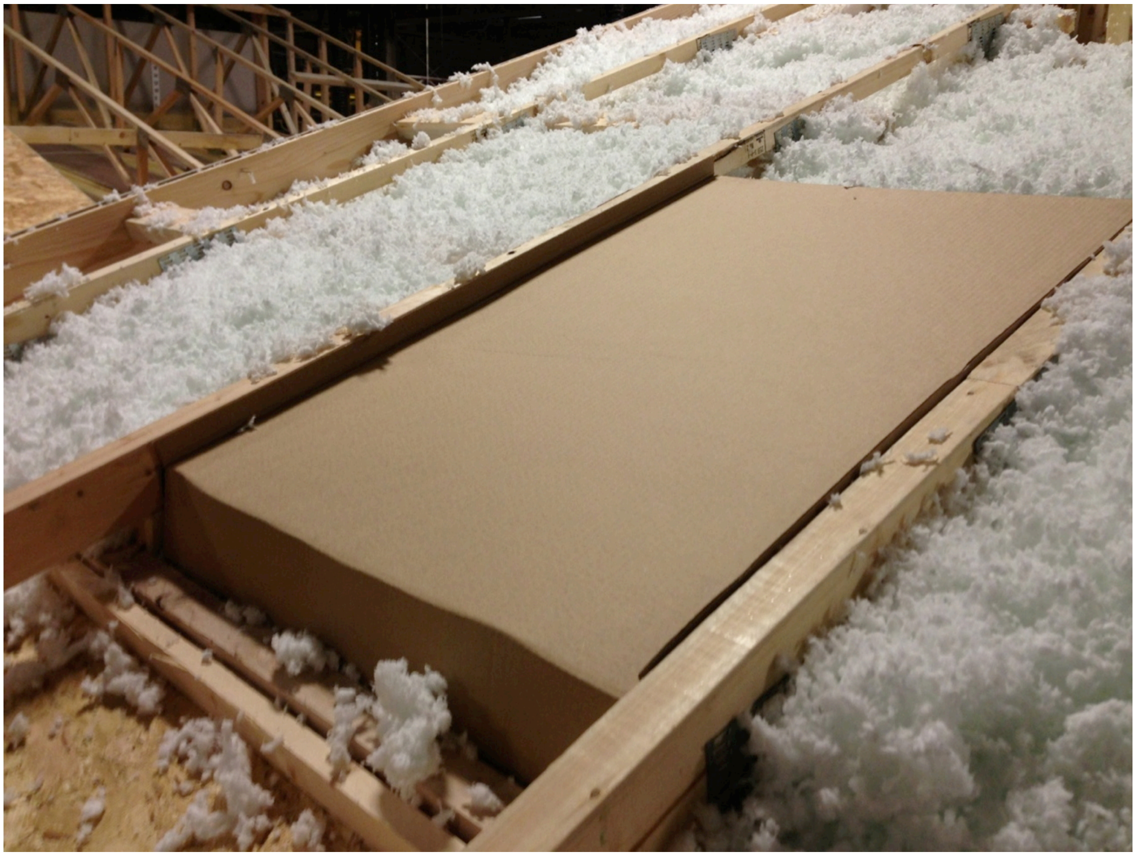

Figure 10. Baffle retaining compressed loose-fill insulation near eave

The current loose-fill insulation practice being used at the plant where the prototyping exercise was performed often results in the eave areas being underinsulated. Much of the eave area typically is blown with greater than a 1-in. airspace, and core sampling indicated that insulation was being installed at less than the manufacturer's required density. Weighed samples showed that insulation was being installed at 0.68 lb./ft^3 versus the manufacturer's specified minimum density of 0.9 lb./ft^3. The insulation density improved sufficiently in the roof areas where it was installed at greater depth. Consequently, the plant's current process is causing approximately a 25% reduction from the expected R-value of the insulation near the eaves.

Figure 11. Core sampling of dense-packed insulation

2.4 Heating, Ventilation, and Air Conditioning System

Ductless heat pumps with zonal heating in secondary zones – Research questions: can in-plant installation of DHP be reliably accomplished in a way that travels well to site? For all floor plans? One DHP or two? What type(s) of supplemental zonal heat are needed?

