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Northwest Energy Efficient Manufactured Housing Program Specification Development

Tom Hewes and Brady Peeks

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Northwest Energy Efficient Manufactured Housing Program Specification Development

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15013 Denver West Parkway

Golden, CO 80401

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Prepared by:

Tom Hewes and Brady Peeks

Northwest Energy Works of the

Building America Partnership for Improved Residential Construction

37368 Blue Heron Rd.

Corvallis, OR 97330

NREL Technical Monitor: Stacey Rothgeb

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Definitions

ACH	Air changes per hour
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
gpd	Gallons per day
gpm	Gallons per minute
HPMH	High performance manufactured home
HPWH	Heat pump water heater
kW	Kilowatt
kWh	Kilowatt-hours
LED	Light-emitting diode
LPD	Lighting power density
MAP	Manufactured Housing Acquisition Program
MH	Manufactured housing
NEEA	Northwest Energy Efficiency Alliance
NEEM	Northwest Energy Efficiency Manufactured Housing Program
NEW	Northwest Energy Works
NPCC	Northwest Power Conservation Council
O&M	Operations and maintenance
PNNL	Pacific Northwest National Laboratory
RTF	Regional Technical Forum
SEEM	Seasonal Energy and Enthalpy Model
Uo	U overall
W	Watt
WSU	Washington State University Extension Energy Program

Executive Summary

The Building America Partnership for Improved Residential Construction, the Bonneville Power Administration (BPA), and Northwest Energy Works, the current Northwest Energy Efficient Manufactured Housing Program (NEEM) administrator, collaborated to conduct research on new specifications that would improve on the energy requirements of a NEEM home. The team also evaluated energy savings that would result from the new specifications. In its role as administrator, NEEM administers the technical specs, performs research and engineering analysis, implements ongoing construction quality management procedures, and maintains a central database with home tracking.

For this project, researchers asked three questions:

1. Which measures could be built into a NEEM home to achieve a 50% reduction in space conditioning, lighting, and water heating energy use, compared with usage levels resulting from the current specifications?

2. What are the challenges in building a high performance manufactured home (HPMH)?

3. What are the modeled energy savings of an HPMH?

This research identified and developed combinations of cost-effective high performance building assemblies and mechanical systems that can be readily deployed in the manufacturing setting. Key technologies explored and implemented included ductless heat pumps (DHPs) with zonal electric resistance heating in secondary zones, heat pump water heaters, high performance windows, new wall assemblies with reduced thermal bridging (e.g., exterior rigid foam sheathing), and new roofline designs that allow for more insulation.

Acknowledgments

We want to thank Eric Martin and the staff of the Florida Solar Energy Center Building America Partnership for Improved Residential Construction and Subrato Chandra and Graham Parker at the Pacific Northwest National Laboratory, in addition to all the other project partners. The region’s manufactured housing industry is a key partner in this project. Northwest Energy Works worked with many of the factories’ engineering, production, and quality management personnel to develop and test each measure proposed for inclusion in the new HPMH specifications. Plant staff at Fleetwood Homes of Oregon and Kit Homebuilders West deserve special thanks for their contributions. 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 the 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.

Thanks to Ecotope Engineering's David Baylon and Bob Davis, who provided engineering, technical support, and measure development to the project. Ben Larson's energy modeling work and presentation to the Regional Technical Forum were absolutely first rate.

Thanks to Jim Russell of RC Creative Group and home design company Ideabox, LLC. Russell's knowledge of and experience with designing and building HUD-code homes allowed him to contribute important market planning for a HPMH program to the project. Ideabox sold 8 of its last 10 homes with DHPs and agreed to prototype a home with R-5 foam sheathing.

The Heat Pump Store specializes in DHPs, and its staff trained the factory personnel to install DHP zonal heating and cooling systems. Jeff Pratt, president of The Heat Pump Store, and his business partners John and Sara Marisconi own and operate Ductless Supply in Portland. Ductless Supply offered wholesale prices to all the manufactured home plants in the Pacific Northwest. In addition they trained plant personnel to factory install the DHP systems. The Heat Pump Store teamed up with Northwest Energy Works to train installers to size and install the hybrid DHP zonal electric heating systems.

1 Introduction

Based on the most recent (2008) evaluation field survey and billing analysis (Baylon, et al. 2009) of the Northwest Energy Efficiency Manufactured Housing Program (NEEM) homes, the annual potential savings percentage for a high performance manufactured home (HPMH) over a typical baseline home produced in the Pacific Northwest region (Idaho, Montana, Oregon, and Washington) would be 50%. This equates to about 8,000 to 10,000 kWh for each home produced and sited. Northwest Energy Works (NEW) worked with the manufactured housing (MH) industry, the involved in-plant primary inspection agency, the appropriate design approval primary inspection agency (DAPIA), retailers, industry associations, the Building America Program, the Pacific Northwest National Laboratory (PNNL), the Northwest Power Conservation Council (NPCC), and utilities to develop the HPMH specifications.

Achieving this level of energy efficiency improvement requires several significant changes to current construction methods and mechanical system designs. This research involved technical support to manufacturers to help them with developing measure costs and construction processes and prototyping new systems and building assemblies. The measures developed for the NEEM HPMH specification have appreciable applicability to existing manufactured homes, especially measures that affect the home's structure. This effort involved engineering approvals for the new construction methods. Construction methods developed through this project might well be readily adopted as best practices in new and retrofit work.

This research identified and developed combinations of cost-effective high performance building assemblies and mechanical systems. These systems can be readily deployed in the manufacturing setting to reduce energy used for space conditioning, water heating, and lighting.

The results of energy modeling of the HPMH were presented to the NPCC's Regional Technical Forum (RTF), which accepted the specifications and established deemed energy savings values based on the energy modeling results. Pacific Northwest private and public utilities use the RTF's approved deemed savings to develop incentives for programs like the HPMH.

Key technologies included in the research at NEEM participating plants and included in the HPMH follow:

- Ductless heat pumps (DHPs) with zonal heating in secondary zones: The hybrid zonal system eliminates the existing electric forced-air furnace and duct system from the home altogether. A single ductless mini-split heat pump connected to one or two indoor heads is sized to meet the majority of the home's heating load, and electric wall or baseboard heaters are located throughout the house so that each room has an independently controlled supplemental source of heat. The DHP differs from conventional unitary heat pump equipment in that a DHP can be reliably installed and commissioned on the production line, ready for transport to the homebuyer's site. This eliminates the need for aftermarket heat pump installation. With technical support from NEW, plant workers will design and install supplemental zonal heating systems appropriate for all Pacific Northwest climate zones.

