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Retrofit of Blown Attic Insulation in Existing HUD-Code Manufactured Homes: Needs Assessment Report

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Retrofit of Blown Attic Insulation in Existing HUD-Code Manufactured Homes: Needs Assessment Report

Prepared for:
U.S. Department of Energy Building America Program
Office of Energy Efficiency and Renewable Energy

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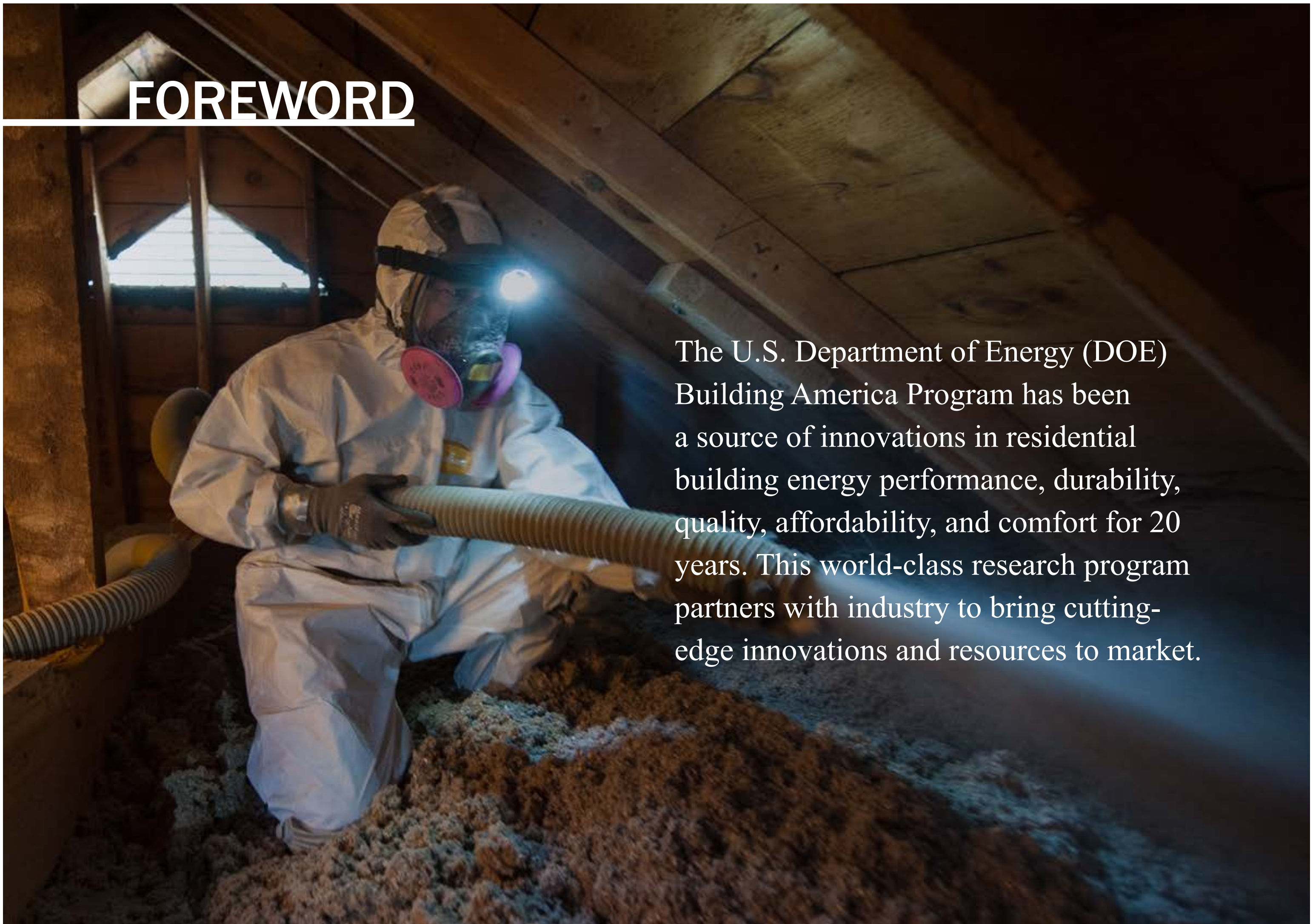
FOREWORD



The U.S. Department of Energy (DOE) Building America Program has been a source of innovations in residential building energy performance, durability, quality, affordability, and comfort for 20 years. This world-class research program partners with industry to bring cutting-edge innovations and resources to market.

The Building America Program supports the DOE Building Technologies Office Residential Building Integration Program goals to:

1. By 2020, develop and demonstrate cost-effective technologies and practices that can reduce the energy use intensity (EUI) of new single-family homes by 60% and existing single-family homes by 40%, relative to the 2010 average home EUI in each climate zone, with a focus on reducing heating, cooling, and water heating loads.

2. By 2025, reduce the energy used for space conditioning and water heating in single-family homes by 40% from 2010 levels.

In cooperation with the Building America Program, the Washington State University Extension Energy Program team is one of many Building America teams working to drive innovations that address the challenges identified in the Program's Research-to-Market Plan.

This report, "Retrofit of Blown Attic Insulation in Existing HUD-Code Manufactured Homes: Needs Assessment Report," explores current practices of the Department of Energy's Weatherization Assistance Program, including insulation and roof venting solutions that improve attic insulation energy savings and durability for manufactured homes.

As the technical monitor of the Building America research, the National Renewable Energy Laboratory encourages feedback and dialogue on the research findings in this report as well as others. Send any comments and questions to building.america@ee.doe.gov.

ACKNOWLEDGMENTS

The work presented in this report was funded by the U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy, Building Technologies Office. The needs assessment was conducted by the Washington State University (WSU) Extension Energy Program with guidance and support from Josh Olsen and Derek Schroeder, of DOE, and Kelly Kutchin and Glen Salas, who are subcontractors at SMS Results.

The purpose of this report is to disseminate the findings from a needs assessment of issues related to attic insulation retrofits in manufactured homes that meet building codes specified by the U.S. Department of Housing and Urban Development (HUD-code) as installed by DOE's Weatherization Assistance Program (WAP).

The original design for this research was developed by the Building Science Corporation (BSC) Building America team with input from WAP stakeholders. As part of the evaluation plan development, the design team consulted with and received feedback from various stakeholders involved with WAP, the HUD-code manufactured housing industry, and residential building science research.