The hybrid zonal system eliminated the existing electric forced-air furnace and duct system from the home altogether, which allows for more floor insulation where the ductwork was located. A single DHP was connected to one or two indoor heads and was sized to meet the majority of the home's heating load. Electric wall or baseboard heaters were located throughout the house so that each room has an independently controlled supplemental source of heat. The project proved that a DHP can be reliably installed and commissioned on the production line, ready for transport to the homebuyer's site. This eliminated the need for aftermarket heat pump installation. With technical support from NEW, staffs at three plants were able to design and install the DHP and the supplemental zonal heating systems appropriate for all Pacific Northwest climate zones. As a result of the project, the team and industry identified three installation options, presented in Table 2, below. In all but the DHP Ready option the factory determines the size of the DHP, and in all cases the factory installs the zonal electric resistance heaters and runs a dedicated electrical circuit to a disconnect box near where the DHP compressor will be located.

Table 2. DHP Installation Approaches

Option	Description	Key Requirements
Factory Turnkey DHP	Factory installed system by properly trained factory staff or outside heating, ventilation, and air conditioning (HVAC) technician. In-factory commissioning before home shipment.	Factory wholesale DHP equipment purchase, and inventory of installation items at the factory. Warranty by factory or partner HVAC contractor.
Field Finished DHP	Factory staff installs the indoor head, prepares any building envelope penetrations and runs DHP electric circuit/disconnect. Home ships with the outdoor unit shipped loose in the home. A certified field contractor installs and commissions the system after the home is installed on site.	Factory wholesale DHP equipment purchase, reduced inventory of installation items at the factory. Warranty by partner HVAC contractor. Onsite permit and inspection for DHP placement and electrical connections to disconnect.
DHP Ready	Factory staff installs DHP electric circuit/disconnect. Retailer hires HVAC contractor to install DHP on site.	No factory inventory. Warranty by local HVAC contractor. Onsite permit and inspection for DHP placement and electrical connections to disconnect.

The team also teamed up with NEEA's NW Ductless Heat Pump Program, retailers and interested local utilities to begin planning and promoting "show and tell" events. At an event in Sequim, Washington, in response to an announcement placed in the local newspaper 20 people attended to hear about the DHP manufactured home on the retailer's sales lot. There was a good 90 minutes of questions and answers after the DHP presentation. The Sequim event promoted DHPs as both an upgrade to existing heating systems and as the best option for new manufactured homes. Most attendees were interested in the retrofit potential for the DHP systems.

The alternative HVAC system, based on a DHP, combined with zonal electric heaters in each bath and bedroom, replaces the electric forced-air furnace and duct system. The system is called a *hybrid DHP zonal electric heating system*, because while the DHP provides most of the home's space conditioning needs, the electric wall heaters or electric baseboard units (sizes range from 500 W to 2.0 kW depending on the climate and room size) located throughout the house give occupants the ability to obtain additional comfort heating in individual rooms.

The high-efficiency DHP is located in the central living area, but it is sized with sufficient capacity to meet the entire home's cooling load and its heating load under most conditions, especially if interior doors are left open. The DHP includes one or two wall-mounted indoor heads in the central space that operate nearly continuously, ramping up and down the fan speed in proportion to the amount of heating or cooling being performed by the unit. The continuous operation of the indoor head blower thoroughly mixes the room air to the point that air throughout the house gets turned over and conditioned by the DHP. Figure 12 shows a DHP indoor head located in the main zone of the home. Remote rooms will be conditioned indirectly most of the time, with the backup electric resistance wall heaters supplementing as needed, especially in extreme conditions. Installing ceiling fans in secondary zones may help evenly cool the home, especially if secondary zones have significant southwest-facing glazing. Additional research is needed to give guidance for designing systems that ensure adequate home cooling performance in areas with hotter summer conditions.

Figure 12. DHP indoor head mounted in main zone

The project team was able to prototype the hybrid DHP zonal electric heating system in six homes built at three different plants. In order to achieve a complete turnkey DHP installation at the plant (achieved in four homes), both the DHP indoor head(s) and the outdoor compressor must be mounted on the same home section. Four homes were prototyped with this approach. Not all floor plans lend themselves to locating the entire DHP system on a single home section, so the team also explored ways to ship the home with a complete zonal electric resistance heating system and perform DHP installation on site. One option the team explored was to have the plant purchase the DHP equipment, install the indoor head, drill all necessary holes through the building envelope, supply an equipment electrical disconnect near where the outdoor unit was to be installed, and arrange for a refrigerant technician and electrician to complete the DHP installation on site (done for one home). A second option field DHP installation was simply to ship the home with the zonal electric resistance heating system installed with an equipment electrical disconnect near where the outdoor unit was to be located on site. The home retailer then arranged for an HVAC contractor to install the DHP system (done for one home). All three approaches proved viable, but each presents a different set of challenges and requirements for achieving successful integration into the home and into the factory building process.