- Heat pump water heaters (HPWHs): The HPMH specification will require that HPWH equipment meet Tier 2 of the Northwest Energy Efficiency Alliance's (NEEA's) Northern Climate Heat Pump Water Heater specification, plus have the ability to fully duct the process air. The project team wants to be sure to achieve three key elements: exhaust air ducting, quiet operation, and defrost capability to permit operation in colder temperatures. For optimal operation in MH applications, the HPWH would be designed to draw air from the home's crawlspace, transfer its heat into the domestic hot water (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.
- High performance windows (R-5): Triple pane vinyl windows are available in the Pacific Northwest. The company that currently supplies the majority of the region's manufactured housing window market is not building R-5 windows, but two window manufacturers supplying a minority of the region's manufactured housing industry are producing R-5 windows.
- Improved wall assembly: A new wall assembly with exterior rigid foam sheathing added to reduce thermal bridging can be implemented with modest impact on plant production processes. The Kit Homebuilders plant in Idaho is prepared to prototype this wall assembly. NEW will assist with any needed DAPIA engineering approvals before the prototype home is built.
- Improved attic thermal performance: New roof insulation strategies can achieve a marginal improvement to current practice without changing the roof trusses being used. Switching to trusses with greater heel heights could result in taller home sections and cause transportation issues. The primary improvement that appears to be feasible for implementation involves increasing insulation levels in the eave areas and extending inward up to 4 ft, resulting in an attic depth sufficient for blown-in insulation to achieve acceptable insulation levels. Compressing high-density R-30 fiberglass batts under baffles and dense packing loose fill cellulose insulation under baffles could prove to be 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. One plant has expressed interest in exploring the use of spray foam for its attic assemblies.

1.1 Background

In 1992 the Bonneville Power Administration (BPA) and the MH industry agreed to a single energy efficiency standard that would apply to all electrically heated homes sold in the Pacific Northwest. This became known as the Manufactured Homes Acquisition Program (MAP). MAP was an unqualified success because of the cooperative agreement among all parties. Between 1992 and 1995, approximately 40,000 homes were built under this program and the HUD standard was exceeded by a factor of two in overall heat loss and heating requirements. The region secured almost 30 average megawatts of savings (260 million kWh annually) from this program.

When MAP ended in 1995, the state energy offices joined with the MH industry to continue operating a certification program for the industry, initially branding homes as Super Good Cents.

This new oversight effort became known as NEEM, which adopted specifications at the MAP level of energy efficiency. Today's homes are branded as ENERGY STAR, Earth Advantage, or Eco-rated (a brand developed by the NEEM program). The underlying energy efficiency specifications have been expanded to cover items like duct testing, lighting, higher efficiency equipment, and better windows, but the core building shell requirements remain largely unchanged.

NEW is the third-party administrator for the NEEM program. NEEM administers the technical specifications, performs research and engineering analysis, implements ongoing construction quality management procedures, and maintains a central database with home tracking. To ensure that qualified homes are recognized in the market for their unique value, NEEM also provides utilities with home certification validation. NEEM is supported by more than 74 utilities in the Pacific Northwest region and California that currently offer incentives for ENERGY STAR labeled homes. Working with the Building America Partnership for Improved Residential Construction research team, NEEM is promoting the HPMH to the utilities and the MH industry.

2 Specifications for the High Performance Manufactured Home

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 average of 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 per square foot basis); CFL, compact fluorescent lamp; LED, light-emitting diode; ACH, air changes per hour; cfm_{50}, cubic feet per minute at 50 Pa; EF, energy factor

3 Developing the Measures

All of the shell improvements and energy efficient mechanical technologies proposed for inclusion in the HPMH package are buildable, but require significant revisions to floor plans and factory processes.

3.1 Improved Floor Insulation Effectiveness

Removing the duct system will allow about 25% more insulation in the floor system, and it will now be possible to install insulation in contact with the subfloor. Plumbing supply lines will be installed with adequate insulation below them to prevent freezing in even the coldest climates.

3.2 Rigid Insulation on the Exterior of the Wall Structure over the Sheathing

R-5 foam sheathing (¾-in.-thick polyisocyanurate) will be installed on the exterior walls of a home, causing about a 25% reduction in the overall heat conductivity of the wall system. R-5 foam sheathing will be supplied by the HPMH project and installed on a prototype home in the plant, with NEW staff on hand to monitor both the time implications for the added process and any potential impacts on building durability or insulation effectiveness. Construction job processes will be monitored in the plants to ensure buildability.

3.3 Triple Glazed Windows

The HPMH specification calls for triple glazed low-E windows with a U-value of 0.22 or better. Two window manufacturers supplying a small portion of the MH industry (Cascade and Jeld-Wen) do build R-5 windows, but the current leading supplier of the MH window market (Kinro) is not building this grade of window. As an example, 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. These windows were recently installed in a laboratory home at PNNL in Richland, Washington. The windows were able to replace the existing window packages without significant design impacts in the PNNL laboratory home. Airtightness tests and light levels will be monitored before and after retrofit.

3.4 Increased Ceiling Thermal Performance

The target performance for the vaulted ceiling assembly is U = 0.026 or R-45. The current assembly for the ENERGY STAR manufactured home program is U = 0.29 for vaulted ceilings. Insulation will be prototyped and costs gathered to change the ceiling insulation detail for conventional trusses, increase the truss heel dimension to approximately 8 in., or use hinged trusses to gain higher heel heights without increasing the overall transport height of the home. New roof insulation strategies for conventional trusses will include using a high-density R-30 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 will be compressed but still have a higher R-value than loose fill insulation) and inward for 4 ft, where the attic depth will be sufficient to transition to blown-in insulation for the rest of the attic. High-density blown cellulose at the eve will also be prototyped.

3.5 Overall Uo Reduction

The combined impact of the changes to the thermal envelope described in sections 3.1 through 3.4 would improve the overall Uo of the home. Uo is the average hourly conductive heat loss for the building envelope on a per square foot basis, per degree (°F) difference between inside and ambient conditions. The changes will result in an improvement from the current NEEM specification of about 0.054 to a level of about 0.040. This represents nearly a factor of two reduction in heat-loss rate over the current national northern tier HUD standard (Uo = 0.079).

3.6 HVAC System

Because the DHP will be combined with zonal electric heaters in each bath and bedroom, the existing electric forced-air furnace and duct system will be eliminated from the home altogether. The alternative HVAC system, based on a DHP, will be installed. The system is called a hybrid DHP zonal electric heating system, because the DHP will be combined with electric wall heaters or electric baseboard units (sizes range from 750 W to 2.0 kW depending on the climate and room size) located throughout the house. In the prototype homes the zonal electric backup units are expected to be from Cadet, a local producer, but any comparable product could be used.

The electric resistance heaters supplement the primary heating system, which is the DHP. 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 heat loss 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. Remote rooms will be conditioned indirectly most of the time, with the back-up electric resistance wall heaters supplementing as needed, especially in extreme conditions. Using a zone heating system of this type eliminates numerous thermal envelope penetrations attributable to the duct system. Although the NEEM program requires each home's ducts to be tested online to ensure no more than 6 cfm_{50} air leakage per 100 ft^2 of floor area, removing the ducts as a leakage path is expected to noticeably reduce whole-house air leakage.

3.7 Domestic Hot Water System

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 in the last 2 years, and a few units have shown good performance characteristics in both laboratory tests and home installations. One product, AirGenerate, has just recently been approved as the only product compliant with Tier 2 of the NEEA Northern Climate Heat Pump Water Heater Specification. Ducted intake and exhaust systems are not available in the United States but are available elsewhere in the world (e.g., in Canada). A model from AirGenerate with ducted intake and exhaust is currently going through UL and HUD approval processes in the United States.