BSC contracted with the WSU Extension Energy Program, which worked with stakeholders to develop this report. The authors thank those who participated in producing the needs assessment, including WSU Extension Energy Program colleagues Ken Eklund, Luke Howard, Adria Banks, Vince Schueler, and Melinda Spencer. We are also grateful to the following people for their significant contributions to this effort:

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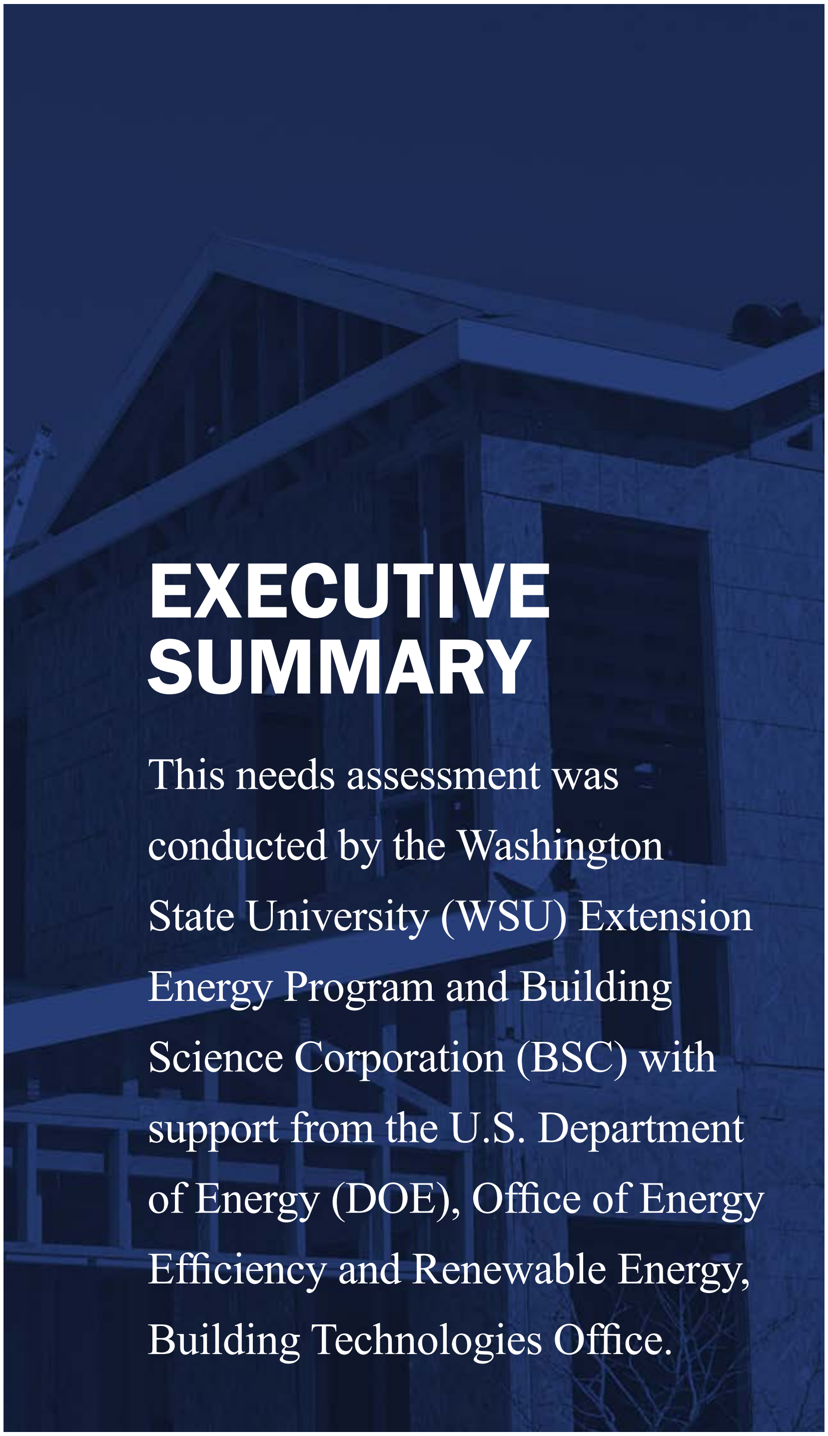
LIST OF ACRONYMS

ACH50	Air changes per hour at 50 Pa
BLAST	Building Loads Analysis and System Thermodynamics
BSC	Building Science Corporation
CAP	Community Action Partnership
CFA	Conditioned floor area
DOE	U.S. Department of Energy
ELA	Effective leakage area
HUD	U.S. Department of Housing and Urban Development
HVAC	Heating, ventilating, and air conditioning
ICC	International Codes Council
IECC	International Energy Conservation Code
MHCSS	Manufactured Home Construction and Safety Standards
NEEM	Northwest Energy Efficient Manufactured Housing Program
OSB	Oriented strand board
PNNL	Pacific Northwest National Laboratory
SHGC	Solar heat gain coefficient
SIR	Savings-to-investment ratio
SWS	Standard work specifications
TMY	Typical meteorological year
TREAT	Targeted Retrofit Energy Analysis Tool
WAP	Weatherization Assistance Program
WSU	Washington State University



EXECUTIVE SUMMARY

This needs assessment was conducted by the Washington State University (WSU) Extension Energy Program and Building Science Corporation (BSC) with support from the U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy, Building Technologies Office.

The primary goal of this research was to identify moisture durability, energy savings, and savings-to-investment ratio (SIR) research needs related to the retrofit of attic insulation in DOE's Weatherization Assistance Program (WAP)—specifically, manufactured homes that comply with building codes established by the U.S. Department of Housing and Urban Development (HUD) built after 1976 and sited in colder climates. This project assessed current practices of WAP insulation and/or roof venting solutions that improve attic insulation energy savings and durability.

WSU and BSC conducted outreach to stakeholders via email, phone, in-person interviews, and group meetings designed to inquire about relevant issues stakeholders might have observed. Needs assessment feedback was provided from stakeholders involved with attic insulation retrofits in existing HUD-code manufactured housing in the colder climates of the United States. The list of more than 50 stakeholders who provided input into this assessment is provided in Appendix A.