Factory-installed DHP systems require that the home have a suitable mounting location on the rear wall of the floor section receiving the DHP equipment (see Figures 13 and 14). Even with the longest trailer tongue installed on the home, a DHP compressor mounted on the hitch end of the home proved to be vulnerable to damage by the transport rig. Sidewall mounting presents similar vulnerabilities, and over-width considerations further limit the potential applicability of this mounting strategy. Many homes built in the Pacific Northwest are sited in western Oregon and Washington—areas with a marine climate. For such applications, using a DHP that has published capacity data for lower temperatures than the U.S. Department of Energy-specified 17°F rating temperature can allow the heating system to be designed without installing supplemental heating in the main zone of the home in many cases, because the DHP still has ample capacity at the mild heating design temperatures common in the marine climate zone—a cost savings and a possible perceived benefit from an aesthetic perspective.

Figure 13. DHP compressor on end wall with indoor head on other side of wall—“up and in” installation

Figure 14. DHP mounting location integrated into home design

Limitations to factory installation include optimal indoor head location, which can be difficult to achieve (due to the need to locate both compressor and indoor head in the same floor section). Wall mounting of the outdoor compressor may present a noise issue when mounted on a bedroom wall, and installation may involve particularly long refrigerant line runs.

Approaches that involve installing or completing installation of the DHP in the field can expand the range of floor plans that lend themselves to DHP integration, as there are more options for equipment location in the home. Field-installed DHP approaches require that the home have a zonal electric resistance heating system installed in the plant that serves the entire home and has sufficient capacity to meet heating loads at design conditions, because the home is required to be complete at the time it leaves the factory. It is possible to ship a home that has elements to be completed on site, but this requires the home to have an "alternative construction" letter and an additional on-site inspection by an In-plant Primary Inspection Agency representative. Additionally, a local electrician and heating contractor are needed to install and commission the DHP, which adds cost and complexity to the system. Also, if the plant supplies the DHP equipment, there are warranty issues in terms of which party takes responsibility for the equipment once installed. On-site installation also makes it more difficult to ensure uniform quality in DHP system performance.

2.5 Domestic Hot Water System

Heat pump water heaters – Research questions: supply air from home or outdoors? Tied into central ventilation system?

The HPMH specification requires that HPWH equipment meet Tier 2 of NEEA's Northern Climate Heat Pump Water Heater specification, plus have the ability to fully duct the process air. The project team examined three key elements: exhaust air ducting, quiet operation, and defrost capability to permit operation in colder temperatures. For ready integration into MH applications, the HPWH would be designed to draw air from the home's crawlspace, transfer its heat into the DHW tank, and then exhaust the resultant cool air via an exhaust duct to the outside. Appropriate products with sufficient availability are only now beginning to arrive in the market. Having the ability to use the HPWH as a key component in a whole-house heat recovery ventilation system remains very attractive to the project team, but there is no appropriate equipment available at this time. Further HPWH research and product development are warranted to help improve and increase the range of applications in which this technology can be used.

Changing to an HPWH will significantly improve the efficiency of the DHW system, relative to a conventional electric tank water heater. Several products have been demonstrated in the Pacific Northwest over the past several years, and a few units have shown good performance characteristics in both laboratory tests and home installations. One manufacturer, AirGenerate, produces equipment compliant with Tier 2 of the NEEA Northern Climate Heat Pump Water Heater Specification, and has reportedly secured Underwriters Laboratories approval for a unit that is capable of fully ducting both intake and exhaust air streams.