To further improve the efficiency of the DHW system, a hot water conservation package would be added. Low-flow (1.75-gpm) showerheads and faucet aerators (1.0 gpm) would be included as well as water-conserving appliances. Given current regional laboratory results and field performance, a 50% reduction in the energy requirements for DHW over the base home was found as a result of the Seasonal Energy and Enthalpy Model (SEEM) modeling the team conducted. The project has identified three approaches to incorporating the HPWH into homes.

3.7.1 Design Option 1

In design option 1, the HPWH would be designed to draw air from the house crawlspace, transfer its heat into the DHW tank, and then exhaust the resultant cool air to the outside. There would be no impact on indoor air temperature or home ventilation systems. One plant's DAPIA has presented this option to HUD, and HUD has ruled that a plant wishing to use this approach would need to submit a request for an alternate construction letter of approval, which could be used for all homes.

3.7.2 Design Option 2

Design option 2 makes use of the HPWH as the central component in a ventilation system for the home. The HPWH would operate intermittently, drawing up to 300 cfm from the house and exhausting it outside, according to the hot water demands of the occupants. Daily run times would range between 3 to 6 h. Using the interior-coupled system, the overall ventilation rates provided by the HPWH could exceed the current NEEM and HUD standards by about 20%. Design option 2, though, is not a viable option because of the HUD approvals needed and because the high ventilation rate would necessitate providing significant make-up air for home pressure balancing. HPWH run times could in theory obviate the need for a separate whole-house ventilation system, although this strategy could be in conflict with HUD standards. The spot ventilators (bath and range hood fans) currently used in the NEEM homes would still be required as part of the ventilation system. Because the HPWH would be moving more air when it runs than the conventional whole-house ventilation fan, fresh air make-up might need to be drawn in via dampered air inlets, possibly located in the bedroom closets and the water heater compartment. Design option 2 is being included in this discussion because it was discussed with the industry and computer modeled in SEEM before being eliminated as a result of the impracticality of introducing the necessary volumes of outdoor air into rooms that are hopefully being largely conditioned indirectly from a single DHP indoor head located in another room.

3.7.3 Design Option 3

The project team refined the heat recovery approach to create design option 3, where the AirGenerate HPWH would be fitted with a restrictor to bring the air flow rate down to 175 cfm. This is the minimum air flow that laboratory testing has shown not to significantly affect the HPWH unit's performance. The 175-cfm HPWH airflow, coupled with a fan like the Panasonic WhisperGreen located in the master bathroom, could be set to provide 30 cfm continuously and bump up to 80 cfm when needed for spot ventilation. This combination could meet the required HUD ventilation rate (the HUD ventilation standard is 0.0035 times the square footage of the home up to a maximum of 90 cfm continuous for the whole house). The president of AirGenerate US toured a NEEM plant and commented that its 175-cfm restrictor would work in this configuration if the HPWH had free access to house air. The combination WhisperGreen/AirGenerate175-cfm option is in the process of being reviewed by the DAPIA for prototyping in one plant. Pressure diagnostic testing of a prototype home will help determine whether fresh make-up air will be required for pressure balancing.

3.8 Lighting

Essentially 90% of all lamps will be high efficacy. Eco-rated home certification, which is a green home brand developed by the NEEM program, already requires 50% CFLs or equivalent. The project team anticipates using some modern LED lighting for accent application, with the bulk of lighting being provided by conventional screw-in CFLs. The effect of this specification would be to reduce the power required by the lighting system by more than 50%.

3.9 Appliances

Appliances are the most difficult areas to address because new home buyers do not always purchase appliances when they buy a home, or they buy appliance at an appliance store after the home is installed. When a new HPMH home is sold, there is no way to require a new high-efficiency laundry set, for instance. The HPMH specification calls for high performance ENERGY STAR (or ENERGY STAR Plus) appliances to be provided as part of the home package when a customer purchases new appliances with the home. These would typically include a refrigerator and a dishwasher. Homes that receive NEEM Eco-rated certification already have to meet this requirement. These products are included in the HPMH package so that both the hot water savings and energy savings associated with these efficient appliances are part of the complete energy efficient package.

3.10 Wholesale Price to the Retailer

Table 2 presents the estimated measure installed wholesale price (which includes labor and materials) from the manufacturer to the retailer before any markup by the retailer for the elements of the HPMH specification. Wholesale price comprises the manufacturer's cost of material, labor, and typical markup to the retailer. The variability in retail markup practices makes it difficult to estimate retail pricing for the energy packages, and retail pricing is not presented here. A retail markup of 15% to 20% for the energy packages, however, seems to be a reasonable estimate. The shell upgrades of R-21 walls with R-5 exterior foam and high R windows (U = 0.22 or better) represent the majority of the envelope wholesale price. Operations and maintenance (O&M) costs are listed for each measure to assist with benefit/cost analysis. The project team has presented its findings for regional utility program consideration. Shell measures are installed one time and there are no differential O&M costs. The HPWH filter has a positive O&M cost of $26 for cleaning the inlet air filter. The lighting system has a negative O&M cost from a reduction in changing bulbs over time, due to the longer life of energy efficient lamps compared to incandescent lamps. Washington State University Extension Energy Program's (WSU's) findings from its 2011 industry survey and market analysis project, "Cost Assessment for Manufactured Homes," provide the basis for the estimates (Eklund and Gordon 2011). Appendix A presents the measures studied by WSU to develop costs for by surveying home manufacturers, material suppliers, and wholesale/retail sources.

Table 2. Measure Wholesale Price by Category

Category	Notes	$ (2011)	$ (2006)	Measure Life (yr)	Annual O&M ($, 2006)
Envelope	Majority from walls and windows	4,277	3,816	45	—
Air Sealing and Ventilation	Whole-house exhaust fan	50	45	20	—
HVAC System	DHP and resistance wall heaters (less the cost of furnace and duct system)	4,701	4,194	20	—
DHW	HPWH	1,110	991	15	26
Lighting	Compact and linear fluorescents	117	105	8	(13)
Appliances	Dishwater and refrigerator	62	55	16	—
Total		10,318	9,205		

3.11 Modeling

The building energy use was predicted by a combination of numerical simulations and engineering calculations. SEEM was used to simulate heating, cooling, ventilation, and water heating energy use. The program combines building shell characteristics, thermostat settings, occupant behavior inputs, descriptions of heating and cooling systems, and duct distribution efficiency to develop an overall estimate of the energy requirements of a house. Additionally, engineering calculations calibrated by field studies were employed to determine the energy use for lighting and water heating. Annual gross lighting savings were calculated as lighting power density (LPD) multiplied by affected floor area and annual operating hours. This method assumes that all lamps in the house operate 1.5 h/day throughout the year.[1] Concurrently, the modeling accounts for heating system interactions by changing internal gains for SEEM simulations.