Critical needs were discussed with the following stakeholder groups:

- *Residential building science community* at the 2016 Thermal Performance of the Exterior Envelopes of Whole Buildings XIII International Conference and 2017 ASHRAE winter and annual meetings. Additional discussions were implemented at the 2017 Westford Symposium.

- *WAP practitioners and management involved in field installations* at the 2017 Home Performance Coalition National Home Performance Conference cosponsored by WAP. WSU coordinated and participated in a session on manufactured housing weatherization at the 2017 conference. This provided an opportunity to engage those involved with all aspects of WAP associated with manufactured home retrofits and gain perspectives related to the real and perceived challenges of attic insulation retrofits under WAP. Additional discussions occurred in June 2017 with the WAP Training Consortium to share the current needs assessment findings and solicit ideas to consider when developing the test plan.

- *Manufactured housing industry stakeholders*, including builders, suppliers, and government stakeholders at DOE, HUD, and other organizations involved with implementing and enforcing HUD-code as part of the HUD Manufactured Home Construction and Safety Standards.

The key project objectives and general findings include:

Objective 1: *Identify and evaluate the* ***cost-benefit challenges*** *associated with attic insulation retrofits*. Targeted Retrofit Energy Analysis Tool (TREAT) and Pacific Northwest National Laboratory energy modeling was used to determine the SIR where attic insulation is cost-effective (e.g., SIR greater than 1.0). Results suggest challenges in milder climates and in locations where lower cost natural gas is available, as expected. Maximum target costs to achieve attic insulation are provided for various climate zones and heating systems/fuel types. These costs vary depending on the climate, fuel type, and attic insulation R-14 or R-20 baseline assumptions. Community Action Partnerships (CAPs) in northern climate states have generally been able to achieve these cost targets except for the natural gas heating case.

Objective 2: *Investigate **building science-related concerns** about why attic retrofits were not occurring as frequently as other measures.* These included challenges presented by (1) access to the attic to insulate, (2) inability to meet the SIR in mild climates and/or where lower cost natural gas is available, (3) code conflicts about reducing venting at the eave, and (4) HUD-code homes not specifically addressed in the standard work specifications (SWS), especially for a new innovative gable end wall access insulation approach. Historically, the SWS focused on pre-HUD-code 1976 vintage manufactured homes.

Objective 3: *Determine **technical resources and future research** that would help stakeholders more confidently insulate attics in manufactured homes.* The recommendations are to (1) conduct a field evaluation to assess the attics that have previously been insulated by CAPs for moisture issues, (2) evaluate the gable end insulation approach and develop training tools, and (3) address low eave venting requirements through research on the effectiveness of alternative mitigation measures.

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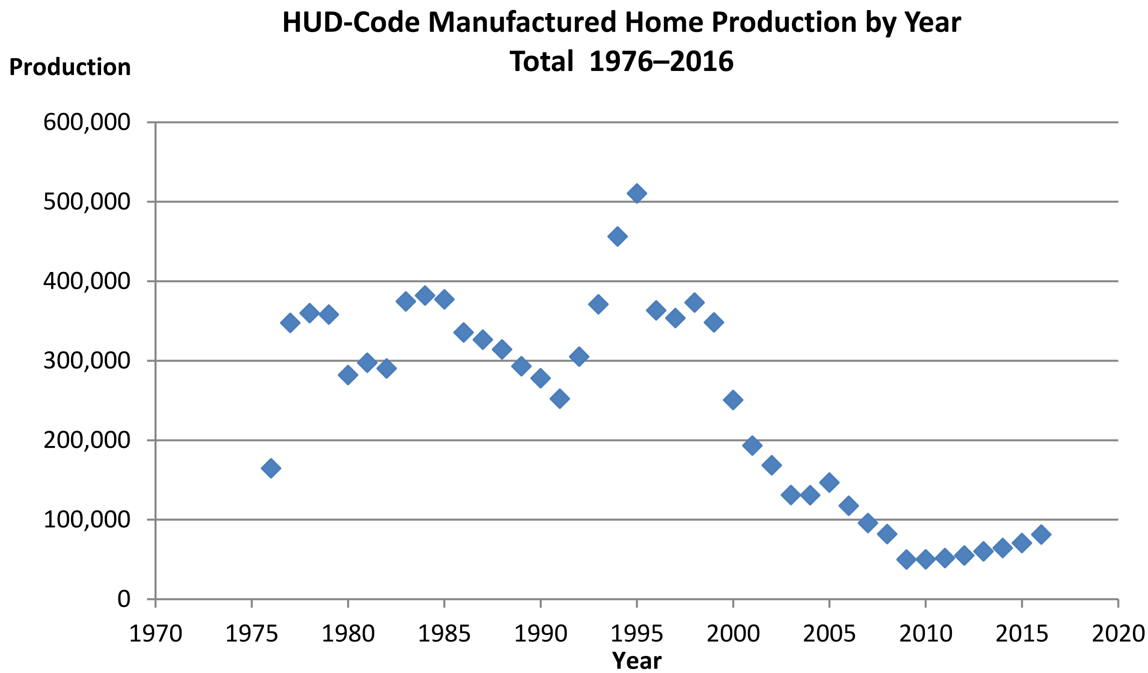
1 Background

1.1 Manufactured Homes and HUD-Code History

The U.S. Department of Housing and Urban Development (HUD) began to regulate the national manufactured housing industry using Manufactured Home Construction and Safety Standards (MHCSS) in 1976. Manufactured homes are typically single- or double-section homes. HUD-code manufactured homes are designed to be built in a factory and transported on a metal frame to the site where they are set up, with the frame remaining part of the foundation support system. Roughly 10 million of these homes were built between 1976 and 2016, as shown in Figure 1. This includes a breakdown by region for the periods from 1990–2016.