The project team worked with AirGenerate to arrange installation of a fully ducted unit in a customer-sold home, but the equipment ultimately proved to be unavailable in time for use in the project's prototyping work. Without a commercially available fully ducted HPWH on the market, the project team turned to PNNL for assistance with prototyping, using the manufactured home laboratory as a surrogate for an actual prototype home built in the factory. The PNNL laboratory homes are equipped with General Electric (GE) HPWH units that are not designed for ducted operation. The project team sponsored additional research testing at the PNNL facility, wherein one of the GE HPWH units was modified to accept duct fittings, and an inline fan was added to generate appropriate airflow through the ductwork. As modified, the HPWH was set up to pull air from the home's crawlspace and exhaust it to outdoors. Figure 15 shows the screened air intake in the crawlspace, and Figure 16 shows the exhaust ducting with inline fan fitted to the HPWH. The laboratory's monitoring and control equipment is being used to detect HPWH compressor operation and energize the inline fan in response.

Figure 15. HPWH screened inlet located in vented crawlspace

Figure 16. HPWH modifications to allow fully ducted operation

The project team is pushing to prototype a HPWH configuration that draws air from the house crawlspace, transfers heat into the DHW tank, and then exhausts the resultant cooler air to the outside, because this configuration has no impact on indoor air temperature or home ventilation systems, which greatly simplifies the home's mechanical systems. While this configuration can be expected to suffer a reduction in HPWH efficiency compared to one that makes use of indoor air, the project team finds this outcome acceptable when compared to attempting to obtain near-term deployable solutions to the challenges of introducing up to 200 CFM of makeup air into a home that is relying upon indirect conditioning of secondary zones to maximize the DHP's heating contribution or working with equipment manufacturers to develop new control strategies that permit interaction between HPWH, DHP, and home ventilation equipment.

3 Discussion

This project phase incorporated in-plant prototyping and preliminary construction process development for five measures that constitute the core components of the HPMH specification. This project will continue in subsequent years with prototyping of complete homes incorporating the full complement of HPMH specifications. Should the region's utilities choose to fund a coordinated program, then the subsequent years' work could involve a significant number of homes. Given that four of the five measures prototyped in this project phase have direct applicability to existing manufactured homes, other activities in subsequent years would include preparation of specifications or guidelines for use by programs retrofitting manufactured homes.

Through the first two phases of this Building America project the project team determined:

- The project successfully scoped the technological challenges at the plants involved with measure implementation for four of the five most challenging measures in the HPMH specification.
- This project phase demonstrated that the HPMH measures can be built as described by the specifications developed during this project's prior phase, so the anticipated electric energy savings ranging from greater than 8,000 kWh/yr up to nearly 11,000 kWh/yr over today's regional baseline home are supported. The actual measure costs will be determined on a plant-by-plant basis in the next Building America project phase that will build HPMH prototype homes. A few obstacles remain in terms of HPWH equipment availability and the extent to which appraisals might fail to value the option package.
- Given the lack of suitable HPWH unit availability, the HPWH measure's development has lagged behind other elements of the HPMH package. NEW staff and BPA met with AirGenerate personnel to discuss installing a unit to prototype in a NEEM home. The AirGenerate HPWH is currently the only HPWH that meets all the NEEA Northern Climate Spec Tier 2 criteria and is capable of fully ducting intake and exhaust air streams. AirGenerate's new fully ducted unit has not become available as anticipated. NEW, PNNL, and BPA are currently conducting testing on the GE HPWH at the PNNL home laboratory. Once the AirGenerate fully ducted HPWH becomes available, NEW plans to prototype the unit in a factory built home.
- The hybrid DHP zonal space conditioning system has performed very well in the first prototype homes, with retailers and homebuyers reporting that the homes have been comfortable in both heating and cooling seasons. The project team has very limited experience with DHP systems in climates with significant cooling loads, and more research into how well a single indoor head can be expected to cool homes with various floor plans is needed. It also is not known the extent to which ceiling fans in bedrooms might be able to increase air circulation throughout the home to effectively extend cooling into these zones. The project team anticipates that a home incorporating the full HPMH specification will prove even more able to be cooled well from a single, centrally located indoor head.
- The attic insulation improvements prototyped proved able to produce a marginal improvement to the attic's overall thermal performance, and they promise the ability to significantly improve the quality of insulation detailing in the attic eave area. The cost

involved with implementing this measure appears to be modest, especially since it also solves a common NEEM program compliance issue. The plants where the measures were prototyped responded positively to the results, as the improvement in insulation detailing was readily apparent.