SEEM (version 0.94), the residential energy simulation program used for this analysis was developed by and for the NPCC and the NEEA and written by Larry Palmiter of Ecotope. It is the simulation engine used to generate heating and cooling energy savings estimates for the residential sector in the Northwest Power Plan and for the Performance Tested Comfort System incentive program, as well as numerous other utility program offerings. SEEM is also used extensively to support state building energy code revisions including, most recently, the revised *Washington State Energy Code* and *Oregon Residential Specialty Code.*

The SEEM program consists of an hourly thermal, moisture (humidity), and infiltration simulation that interacts with ducts, equipment, building shell, and weather parameters to calculate the space conditioning requirements of the building. It is based on algorithms consistent with current ASHRAE, American Heating and Refrigeration Institute, and International Organization for Standards calculation standards. The simulation generates outputs used in this analysis, which include building heat loss, heating equipment input energy, cooling equipment input energy, and ventilation equipment input energy.

The DHP simulation capability is unique to SEEM. The method, based on findings from the *Ductless Heat Pump Impact & Process Evaluation: Field Metering Report* (Baylon et al, 2012), is calibrated to detailed observations of energy use in 91 houses pre- and post-DHP installation. Table 3 presents actual energy use and model predictions. The DHP used has a heating seasonal performance factor of 10 and a seasonal energy efficiency ratio of 20 in the main living zone with electric resistance in other zones. The field metering report shows that the DHP provides differing fractions of the total heating demand based on climate zone with the DHP supplying a higher percentage of total heating demand in warmer climates than in colder ones (heating fractions are heating zone 1 = 74%, heating zone 2 = 63%, and heating zone 3 = 45%). The DHP house-cooling fraction is assumed for the model to be identical to the heating fraction. Based on the small number of metered home data sets that present DHP cooling energy, metered data shows that occupants do not call for cooling when the outside temperature is 74°F or below.

[1] RTF Meeting, Tuesday, September 28. Accessed February 9, 2012: http://www.nwcouncil.org/energy/rtf/meetings/2010/09/.

Table 3. SEEM DHP Performance Calibration Results

Method	Heating Energy Use (kWh/yr)		N
	Mean	SD	
Pre-Installation Billing Data	9,347	3,892	91
Pre-Installation SEEM 66.8°F Set Point	9,331	4,135	91
Post-Installation Metered Data	6,484	3,894	91
Post-Installation SEEM 69.5°F Set Point	6,466	3,151	91

Notes: N, sample size or number of homes; SD, submetered data

The weather files used in all savings simulations are composite Typical Meteorological Year 3 weather files that correspond to the heating and cooling climate zones the RTF has assigned to each Northwest county.[2] The Typical Meteorological Year 2 directory contains the data files for the typical meteorological year data sets derived from 1961 to 1990. Typical Meteorological Year 3 covers 1991 to 2005.

The three prototype houses used in the simulations were as follows:

- 924 ft^2, single-section manufactured house
- 1,568 ft^2, double-section manufactured house
- 2,352 ft^2, triple-section manufactured house.

These are standard analytical prototypes used by the NPCC to develop and evaluate energy forecasts and conservation plans for the region's utilities. When the three prototypes are weighted together by their market fractions, the result is an "average" house with a floor area equal to 1,572 ft^2, which closely aligns with the average home size of what actually is being built in the region. This validates the prototypes as being representative.

In all, Ecotope conducted 675 simulations with SEEM. This number includes the three prototypes; three heating climate zones and three potential cooling climate zones associated with each heating climate zone (nine heating-cooling climate zones in total); a baseline performance house; the current NEEM standard performance house; and three variations of the HPMH (ultimately, the team settled on one specification but investigated three possibilities related to HPWH installation scenario).

The simulations used a HPWH compliant with Tier 2 of NEEA's Northern Climate Heat Pump Water Heater Specification to determine the energy saving over a baseline home. This HPWH was used based on feedback from representatives of DAPIAs, who said that the best way to meet the various HUD rules was not to use any house air. This helped keep the number of HPWH simulations to a lower number.

For this energy modeling exercise the HPWH was configured so that the tank is installed in a sound-attenuated buffered closet that draws air from the crawlspace and exhausts it outdoors. This HPWH configuration avoids conflicts with existing HUD requirements. The annual HPWH

[2] RTF Climate Zone Maps. Accessed February 9, 2012: http://www.nwcouncil.org/energy/rtf/zones/zonemapsx.htm.

energy use is based on mapping the annual crawlspace air temperature profile to a coefficient of performance versus temperature performance map. Water heating energy was calibrated to the equivalent of 17–18 gpd per occupant.[3] The home occupancy was set at 2.2 based on a 2009 survey of NEEM program houses. The baseline house gallons per day use is higher than the HPMH case because the HPMH specification calls for a 1.75-gpm showerhead, but the baseline assumes the federal maximum of 2.5 gpm. The HPWH installed in a closet might be the final solution or it could be another option. The HPMH project team will prototype other options in the future.

The regional baseline (non-NEEM) home used for the SEEM energy modeling has U overall (Uo) = 0.0647 (current practice home being built in the Northwest, referred to as "HUD+" in Table 4, below). Minimum HUD standards require homes to have a Uo ≤ 0.079. The HPMH home used in the SEEM energy model has a Uo = 0.040. In 2011, the project team personally interviewed representatives of each of ten manufacturing plants in the region to gather information on NEEM percentage versus current practice percentage versus modular percentage.

NEW used the database and the prescriptive performance paths list in the database for each manufacturer, along with the 2010 composite weighted average baseline for non-NEEM home thermal performance. Production percentages were used and adjusted to reflect the mix of basic HUD homes and partially thermally upgraded homes for each manufacturer. The team then multiplied the R- or U-value for each component of each package by that package's fraction of plant production to arrive at each manufacturer's weighted average thermal package. Using the 2010 production numbers to obtain each manufacturer's market share of non-NEEM homes, NEW then multiplied each manufacturer's average thermal package component R- and U-values by the respective market share percentage, which resulted in a composite, weighted average baseline, non-NEEM, thermal shell package for the industry as a whole. The regional baseline home has a window thermal performance value derived from a mix of aluminum and vinyl windows. The non-NEEM baseline home presented is intended to be conservative (at the energy efficient end of the likely range). R-19 walls were de-rated to reflect the actual value in a 2 × 6 wall (R-17), but assemblies like R-11 batt insulation in a 2 × 6 wall cavity were not de-rated because commonly agreed-on thermal performance values for the assembly were lacking. When the baseline components are substituted for NEEM program requirements in the prototype home models, the resulting weighted average Uo comes in at 0.0647.

3.12 Energy Use Calculations

Ecotope analyzed the HPMH specifications for their energy savings and cost-effectiveness potential, and the energy modeling results were presented to the NPCC's RTF. Figure 1 presents the HPMH package energy savings over the regional baseline home produced by NEEM-participating builders. Figure 2 presents total energy use in each of the climate types in the region, and Figure 3 further breaks out end uses in the home. Gaining RTF concurrence with cost-effective energy savings attributable to the new specifications is a necessary step to permit BPA to consider moving forward with developing a program around the HPMH.