Data from the Institute for Building Technology and Safety

Figure 1. HUD-code manufactured home production in the United States

Unlike site-built and/or modular homes, manufactured homes must meet national requirements mandated by HUD in MHCSS Subpart 1. State building codes are preempted by HUD's MHCSS requirements and are typically more stringent than MHCSS in energy efficiency. HUD-code energy-efficiency minimum standards were included in MHCSS in 1994 and have not changed since, although many manufactured housing plants offer attic insulation that is higher than minimum as an energy-efficiency option. Manufactured homes built before 1994 are likely to have between R-11 and R-14 attic insulation. In 1994, energy-efficiency improvements were adopted that generally require R-19–R-22 attic insulation even in colder climate zones. Industry tends to install the close-to-minimum insulation to reduce the purchase price. R-28–R-38 is an above-code, nonstandard option in some newer manufactured homes built to above-code standards and for ENERGY STAR®.[1]

1.2 Manufactured Home Attic Insulation and Ventilation

As shown in Figure 2, manufactured homes built after 1980 began to transition from a metal roof bow truss to a low-slope (typically 2:12) wood truss design with limited 3½-in.–5½-in. truss heel depth over exterior walls at eaves. Typically, they have a combination of vaulted and flat scissor trusses, with vaults located in the main living area. Additional typical manufactured home truss details are provided in Appendix C.

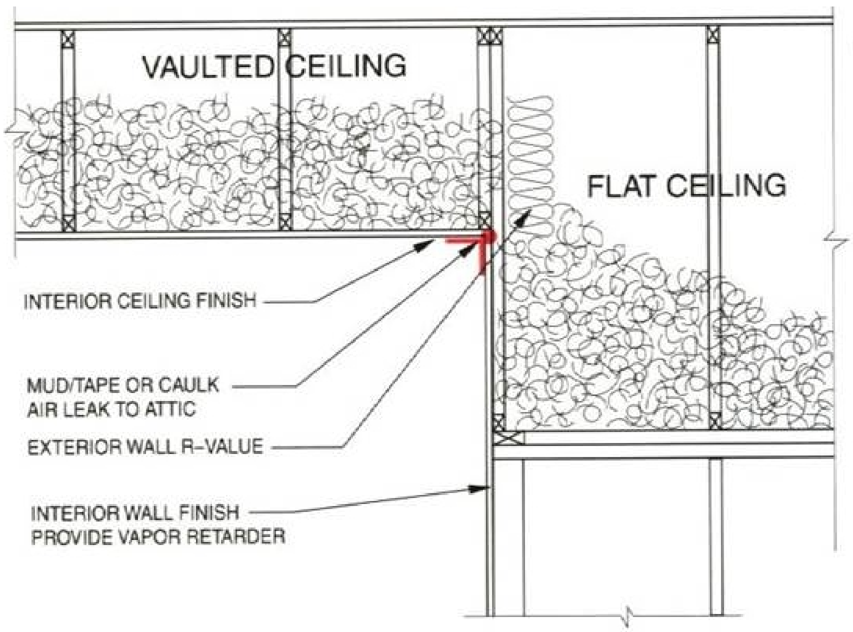


Image from Northwest Energy Works

Figure 2. Manufactured home attic truss transition from flat to vaulted ceiling—challenging to access, install insulation, and air seal

Pre-HUD-code manufactured home roofing systems more often employed metal cladding and bow roof truss design, with little or no wood decking used. Manufacturers began to use wood structural sheathing (plywood and, later, oriented strand board [OSB]) as a lower cost option in the residential market. As this transition took place, more manufactured homes were built with passive venting. This practice began to comply with asphalt shingle manufacturer warrantees and, in 1994, with HUD MHCSS requirements.

HUD MHCSS requires 1 ft2 of venting free area per every 300 ft2 of ceiling area (1/300) venting with both high and low venting required and maintaining 1-in. air space. The following approaches are generally used to comply with HUD attic ventilation requirements, as shown in Figure 3:

[1] Outside the Pacific Northwest, fewer than 10% of new manufactured homes are ENERGY STAR-certified (more than 50% in the Pacific Northwest). Pacific Northwest utilities have worked with the manufactured housing industry since the 1980s to voluntarily install R-38 attic insulation in more than 150,000 manufactured homes in Washington, Oregon, Idaho, Montana, and parts of Utah and California, which avoids attic insulation "lost opportunities." Unfortunately, much of the United States does not have these utility partnerships, and HUD-code manufactured homes might be more likely to have lower attic insulation levels. Utility manufactured home programs outside the Pacific Northwest other than ENERGY STAR tend to focus on HVAC improvements, such as duct sealing and heat pumps, and require R-30 attic insulation in colder climates. Nationally, few HUD manufactured homes have been built under the national ENERGY STAR program since inception.

- Eave vent low, high vent caps (e.g., flat rectangular or round "mushroom")
- Eave vent low, high gable vents
- Eave vent low, high roof ridge vent
- No eave vent, high vent caps
- No eave vent, high vent cap and/or gable vents
- Mechanical attic ventilation with minimal vents.[2]

Figure 3 and Figure 4 illustrate passive and mechanical attic ventilation systems.