- MH industry leaders have said that the appraisers will not give added value to the HPMH measures and will use simple $/ft^2 numbers to value even the HPMH. Low appraised values could cause a problem for anyone applying for a loan on a HPMH home. NEW staff will be working with Robin LeBaron of the Fair Mortgage Collaborative, to educate appraisers and banks to account for the value of the efficiency upgrade in the home valuation (Hewes and Peeks 2012). The HPMH specifications and measures have relative market acceptance/value from the perspective of MH industry leaders at the plants and retail home centers. The industry is eager to find ways to position its homes such that they will appeal to buyers looking for a more modern home and to take advantage of the positive momentum being generated by “Prefab” and “Factory-built” home media coverage.
- Housing Authorities, Habitat for Humanity, the U.S. Department of Agriculture, Indian tribes, and utilities are interested in the outcome of the HPMH project. The Housing Stock Upgrade Initiative in Oregon is interested in the project. This program incentivizes and induces the replacement of rural substandard housing, specifically obsolete manufactured homes, in a systematic manner and with a simplified approach for homeowners. The Housing Stock Upgrade Initiative is a broad-based and far-reaching initiative that intersects several important community and economic realms: local, regional and state economies; home building, home rehabilitation, green-building, and housing-related industries; job creation and retention in established industries; new business in leading-edge industries; employment skills and education; public health and public safety; energy use and efficiencies; preserving the environment. NEW has been working with the Governor’s Regional Solutions Team for SW Oregon and partnering with Curry County to identify priority projects with positive economic and human outcomes. The Housing Stock Upgrade Initiative is a priority project for Curry Co. Three homes have been replaced with energy-efficient manufactured homes in the last 5 months.

4 Conclusions/Lessons Learned

1. Electric energy savings ranging from more than 8,000 kWh/yr up to nearly 11,000 kWh/yr over today's regional baseline home are anticipated using this package across the entire region. The actual cost will be monitored in the next phase of this project where each plant will build an HPMH prototype home.

2. The higher cost of the HPMH home package could affect regional adoption of HPMHs in the Pacific Northwest. This cost factor could make it more difficult to secure mortgages, affecting customers' ability to finance homes. The utilities might be willing to incentivize the HPMH up to a level that could make the make the HPMH affordable. Affordability will be the focus of the next phase of the project.

3. The fully ducted HPWH is not available for purchase. The project team tried to prototype a home with an early release of a fully ducted HPWH, but the manufacturer was unable to make available the appropriate equipment.

4. Feedback from retailers about home sales indicates that the hybrid zonal DHP system is now being requested by some homebuyers. Retailers and customers can now order new homes with hybrid DHP systems installed in the factory. One retailer is selling more than 90% of homes to its customers as hybrid DHP-ready, with the zonal system installed in the factory and a DHP circuit wired to a disconnect outside the home, greatly simplifying DHP installation once the home is sited. One plant reports having installed nearly 50 DHP units. The DHP is a measure that has been accepted by the industry.

5. The hybrid zonal DHP system can be adapted to many manufactured home floor plans. The noise reduction might be a significant benefit of DHPs compared to typical manufactured home forced-air systems. Further work is needed to develop DHP installation approaches that rely upon work performed on site. It will be important for the NEEM program and local utilities to be able to track and be assured of quality installation.

6. Installation of exterior foam sheathing adds additional labor at a point in construction where most plants already experience production bottlenecks, so reconfiguring plant workstations might be required. The foam installation proved to be straightforward, and the modest material thickness appears to avoid the problem of siding fasteners missing framing members that other research efforts have reported with thicker foam layers being incorporated into the wall system. While it is too soon to be certain, the prototype home built for this project endured a 400-mile transport without any issues apparent at the time of setup or subsequently reported by the homeowner. The plants appear to recognize the thermal benefit from this measure, but they have not embraced it as yet. Additional prototyping on a simpler home might help prove to the plants the ease of implementation of this measure.

7. Triple-pane windows do not appear to present any significant technical challenges beyond the possibility that the additional weight of the windows might require some home models to be built with an additional axle under the home sections, but adoption of

the technology will require a window manufacturer to step forward and begin producing a value-oriented window line that incorporates the thermally improved extrusions and glazing units that together can achieve U-0.22 or better. More information on weight, transport, and cost issues will be needed to ensure this measure is durable and saleable.