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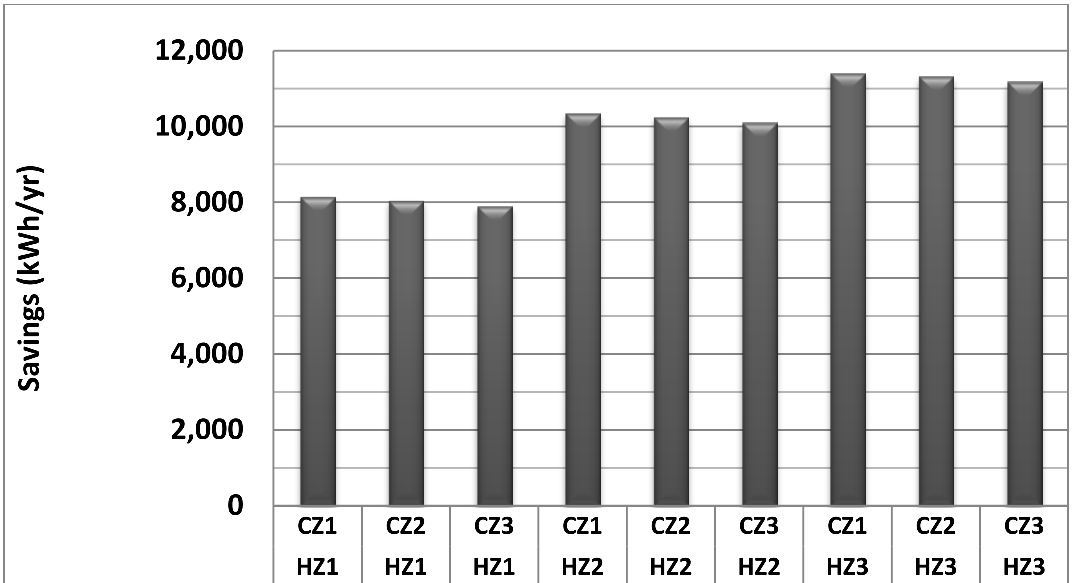
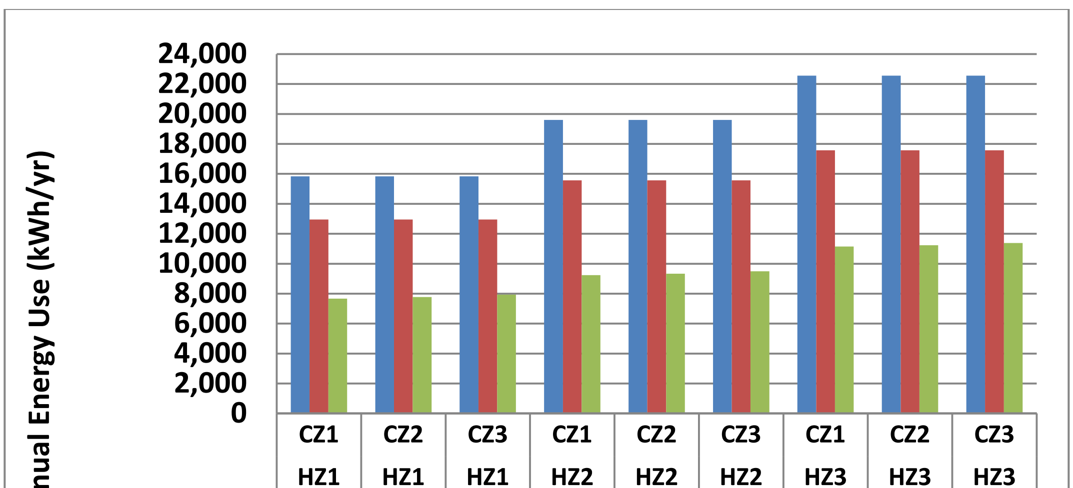
[3] RTF provisionally approved savings measure. Accessed January 4, 2013: http://www.nwcouncil.org/energy/rtf/measures/measure.asp?id=176.



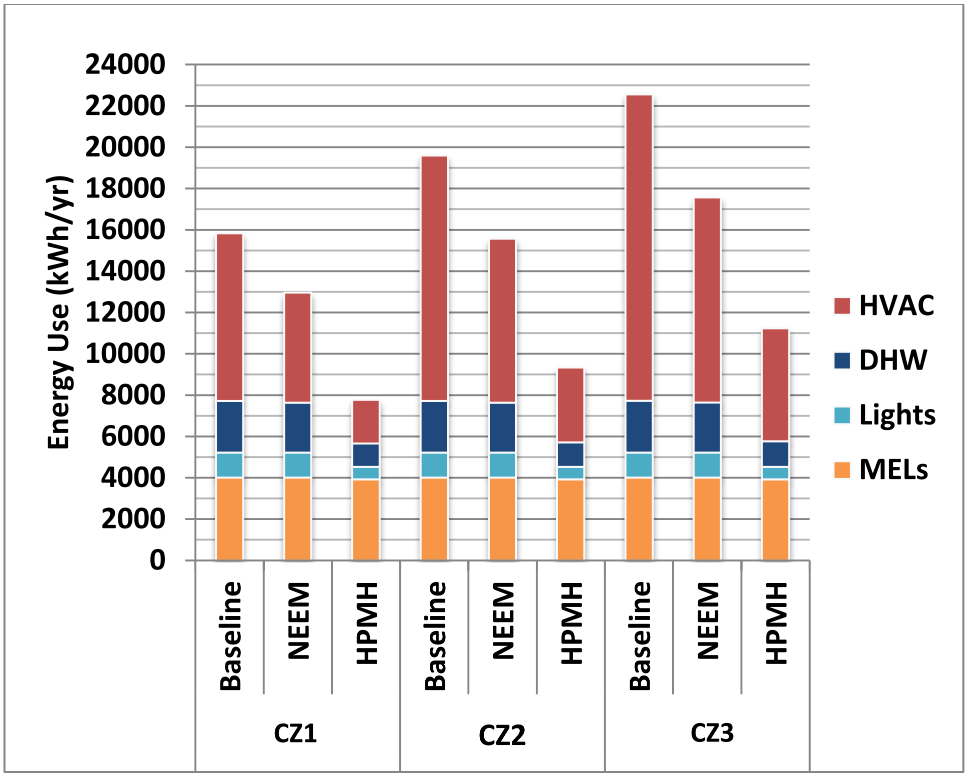
	CZ1 HZ1	CZ2 HZ1	CZ3 HZ1	CZ1 HZ2	CZ2 HZ2	CZ3 HZ2	CZ1 HZ3	CZ2 HZ3	CZ3 HZ3
HPMH to Baseline	8,168	8,066	7,902	10,358	10,261	10,102	11,411	11,323	11,179

Figure 1. HPMH annual energy savings (prototype weighted)



	CZ1 HZ1	CZ2 HZ1	CZ3 HZ1	CZ1 HZ2	CZ2 HZ2	CZ3 HZ2	CZ1 HZ3	CZ2 HZ3	CZ3 HZ3
Baseline	15,836	15,836	15,836	19,597	19,597	19,597	22,558	22,558	22,558
NEEM	12,957	12,957	12,957	15,567	15,567	15,567	17,570	17,570	17,570
HPMH	7,668	7,771	7,935	9,239	9,336	9,495	11,147	11,235	11,380

Figure 2. Manufactured home total energy use (prototype weighted)



Note: MELs, miscellaneous electric loads

Figure 3. House energy use by category

3.13 Savings

NEW and its partner, Ecotope, used SEEM to predict energy usage and the NPCC Pro-Cost model for the preliminary cost-effectiveness assessment. These tools were selected because BPA and the NPCC use them to assess energy savings and regional cost effectiveness. Broadly, the analysis methodology is to develop a representative set of prototypical houses in which energy use can be estimated through simulation tools. The energy savings are then used as inputs to the Pro-Cost calculations to estimate the benefit/cost ratio over the lifetime of the house. Table 4 gives the results.