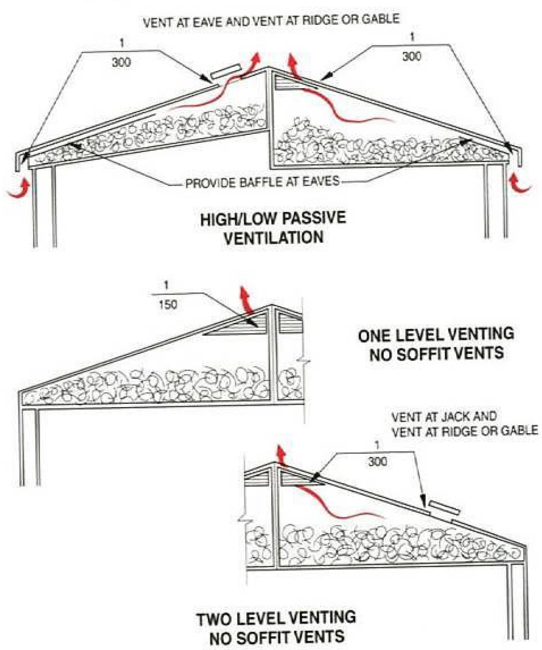
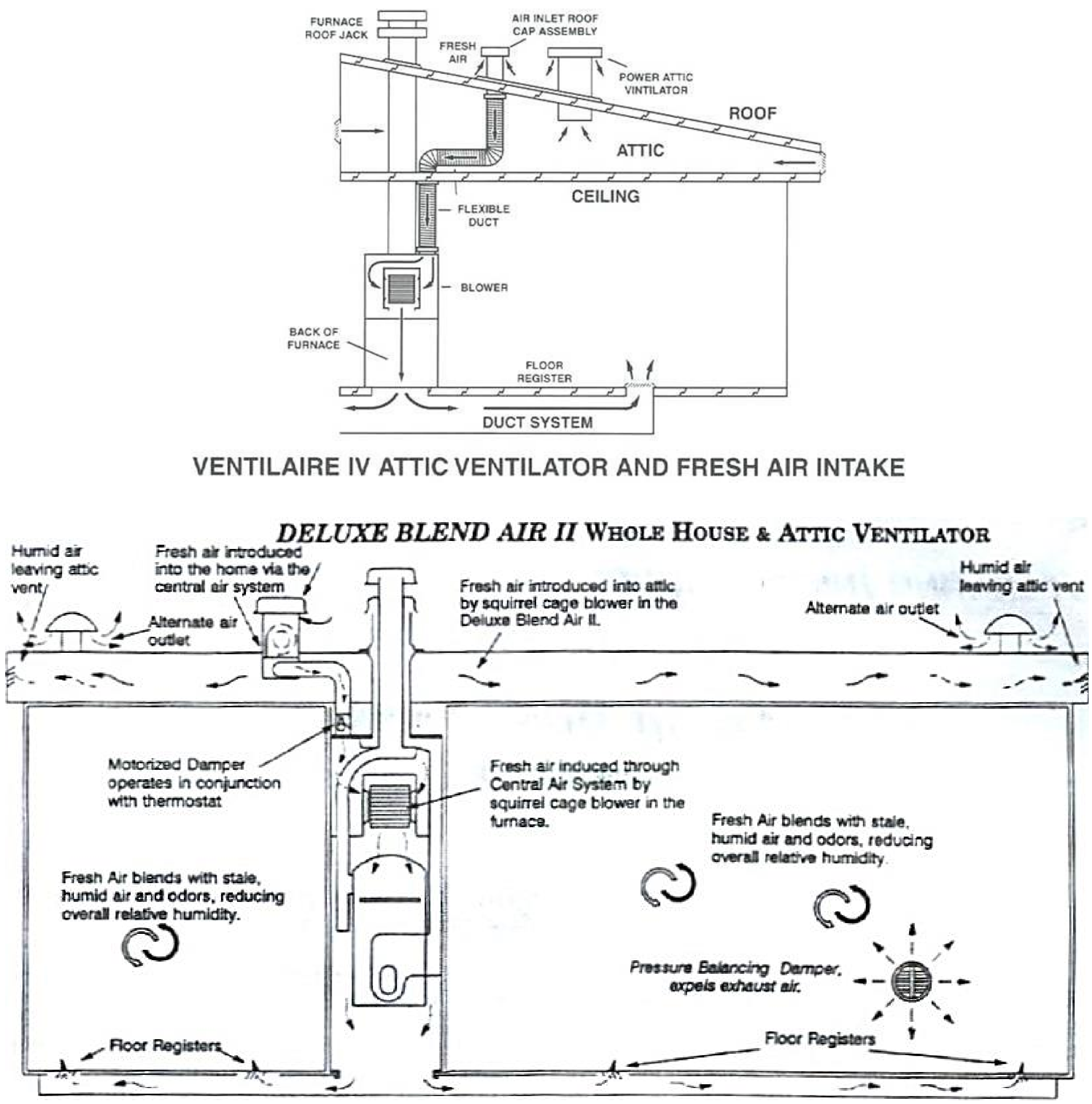


Image from Northwest Energy Works

Figure 3. Typical passive attic venting in flat and vaulted scissor truss ceilings

[2] A smaller percentage of manufactured homes use mechanical attic venting systems that require only a few roof vents. These mechanical systems were intended to provide whole-house supply ventilation via the furnace return plenum whenever the furnace operated (Figure 4). As reported by various stakeholders and published research, many of these systems have not been functioning as intended. In 1994, HUD-code manufactured homes built in colder climate zones 2 and 3 were also required to have ceiling vapor retarders after 1994. This was typically an approved paint or primer installed with factory HUD-approved quality assurance-quality control protocols. Pre-HUD-code homes often had plastic vapor retarders above the ceiling drywall or panels (this was before trusses were glued to the ceiling).



Images from Northwest Energy Works

Figure 4. Mechanical ventilation systems that vent attic and home

1.3 Manufactured Home Energy and Economic Impacts

Approximately 20 million Americans live in manufactured homes, with 92% located in rural or suburban areas (National Rural Electric Cooperative Association 2011; Keegan 2016). Electric cooperatives serve more than one-quarter of these homes. Information provided by industry indicates that there are roughly 10 million single- and multi-section HUD-code manufactured homes built from 1976 to 2016, and at least 7 million are a minimum of 10 years old (Manufactured Housing Institute 2017).

National Rural Electric Cooperative Association research suggests that manufactured home clients pay a disproportionate amount of their disposable income on utility bills to heat and cool these homes. Rural electric utilities also report that electricity use by customers living in manufactured homes is higher than necessary and is a chronic problem for many cooperative electric utilities countrywide. High utility bills were cited as the most frequent complaint received by utilities from customers living in manufactured homes, despite having half the square footage as site-built homes (personal communications with Pat Keegan in 2016 about study by the 2011 National Rural Electric Cooperative Association). This is supported by data from the U.S. Energy Information Administration 2009 Residential Energy Consumption Survey, which suggests that, on average, manufactured home residents pay nearly as much for electricity yearly as residents of single-family, detached, site-built homes, which typically have twice the square footage as manufactured homes (U.S. Energy Information Administration 2011).

U.S. Department of Energy (DOE) (Blasnik et al. 2014) evaluation research for the 2008 program year snapshot of the Weatherization Assistance Program (WAP) clients suggests that:

- Manufactured homes tend to represent a disproportionately high share of WAP homes.
- Manufactured homes are more likely to be both owner-occupied and lower income.
- Around 18% (17,754) of all WAP clients live in mobile homes; the term mobile home includes both pre- and post-1976 HUD-code manufactured homes.
- Roughly 90% of these manufactured homes were built after 1970, and most of those were built to HUD-code.
- Approximately 60% (roughly 10,544) of the clients served were in very cold or cold climates; an additional 28% (4,987) were in moderate climates.

The main heating fuel was equally divided among natural gas, electricity, and delivered fuels.[3] About 70% of clients had air conditioning, whereas 30% did not. Some WAP clients use electric zonal heating and/or supplementary wood heat.