8. Marginal improvement to attic insulation proved to be possible using commonly available materials. The prototyping effort also succeeded in demonstrating common deficiencies in current insulation practice, so the industry might be persuaded to adopt these improvements as a way to correct their current process.

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Appendix A: Outline of Construction Processes

Improved Attic Construction Practice

Option 1. Dense-packed loose fill insulation near roof eaves

Applicability: Flat or vaulted ceiling roof cavities insulated with blown-in fiberglass

Additional Materials Required:

- Insulation baffles, cardboard 32 × 24 in. with 1-in. side tabs and "tail" at least equal in length to truss heel height.

Installation procedure:

1. Prepare roof assembly and insulate ceiling as is typically done, except with the target insulation depth being the value determined by the specific truss geometry. See Table 3 and Table 4 for insulation target depth for commonly used roof trusses.

Table 3. Cellulose Loose Fill Insulation in Attic

Eave Insulation Strategy	Heel Height (in.)	King Post Height (in.)	Insulation Target Depth (in.)	Area-Weighted R-Value
Loose Cellulose	5.25	22.25	18.25	45.6
Fiberglass Batt	5.25	22.25	18.25	45.6
Loose Cellulose	5.25	37.4	13.9	45.2
Fiberglass Batt	5.25	37.4	13.9	45.0
Loose Cellulose	7	23	14.8	45.0
Fiberglass Batt	7	23	14.8	44.7

Table 4. Fiberglass Loose Fill Insulation in Attic

Eave Insulation Strategy	Heel Height (in.)	King Post Height (in.)	Insulation Target Depth (in.)	Area-Weighted R-Value
Dense-Pack	5.25	22.25	21	45.4
Fiberglass Batt	5.25	22.25	21	45.6
Dense-Pack	5.25	37.4	14.3	45.4
Fiberglass Batt	5.25	37.4	14.3	45.0
Dense-Pack	7	23	15.5	45.1
Fiberglass Batt	7	23	15.5	44.7

2. Install baffles, if not installed for initial insulation blow, stapling the side tabs and the tail to framing members so as to create an even 1-in. airspace along the truss top chords and completely enclose the wall top plate under each baffle.
3. Rake insulation down ceiling toward eave, packing it into the cavity formed by the ceiling and insulation baffles until the center of the baffles are deflected upward by approximately 1 in.

4. Push down on baffles, further compressing the insulation and returning the baffles to a flat shape.
5. Reblow insulation to fill the void created by raking insulation toward the eave, anticipate needing one 30-lb bag of insulation per 10 ft of attic length (depending upon specific truss geometry).

Option 2. Compressed fiberglass batt insulation near roof eaves

Applicability: vaulted ceiling roof cavities insulated with blown-in fiberglass or stabilized cellulose

Additional Materials Required:

- Insulation baffles, cardboard 32 × 24 in. with 1-in. side tabs and "tail" at least equal in length to truss heel height
- R-38 fiberglass batts, 48 × 24 in.

Installation Procedure:

6. Install fiberglass batts in eave area, ensuring proper fit of batt:
    - completely cover wall top plate
    - split insulation around wiring, framing, plumbing vents, etc. to keep insulation in full contact with attic floor
7. Install baffles, compressing the batts, then stapling the side tabs and the tail to framing members so as to create an even 1-in. airspace along the truss top chords and completely enclose the wall top plate under each baffle

Prepare the roof assembly and insulate ceiling as is typically done, except with the target insulation depth being the value determined by the specific truss geometry and considering the thermal performance of the compressed fiberglass batt for the given heel height of the truss. Anticipate saving about 1½ 30-lb bags of loose fill insulation per 10 ft of attic length (depending upon truss geometry). See Table 3 and Table 4 for insulation target depth for commonly used roof trusses.

Wall With Exterior Foam Sheathing Construction Practice

Applicability: all conventional wood-framed walls

Additional Materials Required:

- ⅝-in. thick R-4 polyisocyanurate foam sheathing, 4 × 8 ft sheets
- 0.092 × 2½-in. collated siding nails (for use with ⅜-in. thick cement or composite board siding, other fasteners may be needed for different siding types)
- Doors ordered with ⅝-in. deeper jambs to allow for the walls' added thickness, or
- ⅝-in. thick moulding stock to add between door jamb and casing.