Table 4. Energy Use, Savings, and Benefit/Cost Ratio

Climates		Total Annual Energy Use (kWh/yr)			Savings (kWh/yr)		(yrs)
Heating	Cooling	Baseline "HUD+"	NEEM	HPMH	HPMH to Baseline	B/C Ratio	Measure Life
HZ1	CZ1	15,836	12,957	7,668	8,168	1.9	37
HZ1	CZ2	15,836	12,957	7,771	8,066	1.8	37
HZ1	CZ3	15,836	12,957	7,935	7,902	1.8	36
HZ2	CZ1	19,597	15,567	9,239	10,358	2.3	39
HZ2	CZ2	19,597	15,567	9,336	10,261	2.3	39
HZ2	CZ3	19,597	15,567	9,495	10,102	2.3	38
HZ3	CZ1	22,558	17,570	11,147	11,411	2.6	39
HZ3	CZ2	22,558	17,570	11,235	11,323	2.6	39
HZ3	CZ3	22,558	17,570	11,380	11,179	2.5	39

4 Next Steps

NEW will work with manufacturers, DAPIAs, and in-plant primary inspection agencies to develop the specific details of how various measures could be implemented. These details include how to meet structural and other code requirements, optimize cost efficiency in implementing measures, and ensure consistent outcomes when installing the measures.

NEW will ask the MH industry to build prototypes of some of the equipment (DHP and HPWH) and building materials such as foam sheathing and windows in a few of its new NEEM homes to ensure correct operation. NEW will purchase materials or equipment in some cases or the homebuyer will purchase the equipment such as the DHP. BPA will provide funding for materials to be used in the prototype homes. Prototyping shell and mechanical innovations in the plants will include drawing new details or floor plans and working with suppliers to gain access to new equipment and materials.

The DHP measure involves significant changes to how the homes are designed and built, so NEW plans to hold a half-day session on designing, installing, and pricing DHP hybrid heating systems in Portland, Oregon, at Ductless Supply, a wholesaler interested in working with the industry to incorporate DHPs. NEW staff and the manufacturers will run the designs for the hybrid DHP through the DAPIAs used by those plants. The factories will need DAPIA and possibly HUD approval for the prototype homes. NEW will work with the plant staff and Ductless Supply to coordinate installation details and assess how well the DHP installation process might be incorporated into the plant's regular production methods. The DHP-ready home will receive the DHP equipment when it arrives on site, with NEW staff present to assess the relative efficacy of this approach. NEW will visit the sites and train retailers to ensure proper O&M of the hybrid DHP system. Retailers will show the model homes.

Other materials, such as foam sheathing and triple pane windows, should be fairly straightforward changes to implement. Materials will be provided by the HPMH project and installed in the plant, with NEW staff on hand to monitor both the time implications for the added process and any potential impacts on building durability or measure effectiveness. Two NEEM homes will be used to prototype exterior R-5 foam sheathing, and one home will receive triple pane windows. NEW staff will also meet regularly with key groups, such as state MH associations, to bring the industry up to date on progress with the different shell and mechanical systems measures. These regular meetings will also maintain an active dialogue about positioning the concept of high performance in the MH market.

5 Discussion

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 anticipated using the HPMH package across the entire Pacific Northwest. Total package cost in 2011 dollars is estimated to be $10,300.

As technical specifications were developed, NEW assessed the relative market acceptance/value of the measures and scoped the levels of technological challenge involved with their implementation. For example, the process of designing and siting a DHP, running refrigerant line, and installing wiring and condensate drains will require three or more factory installs for a plant to become proficient enough to determine whether in-plant installation is feasible. HPMH homes can be sold with the DHP factory installed or DHP ready. The latter option requires the DHP to be installed on site. Retailers and factories need to be trained on how to sell DHPs and the finer points of design (e.g., where to locate the indoor head for optimal performance and ease of installation). The ideal install's floor plan would have an alcove on the exterior side of the home where the DHP is installed and the refrigerant lines are run up and in without lengthy line runs. As an alternative to the alcove, DHP outdoor units can be wall-mounted on the non-tongue end of the home and refrigerant and power lines can be run along the steel I-beam and up into a closet behind the wall where the indoor head is located.

Given the lack of suitable HPWH unit availability until just recently, the HPWH measure's development has lagged behind other elements of the HPMH package. NEW staff and BPA will meet 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. AirGenerate is a pioneer of heat pump water heaters based in Houston, Texas. AirGenerate builds hybrid HPWH models that are available as 50-gal or 66-gal configurations. Both models include a stainless steel tank, an auto-defrost system, a duct for exhaust air, and industry-leading efficiency with an energy factor of 2.4. There is also an AirTap add-on model that can convert any existing water heater tank to an energy-efficient one. AirGenerate is conducting laboratory and field testing on the HPWH with the help of BPA, NEEA, and the National Renewable Energy Laboratory. NEW is hoping to prototype the unit in one factory built home in the near future.

In the past, customers or home manufacturers have given no negative feedback on R-5 exterior foam sheathed walls except for the associated material and labor cost. The triple pane R-5 windows have only been retrofitted into a PNNL laboratory home in Richland, Washington, and have not been tried in a production line setting because of the high cost. High-density fiberglass batt over the top plate is easy to install (with a corresponding increase in production time) but requires the manufacturer to inventory another type of insulation, which is not normally used by most plants.

NEW spoke on four occasions at industry association meetings, asking participants to give honest feedback to the team on the HPMH specification. Industry association membership comprises banks, finance companies, home retailers, material suppliers, and home manufacturers. The industry leaders have said that the appraisers will not give added value to the HPMH measures and will use simple dollars per square foot numbers to value even the HPMH. Low appraised values could cause a problem for anyone applying for a loan for the HPMH homes. NEW staff spoke to Robin LaBaron of the National Home Performance Council, who reported that the council had just developed a new MH loan product for credit unions with an energy efficiency addendum that the appraisers could use to add the value of the efficiency upgrade to the value of the home (Hewes and Peeks, 2012). That would allow Fannie Mae and Freddie Mac to take into account P(principal)I(interest)T(taxes)I(insurance) and E(efficiency) instead of just PITI when qualifying buyers.

6 Conclusions

1. 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 anticipated using this package across the entire region. Total current package cost (2011 dollars) is $10,300.

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

3. The MH industry is awaiting the results of the utility system's cost-effectiveness calculations and possible incentive program.