[3] Rural electric utility research reported that approximately 60% of manufactured homes are heated with electric resistance heat, compared with 30% of all housing units, which is twice the number reported in the WAP evaluation.

2 Assessment of Industry Needs Related to Attic Insulation Retrofits

The Washington State University (WSU) Extension Energy Program conducted outreach to stakeholders via email, phone, and individual and group meetings. This sought to assess the current needs of the industry by identifying issues that appear to restrict the implementation of WAP attic insulation retrofits in existing HUD-code manufactured homes in colder climates of the United States. Critical needs assessment discussions were held with more than 50 stakeholders from three stakeholder groups in phone discussions and at meetings. The stakeholder group areas of expertise included:

- Community Action Partnership programs (CAPs) in the field that are involved with manufactured home WAP efforts
- Manufactured housing industry stakeholders
- HUD, DOE, and other organizations involved with implementing and enforcing HUD-code manufactured housing as part of the MHCSS.

Stakeholder engagement (a list of stakeholders is provided in Appendix A) was used to examine current practices of WAP CAPs and identify potential insulation and/or roof venting solutions that improve the energy savings and durability of attics in manufactured homes.

Many WAP practitioners involved with the management and/or field installations who attended the National Home Performance Conference in March 2017 participated in a session titled “Mobile Home Weatherization.” This provided an opportunity to engage those involved with all aspects of WAP and with manufactured home retrofits and to gain perspectives related to attic insulation. About 80 people involved with WAP attended the session and provided positive feedback about its value. The session provided the opportunity for:

- WSU to make connections and follow up with CAPs interested in the needs assessment research
- DOE staff to present the findings of the manufactured home WAP evaluation
- The Opportunity Council to present information on insulating the attic via gable end walls instead of from the roof or ceiling.

Findings gleaned from stakeholder outreach efforts are discussed below.

2.1 Current Practices and Potential Solutions

2.1.1 Approaches to Access and Install Blown Attic Insulation

Many CAPs contract out weatherization work, including insulation and HVAC measures, rather than running crews and installing measures themselves. Typically, one or more contractors take on insulation, and some provide services for many agencies. It has been reported that it is challenging for agencies to get any contractor to take on work such as manufactured home attic insulation.

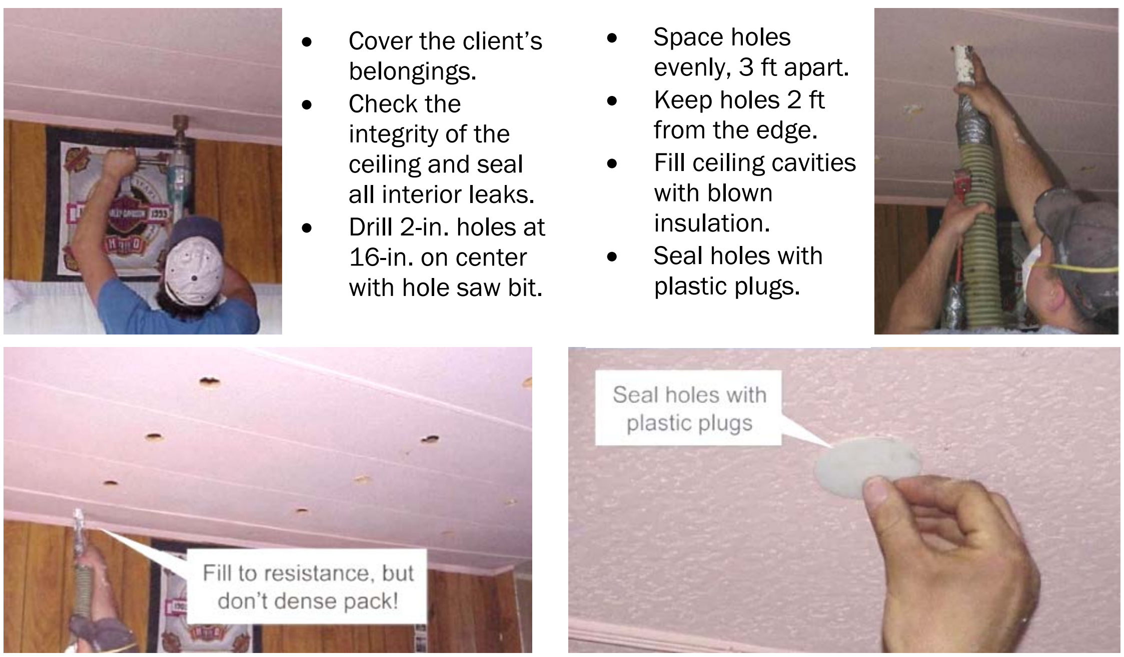
Installing attic insulation is difficult in manufactured homes because they typically lack attic hatches and have low-slope roofs, creating very confined attic spaces. CAPs use various approaches to access the attic and install insulation, including through the roof, ceiling, or gable end wall.

Stakeholder discussions identified the pros and cons of these access and insulation approaches. The roof access approach requires penetrating the roof deck, either by cutting individual access points or cutting an access opening along the ridge line (Figure 5). This can create a real or perceived liability for potential leaks and other issues that could be tied to the work.

Photos from WAP

Figure 5. Insulating attic from roof (left: cut into ridge, Vermont; right: top fill, DOE WAP)

The ceiling access approach involves drilling multiple evenly spaced holes through the ceiling drywall from inside the home. After the insulation is blown, plastic plugs are used to seal the holes made in the ceiling (Figure 6). CAPs have noted that the ceiling access approach requires engaging the occupant on logistical installation issues and post-weatherization aesthetic issues associated with ceiling plugs.



Photos from DOE

Figure 6. Insulating the attic from inside the house via the ceiling

One promising approach that is getting more attention is to access the attic through each gable, the triangular attic wall area on the narrower sides of the home, below the roof line, and above the ceiling line (Figure 7). This approach involves removing the gable siding and cutting a hole through the gable. By using scaffolding, this method keeps the installers off the HUD-code roof and out of the home. CAPs using this approach note that only 15–30 minutes are required to install and remove scaffolding before and after attic blow. In some cases, CAPs install gable vents in the hole cut in the siding after the insulation is added to provide future access and additional ventilation.