Recommended Additional Materials:

- Building wrap, or (if suitably faced foam is used)
- Sealing tape designed for use to face-seal foam sheathing and create a water resistive barrier

Installation Procedure:

1. Construct and install exterior walls as is typically done, up to the point of siding the walls.
2. Install building wrap, if not face-sealing foam sheathing.
3. Staple rigid foam to wall assembly, taking care to tightly butt joints of foam sheets.
4. Cut out window and door openings where foam may have been installed over said openings.
5. Measure and mark stud locations as needed to ensure fasteners strike framing through foam.
6. Face-seal foam with special tape, if applicable, and seal any damaged areas on foam facing.
7. Install siding and corner trim.

Triple-Pane Window Installation Practice

Applicability: all homes

Additional Materials Required:

- U-0.22 or lower windows
- Shims, wood or plastic, for supporting window on sill of rough opening
- Backer rod and caulking, or
- Spray foam, soft formulation for use with windows and doors

Recommended Additional Materials:

- Flexible adhesive window flashing

Installation Procedure:

Note: each window manufacturer will supply installation instructions specific to its products. While these recommendations are intended to describe quality installation practices, window manufacturer's instructions take precedence, as they constitute requirements for obtaining warranty coverage.

1. Apply flexible adhesive flashing to window sill, ensuring that the material:
    - Laps over foam sheathing and adheres to the rough opening sill
    - Extends down foam sheathing at least approximately as far as the window nail fin covers
    - Wraps up the sides of the window opening by at least 2 in.
2. Apply caulking sealant to window nail fins on four sides of the window, leaving a few small gaps on the bottom fin
3. Install window into rough opening, using shims to set window square in the opening support corners of window and interior edges of glazing units on horizontal sliders
4. Install fasteners through nail fins in accordance with window manufacturer instructions, ensuring that smooth window operation is maintained
5. Install adhesive flashing over vertical side nail fins, then install over head of window, lapping over side pieces
6. Trim window as is typically done
7. Install appropriate diameter backer rod between window and rough opening on all four sides, apply caulking to complete the seal
8. Finish interior window trim as typically is done, noting that the depth of the window opening may be different as a result of the foam sheathing adding thickness to the wall assembly and the triple pane window possibly extending further into the window opening

Ductless Mini-Split Heat Pump Hybrid Electric Zonal Heating System

Applicability: Most one- and two-section homes, many three-section or larger homes with open floor plans and low to moderate cooling needs

Additional Required Materials and Equipment:

- Ductless mini-split Heat Pump equipment
- Electric resistance heaters
- Refrigerant lineset
- 14-2-G cable suitable for indoor/outdoor use, tray cable recommended, UF-rated cable also acceptable—for interconnection between compressor and indoor head
- Condensate piping/tubing, size and material selection depending upon application
- Compressor wall-mounting brackets (consider keeping at least one set of rail-hung brackets in inventory to facilitate installation in the event of wall framing errors or construction change orders fail to deliver wall studs and/or blocking in the necessary locations
- Vibration isolator pads
- Stainless steel fasteners for mounting brackets to wall and compressor to brackets
- Equipment electrical disconnect on a circuit sized for the equipment load or fused to provide the necessary protection for the DHP equipment
- Flexible weather-tight conduit, fittings and securing clamps
- Lineset cover with various terminus, weather head and corner fittings
- UV and weather resistant tape for lineset protection and dress-up
- UV resistant low-expansion foam sealant
- Self-drilling concrete/metal screws (#10 or #12 by ½-in. to 1-in. long) and plumber's strapping or clamps for securing lineset along chassis, if applicable

Installation Procedure:

Note: The following is not an exhaustive job process description, as specific applications will vary in the specific actions required for proper installation of the DHP and the supplemental electric resistance heaters. DHP equipment has model-specific requirements for clearances, electrical connections, etc. that must be considered when planning for equipment location. In-plant training of all personnel involved with designing, drafting, installing, supervising, and inspecting should be considered a necessary pre-requisite to incorporating DHPs into the plant's homes. A properly licensed refrigeration technician is required to evacuate and release refrigerant into the system, and it is highly recommended that the same individual make all refrigerant connections. DHP systems completed in the field also will require a licensed electrician to make the connections between the equipment disconnect, indoor head and the outdoor compressor. The following job process outline is for a DHP system completely installed in the plant.