4. Feedback from retailers indicates that they might order a DHP in their model homes in the future. Retailers and customers can order new homes with hybrid DHP systems installed in the factory. A retailer can also sell homes to their customers as hybrid DHP-ready, with just the zonal system installed in the factory and a DHP circuit wired to a disconnect outside the home.

5. The hybrid zonal DHP system can be adapted to many MH home floor plans.

6. The noise reduction might be a significant benefit of DHPs compared to typical MH forced-air systems.

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Appendix: Cost Assessment for Manufactured Homes

In 2011 Washington State University Extension Energy programs conducted a cost study and literature review of potential technologies that could be considered for the HPMH program. The project considered a number of measures and examined several approaches to implementing each measure. NEEM-participating homebuilders were consulted for their experiences, concerns and levels of interest in exploring each of the measures and the various approaches. The resulting white paper was titled "Strategic Recommendations to Improve Energy Efficiency in Manufactured Housing" (Eklund et al. 2011). Following a brief summary of the options found, this appendix contains an excerpt from Eklund et al. 2011 (pp.8-12). The authors of this report have added comments in italics throughout the excerpted material, which is not part of the original work.

Summary of Options Found in Literature Review

There are a number of envelope, HVAC and lighting technologies that have potential in manufactured homes. The most cost effective of these are probably envelope measures that are not significant variances from current practice. For example, advanced framing cuts production cost and increases efficiency. Blown in Blanket (BIB) type insulation systems are efficient and require little clean up. Rigid foam on the exterior of walls does not require special equipment or safety measures in plants. High efficiency windows may compare well to more dynamic measures such as Structural Insulated Panels.

The excerpt from the white paper follows:

High R Walls

Advanced Framing: the manufactured industry has moved away from 24-inch on center framing and insulated headers. The concerns identified by industry need to be addressed before this approach sees wide adoption, via direct technical assistance, and where needed, research and demonstration to identify issues with (and corrections for) construction processes, preservation of roof loading capability and avoidance of material failures that might lead to uneven siding or "nail pops." In addition, even where manufacturers have used 24- inch on center framing and fully insulated headers, these construction practices may fall short of fully optimized advanced framing approaches, using more framing lumber at corners or interior walls than is necessary.

Structural Insulated Panels (SIPs): In 2000, Champion Industries constructed the first HUD code home using SIPs. While there were challenges associated with design of an all-SIPs house, the DAPIA approval process, and training of plant staff to accommodate new processes and materials, the home was successfully constructed in-plant, experienced fewer transportation-related complications compared to other factory built homes, and was found to be more airtight than a typical HUD code home (Baechler, Hadley, Sparkman, & Lubliner, 2002). In addition, the manufacturer concluded that SIPs construction could be easily incorporated into the HUD code construction process, and could even increase production capacity, helping to offset increases in production costs.

In spite of these advantages, it's important to note that no HUD code home has been built with SIPs since 2000. In one case, NEEM staff working in Idaho was actively engaged with a manufacturer that also owned a SIP plant opted not to construct their HUD homes with SIPs; even with that vertically integrated structure, the use of SIPs was not perceived as economically feasible.

Spray foam: In 2002, WSU and the Idaho Energy Division worked with Kit Homes to construct the Zero Energy Manufactured Home on the Nez Perce reservation in Lapwai, Idaho. The project specifications called for the use of spray foam (Icynene) in the walls, floors and ceiling. Kit's experience with using spray foam within the factory setting was that using foam requires significant modification of the production process, with additional needs for worker safety, and a significant amount of cleanup post- installation. The foam industry has expressed interest in working with the manufactured housing industry and other interested parties to overcome these issues.

Blown in Blanket Type Systems (BIBs): These systems are widely used in site-built housing and produce better quality installation and higher R-values. Most of the systems are designed so preparation is quick and there is no significant cleanup. No extraordinary measures are required to ensure worker safety beyond those needed for batt insulation. Many manufacturers already use blown insulation for ceilings and even floors, and should be able to adapt to blowing insulation into walls.

Exterior foam walls: While exterior foam sheathing has made inroads into the site built market, and has even been used in some modular homes, this building practice has not, to our knowledge, been used in manufactured housing. According to WSU's interviews with the DAPIAs, there are no structural issues with the use of foam sheathing in manufactured housing, when used in conjunction with the current shear system. Additional research may be required as to the maximum thickness of the foam, given transportation and on-site setup considerations. *The project opted to develop this approach for potential inclusion in the HPMH package*.

High R Roofs

SIPs: As noted in the walls section, other than for demonstration purposes, SIPs have not been adopted by the manufactured housing industry, largely because of cost considerations. SIPs applications in attics can provide a conditioned space for HVAC duct chases and other mechanical systems, and can eliminate the house to exterior leakage related with the use of a vented attic. Also, for single section homes, SIPs can provide higher R-value throughout the roof assembly, including at the eaves, and may accordingly reduce the overall height of the home, avoiding transport height restrictions.

Spray foam under roof decking: Application of spray foam to the roof deck could potentially provide similar benefits to the SIPs roof noted above, allowing for inclusion of mechanical systems in an unvented attic, and reducing house leakage. DAPIAs noted that the use of foam would require a change to the HUD requirements for attic venting (unless the assembly was fully enclosed), *and the current production process that constructs the ceiling assembly as ceiling drywall glued to roof trusses and ridge beam would require significant re-design*.

High density R-30 Fiberglass: a four-foot batt could be extended to the first 48" of the eaves. Typical insulation at eaves is about R-15. Use of high-density batt at the eaves would improve this by about a third, even with compression. *Use of a commercially produced insulation baffle would assure adequate attic ventilation space, prevent wind washing and cause only the necessary amount of insulation compression.*

Foam at eaves: Since high-density polyurethane foam is already used for gluing the bottom of the truss chord to drywall, it may be that this foam could be extended to cover the ceiling for the first 24" in from the eaves. Typical insulation at eaves is about R-15. Use of high-density foam at the eaves could potentially double this, *but plants reported that the product currently being used is not designed to be installed at the depth being considered and is prohibitively expensive to be used in this manner.*

Foam blocks at eaves: Similar to the strategy noted above, this approach would use a foam wedge to baffle blown roof insulation, and add high-density foam insulation to the eaves to significantly increase the R-value. This product is currently unavailable, but could be developed if program standards included a requirement for full insulation value at the eaves.

High density R-30 Fiberglass: a four-foot batt could be extended to the first 48" of the eaves. Typical insulation at eaves is about R-15. Use of high-density batt at the eaves would improve this by about a third, even with compression. Use of a commercially produced insulation baffle would help assure adequate attic ventilation space, prevent wind washing and cause only the necessary amount of insulation compression. The project opted to develop this approach for potential inclusion in the HPMH package.