Some CAPs that have used this gable approach believe that it allows more manufactured home candidates to receive attic insulation, could reduce labor costs, and improves the SIR compared with other approaches that require cutting and patching roofs and/or ceiling access holes. This gable approach might also receive less pushback from occupants than when the attic is accessed via holes in the ceiling and/or the roof, which might cause concerns about aesthetics or roof leaks.

Photos from the Opportunity Council/WAP

Figure 7. Insulating attics from gable end walls

CAPs might use more than one access approach, such as when encountering a combination of flat and vaulted scissor trusses or inaccessible roof gables. This is usually decided on a home-by-home basis based on the CAP's field experience and training. CAPs without this training and experience might be less likely to attempt to insulate the attic. One comment received was, "Folks do what is easiest and what they are familiar with doing." CAPs that have developed an expertise for assessing reroofing issues and insulating manufactured home attics of HUD-code homes can encourage peer-to-peer discussions with others who do not often conduct attic insulation measures. One comment from a pioneer of manufactured home WAP suggested that, "DOE should require attic insulation and provide specific reasons that CAPs can use to document why attic insulation was not employed."

2.1.2 Retrofit R-Value Levels and Targets

Most CAP audits encounter attic insulation that is less than R-20 and might have been installed with significant voids and compression. Before 1994, insulation was typically fiberglass batt; after 1994, use of blown fiberglass, rock wool, and cellulose insulation increased. CAPs typically use blown fiberglass to a level that achieves R-38 at the peak of the insulation and tapering down at the eaves to fill the space. CAPs do not typically use blown cellulose in attics partially because of concerns about weight and moisture absorption.

Evaluation of the associated added weight and structural capability of the ceiling drywall to hold the insulation in accordance with MHCSS is a potential future research area.

Most use rules of thumb based on the loose fill attic insulation bag count provided by the manufacturer. A bag count is typically used to ensure that the correct amount of insulation is installed. Different approaches are used to account for the sloped ceiling areas where full depth insulation based on the nominal R-value is not possible. A small amount of the remaining insulation is generally added to the peak where insulation depth is available and/or installed at higher densities.

Most CAPs that regularly install attic insulation have mastered adequate insulation blowing techniques but cannot always observe the areas they are insulating, especially at eaves and where vision is obstructed by truss members, flat to vaulted transition areas, and at HVAC woodstove flue penetrations. Experienced CAPs have developed significant knowledge and hands-on experience to ensure that they insulate the attic to the desired bag count.

Most CAPs target a value of R-38 for attic insulation measures. Typically, this would require at least 10 in. of blown cellulose or at least 14 in. of blown fiberglass.4 The R-value depends on the installed density as well as the depth. Because of the limited access and attic height of manufactured homes, this depth can be challenging to achieve. Using the bag count as a guide, any insulation displaced by the sloping of the roof ends up in the center of the attic, where the attic height is greatest. Discussions have occurred to engage insulation manufacturers to provide more specific guidance on bag counts for nonuniform insulation depth in manufactured homes.

2.1.3 Retrofit of Attic Insulation and Attic Venting

As discussed in Section 1.2, HUD MHCSS requires 1 ft^2 of venting-free area per every 300 ft^2 of ceiling area (1/300) venting with both high and low venting required and maintaining a 1-in. air space. This can be an issue when adding insulation to manufactured home attics (Figure 8).

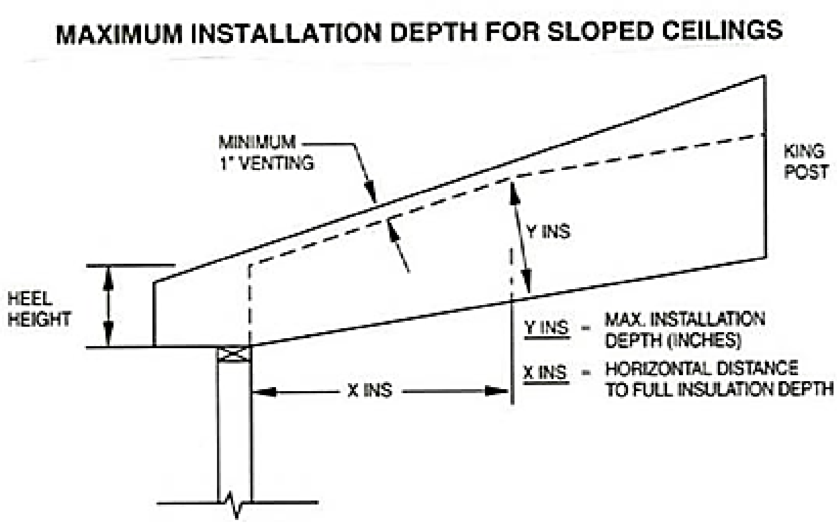


Image from Northwest Energy Works

Figure 8. Typical factory insulation installation strategy (1-inch minimum air space between roof deck and insulation required for low eave venting)

[4] See http://www.energy.wsu.edu/documents/AHT_Inspection%20Attic%20Insulation.pdf.

CAPs and many others in the building science research community involved in this needs assessment, however, believe that improving the ventilation systems, reducing ceiling air leakage to the attic, and addressing other underlying moisture problems through a whole-house approach is more important than changes to low attic eave venting.

Some CAPs using the gable end approach install additional gable vents in the hole cut in the siding after the insulation is added. This would address the reduction in venting that might occur when insulating the eaves. For example, a 1,000-ft^2 double-section home would require roughly 240 in^2 of high vents and 240 ft^2 of low vents. If the 240 in^2 of low vents were eliminated when attic eaves are insulated, that venting deficit could be made up by installing gable vents (120-in^2 net free venting in each gable) in the openings made by the CAP to access the attic. This might provide some additional level of compliance, although the MHCSS still requires that at least half of the venting be located low. There is also a requirement that the insulation not contact the roof decking to maintain a 1-in. air space for connecting low and high vent flow patterns.

The need to avoid decking insulation contact and the minimum percentage of low vent requirements in MHCSS and standard work specifications (SWS) might be appropriate to explore with stakeholders in the future. The minimal percentage of low vents is a critical code-compliance issue. Note that at least one state agency responsible for overseeing manufactured home alterations does not allow for any modifications to the attic venting design.