1. Before construction begins, perform heat loss calculations for the home using design temperatures appropriate to the home's potential siting destination.
    a. Select appropriate DHP equipment. Primary considerations include appropriately sizing indoor head to the space where it is to be located. A unit that is too large may result in the indoor head delivering high airflow close to where people likely will be sitting, and a unit that is too small may require more electric resistance heating in the main zone of the home.
    b. Determine DHP equipment placement. Primary considerations include locating indoor head and outdoor compressor on the same home section to facilitate complete installation at the factory and placing the indoor head where it will be able to mix air within the main zone of the home. Avoid placing the indoor head near heat-producing appliances. Whenever possible, locate the indoor head on an interior wall that backs up to a closet or on an exterior wall to facilitate access to the indoor head's lineset connections. Include wall framing and/or blocking in locations where equipment will be mounted to the home. This is most critical for the outdoor unit, as its mounting brackets must be fastened into framing members.
    c. Determine electric resistance heater locations. If supplemental heating is required in the home's main zone, locate it away from the DHP and close to heavily glazed areas in the zone, if possible. Bedroom heaters require a 3½-in. deep wall cavity for mounting, and locating heaters on a closet wall can minimize the amount of wall that must be framed with 2 × 4 studs.
2. Prepare indoor head mounting and holes for lineset routing.
    a. Tack wall mounting bracket in place, ensuring each end of the bracket is the same distance up the wall from the floor (level). Using bracket as a template, mark locations of mounting holes on the wall. Install drywall anchors in locations near attachment tabs on mounting bracket that are not backed by wall framing or blocking. Install mounting bracket to wall.
    b. Using guides on mounting bracket locate center of hole to accommodate refrigerant and condensate lines and power cable. Drill pilot hole through wall, taking care to drill perpendicular to wall. Use pilot hole as the center of larger hole to be sawed on the side of the wall with the indoor head and as the top of the hole on the opposite "backside" of the wall to ensure that the condensate line will get a good drop out of the indoor head.
    c. If indoor head is being mounted on an interior wall, saw hole through floor deck, directly adjacent to the backside wall (so lineset cover will cover the hole) to accommodate condensate line and, if routed under the home, refrigerant lines and electrical cable. If lineset and electrical cable are to be routed through the attic, drill hole through ceiling directly adjacent to the backside wall.
    d. Install back half of lineset cover and fittings to wall(s)
3. Working outside the home, unroll refrigerant lineset and tape it together with electrical cable every few feet to facilitate routing through the home's attic, along the chassis or in lineset cover mounted on the exterior of the home.

4. After the home is sided and painted, bore hole through gable end wall into attic or through floor rim joist near the outdoor compressor, or trim siding that hangs below bottom of rim joist for routing lineset against bottom of rim joist (also requires including setup instructions for notching skirting or perimeter foundation at the location where lineset passes through).
5. Route lineset and electric cable from outside the house to the inside head location, taking care not to kink the copper lines. Bends in the lines must be made gradually and with proper support given to the inside of the bend. Be certain ends of lineset remain tightly closed at all times, and leave enough extra length at both ends to allow for making tubing flares and connecting the lines to the DHP equipment.
6. Mount outdoor unit. For applications where the outdoor unit will be mounted to the end wall, locate framing members installed to accommodate mounting brackets. Measure to ensure level bracket mounting, drill pilot holes, apply caulking to the holes and install brackets with stainless steel lag bolts.
7. Mount outdoor unit with stainless steel bolts to brackets, using vibration isolators between unit and brackets.
8. Make electrical connections from the indoor head to the interconnecting cable and install indoor head onto mounting bracket, pulling slack cable toward the outdoor unit as the head is installed. Take care to ensure the condensate drain line is located at the bottom of the bundle of lines and tubes as the head is installed onto the bracket.
9. Make electrical connections to the outdoor compressor, running wiring in flexible weather-tight conduit wherever it exposed outside of the home. Secure conduit to home with clamps as necessary.
10. Connect condensate drain tubing to indoor head’s stub out. Run tubing through floor decking and transition to pipe to carry condensate outside the home footprint. Plumb the piping in the same manner as is done for high efficiency gas furnace condensate drain piping.
11. Refrigerant technician can now cut lineset tubing to length, flare the tubing ends, make connections to the indoor head and outdoor compressor, flush the system with nitrogen, check for leaks, evacuate the system, check for leaks, release refrigerant, and test system.

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