High R Floors

SIPs: When Champion constructed their all SIP home in 2000, they chose to locate the duct system in the crawlspace. If used in conjunction with a SIP cathedralized attic, the duct system could be brought into conditioned space. *The underfloor plumbing system, on the warm side of the floor insulation with the plants' present floor system, would be outside the conditioned space of the home and would require insulation to prevent pipe freezing. No plants reported interest in making the capital investment that would be required to change their production lines to accommodate SIPs construction.*

Spray foam: In the Zero Energy Manufactured Home constructed in 2002, the manufacturer needed to apply the foam to an R-11 belly blanket, because the foam wouldn't adhere to the belly fabric. The research team working on the home also determined that the trunk ducts should not be foamed, to allow for beneficial conductive heat loss from the ducts to the home (regain). *The plant reported a significant cost increase and production impacts from this spray foam application.*

Fiberglass batt and blanket: Many manufacturers currently install R-33, via batts between floor joists and blankets under the entire floor assembly to meet the present NEEM specifications. Others install a single fiberglass blanket under the entire floor assembly and blow-in loose fill insulation on top of that to achieve the full R-value. 2x6 floor joists constrict the depth of the insulation in the 24- to 36- inches of the floor outboard of each of the trailer chassis I-beams.

Switching to 2x8 floor joists would help improve the insulation in the "outrigger" areas, but the added house height can be problematic when it comes to home transport. If the heating duct can be removed from the floor, the possibility arises to add more insulation to the center section of the floor – the "belly" area. The project team opted to develop this approach for potential inclusion in the HPMH package.

High Efficiency Windows

Production windows are now approaching U factors of 0.2. An issue with these windows is whether they employ multiple panes that may make them too heavy or fragile for transport in a HUD Code home. This should be investigated and tested *for potential inclusion in the HPMH package.* If they work, they may be at the top of the list for acquisition, as they are likely to be a part of future versions of the IECC.

HVAC Equipment and System Technologies

Ductless heat pumps: Ductless heat pumps (DHPs) have become a popular option in the site built industry, in new construction and retrofit applications. Manufactured homes, because of their layout, may be good candidates for this technology, utilizing a central DHP, in conjunction with zonal electric resistance heating in bedrooms. Multi-head systems may allow for further reductions in zonal electric heating, at higher cost and with some penalty to DHP system efficiency. Another potential element of a DHP hybrid electric zonal heating system that needs further research is the use of transfer fans to move conditioned air from the central zone into the back rooms. (HUD's requirement for a heat source in each habitable room may be not permit the full benefit of this approach from being realized.) Further investigations are also needed into any potential requirements for HUD listing of equipment or code conflicts that may need to be resolved to best accommodate DHPs. *The project team opted to develop this approach for potential inclusion in the HPMH package.*

Variable refrigerant flow central heat pumps: Variable refrigerant flow (VRF) heat pumps utilize technology similar to the ductless heat pump noted above, achieving significantly higher efficiencies than traditional air source heat pumps. Nordyne has recently begun producing a VRF system that will work in manufactured housing – additional independent research is needed to determine viability of this system in manufactured housing and in the Pacific Northwest climates.

Heat Pump system commissioning and controls: Heat pumps need to meet specifications for charge, flow, thermostat setup and outdoor lockout to operate correctly. Heat pumps meeting the Northwest's PTCS specification are estimated to achieve an average of 900 kWh annual savings over heat pumps without commissioning.

Electric furnaces with improved blowers and good duct design: Given that the majority of manufactured homes are shipped with electric furnaces, it would be useful to examine how this technology could be improved. The use of a blower with an electronically commutated motor (ECM) can result in savings of 30% and upwards, when compared with a standard blower motor. The use of ECMs also introduces opportunities to mix air from a centralized DHP system, and may also allow for use of the blower fan as an efficient ventilation system. It's important to note that ECMs are very sensitive to high static pressure, requiring intelligent duct design that keeps the static pressure to .5 inches of water column (125 Pa) or less.

Electric Zonal heating and cooling: The use of zoned heating and cooling systems has the benefit of eliminating the need for a ducted distribution system. The disadvantages cited by the industry are higher system costs, and eliminating the option of post setup installation of a heat pump or central air conditioner (this argument holds less weight given the increased availability of ductless heat pumps).

Other systems: Other technologies with wide deployment throughout the United States, but with less use in the Pacific Northwest, include residential economizers and evaporative coolers. Evaporative coolers have long been used to cool manufactured homes in southwest Idaho and eastern Washington. Demonstration of new technologies incorporating these methods of cooling may expand their use in manufactured homes.

Domestic Hot Water Technologies

Heat Pump Water Heaters: Heat pump water heaters (HPWHs) are a high visibility technology beginning to be heavily promoted throughout the country. In the heating-dominated Pacific Northwest, extracting heat from the conditioned space to heat water has the effect of delivering space cooling during the many months of the year when it very likely is not desired. HPWH configurations that may be appropriate for the Pacific Northwest include placing the HPWH in a sectioned-off utility room where colder temperatures are not a significant issue, or using the HPWH to exhaust cooled air from the house to the exterior, which has the added benefit of providing heat recovery ventilation. If the home is heated with a ductless heat pump, the combined system acts in effect as a two-stage heat pump. If HPWHs are to be promoted, they should meet and be installed to NEEA's Northern Climate Specification (Northwest Energy Efficiency Alliance, 2009) to ensure savings are obtained and the units are installed properly. *The project team opted to develop this approach for potential inclusion in the HPMH package.*

Plumbing system design: "Structured plumbing" systems, which reduce energy and water losses through designs that limit trunk and branch runs, insulate all pipe, incorporate circulation loops and a recirculation pump, have the potential to save 80% or more of the waste water and hot water in a "typical" home. Manufactured housing, with single story layouts, has the potential for a lot of wasteful design (distances of 60 feet from water heater to appliance are not unheard of in multi-section homes. WSU has had discussions with Gary Klein of Affiliated International Management on the potential of structured plumbing approaches in both the IECC and HUD codes, as well and energy and water conservation programs.

Lighting Technologies

Compact and other fluorescents: While compact fluorescent lighting (CFL) is widely available in retail, and CFLs are widely used in energy efficiency programs for site built homes, WSU's survey of the northwest manufacturers only identified five of ten manufacturers who shipped CFLs with the home, and then only when the customer selected the Eco-Rated or Earth Advantage options. Manufactured housing has a lot of untapped potential in this regard. *The project team opted to specify an efficient lighting target as a fraction of installed lamps for* *potential inclusion in the HPMH package*. Alternative design strategies for fluorescent technologies, such as dimmable T8 and T5 lamps in wall and ceiling valances, have proved to be effective and aesthetically pleasing in demonstration homes such as the WSU Energy House (Lubliner, 2000).

LEDs: LED technology has progressed significantly in the last decade, though costs remain high, especially for lamps with better color rendering ability. A demonstration home using LEDs might be the best strategy for deploying this technology in the manufactured housing marketplace.

Solar Technologies

Solar ready: Given the high first costs for both solar thermal and PV systems, neither technology is a cost effective option for the mainstream manufactured home buyer. However, including a "solar ready" option facilitates the after-market installation of solar technologies by implementing in-plant provisions such as roof load calculations, roof penetration flashing and mounting systems, pre-installed piping and conduit chases, and mechanical room design. Incremental costs are estimated at $300-$2100 (in climates with reduced snow loads, the existing roof design can accommodate the weight of the panels, reducing the need for a roof upgrade).

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