No CAPs reported any callbacks or complaints associated with roof deck condensation after adding attic insulation. Although no complaints were received, this does not mean there was no increase in roof deck condensation. Field assessments researching the moisture content in roofs of well-sealed and correctly ventilated manufactured homes with ceiling cavities nearly full of insulation would help to further inform this important code-compliance and hygrothermal performance issue.

2.1.4 Importance of the Whole-House Approach in Weatherization

A whole-house approach employs a variety of energy-efficiency measures based on an understanding of the interactions and effects of the measures on moisture management, energy savings, comfort, SIR cost-effectiveness, durability, resilience, and indoor air quality. DOE rules require that all measures with a savings-to-investment ratio (SIR) greater than or equal to 1.0 be installed in order of cost-effectiveness so measures cannot be easily skipped or bypassed. CAPs and some building science moisture expert stakeholders use a whole-building approach to weatherizing manufactured homes in WAP. The whole-building approach considers the interaction of the heating, ventilating, and air conditioning (HVAC); mechanical; and building envelope systems. An example of this approach is to always seal the ductwork system first and never install new HVAC equipment without testing and sealing the ducts that deliver the HVAC (Manufactured Housing Research Alliance 2000).

CAPs generally use a whole-house approach that limits air leakage to the attic from the conditioned space and provides mechanical ventilation. A whole-house approach considers "seal tight, ventilate right" measures, such as ceiling air sealing and effective mechanical ventilation. These measures reduce risks of future moisture issues whether or not the attic insulation measure is used. The durability and indoor air quality (nonenergy savings) benefits need to be considered for these measures alone or when used with attic insulation.

All the needs assessment stakeholders contacted in the project believe that the following two critically important whole-house efforts must be used before adding attic insulation:

- ***Reduce moisture pathways from the house to the attic.*** The typical pathways for moisture-laden air to enter the attic from the home include ceiling light fixtures and ceiling fans, electrical receptacles, bath fans, plumbing vents, holes in the top plate, the intersection of ceiling and wall panels, flexible ductwork for supply ventilation systems, skylight wells, and, for multi-section homes, wall, floor, and ceiling marriage lines that connect sections on-site (Figure 9). Manufactured homes tend to have less ceiling leakage than site-built homes at the interior partition walls because of the construction approach that uses continuous ceiling drywall. Manufactured homes can also be effectively and systematically air sealed as a result of the standard construction systems used in each home. Most manufacturer installation instructions refer to using a ground moisture barrier in the crawl space to limit moisture.

Photos from Opportunity Council (left) and DOE WAP (right)

Figure 9. Moisture issues associated with inadequately installed bath fan (left: moisture problems that stain ceiling drywall panels; right: replacement of old fans with new exhaust ventilation to reduce moisture generation)

- ***Install and operate whole-house ventilation systems.*** Most WAP training involves addressing the requirements in ASHRAE Standard 62.2 Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings, Normative Appendix A–Existing Buildings. This typically involves assessing and testing existing ventilation system measured airflow and installing ASHRAE Standard 62.2-compliant ventilation systems. This is typically a continuously operating, whole-house exhaust fan that is quiet and low wattage. The WAP is the largest single user of the standard's existing homes criteria, and many CAPs have found that using an "air seal tight, ventilate right" approach greatly improves air quality and reduces moisture issues in the manufactured homes they weatherize. CAPs tend to evaluate the current mechanical ventilation system performance and upgrade as needed to comply with the standard, often by replacing older, nosier, low-flow bath fans with quieter fans with occupant controls. CAPs also attempt to educate occupants on how to operate and maintain ventilation systems. There has been considerable effort in this area to train CAPs and integrate guidance for existing homes in ASHRAE Standard 62.2.

2.1.5 Perceived Risks Influence Decision to Install Attic Insulation

CAPs agree that identifying the roof's useful life and associated potential of leak risks is part of the audit decision process. The outcome of this evaluation influences their decision to not insulate an attic as they install other weatherization measures, citing the truism, "You touch it, you own it." There is often some concern that they might be blamed for roof leaks even if the CAP's activity on the roof was not related to, and did not cause, the leak. CAPs that typically access roofs to install attic insulation, however, reported smaller perceived risk of future roof leaks associated with their efforts. These CAPs do not typically experience these perceived problems, nor do they often receive complaints about causing roof leaks.

Risk of Damage Caused by Condensation

The underside of roof decks in manufactured homes in cold climates will experience some condensation when moisture in the attic condenses on cold deck surfaces that are below the attic air dew point (Figure 10). If the condensation happens often enough and is severe enough under certain climate conditions, mold deposits might occur on the underside of the decking. Air sealing at the ceiling will help reduce and mitigate pathways for pollutants, such as mold spores, from entering the house from the attic.

Photos from the Opportunity Council

Figure 10. Underside of decking with signs of past roof leaks and/or condensation

If severe enough, this increase in magnitude and/or frequency of roof deck condensation might also lead to structural rot and the need to replace some or all roof decking or roofing sooner than normally required. Condensation tends to occur at night when the roof experiences night sky radiation that might cool the roof surface temperature below the outside air temperature. Further, daytime exposure to solar radiation might dry out the roof. Adding attic insulation without using a whole-house approach (i.e., limiting air leakage and moisture transport to the attic, providing mechanical ventilation, and controlling indoor relative humidity) might incrementally increase the roof deck condensation. It is important to determine if attic insulation can lead to condensation with the severity and frequency that reduces the useful life of the roof. Field investigation of retrofitted manufactured homes is an appropriate approach when investigating the implications of roof deck condensation in terms of durability and associated roof maintenance expenses.

Although the frequency of condensation on the underside of the roof decking tends to increase as the outside temperature drops and additional insulation is added, experience shared from most CAPs suggests that these can be mitigated by using a whole-building systems approach. Reducing air leakage from the interior to the attic will decrease condensation-related issues. In addition, any information that helps inform occupants about operating and maintaining mechanical systems, and maintaining building envelope systems, could help minimize bulk water intrusion, which is the most typical reason for moisture problems. This includes addressing proper maintenance schedules for roofing, wall cladding/flashing systems and rain gutters (when installed), snow and/or moss removal systems (if required), and perimeter drainage systems. Identifying and addressing moisture-related issues encountered at the audit is key to using an effective whole-house system approach. As one CAP noted, “If you have these types of moisture water issues, don’t do any weatherization until you have a plan to address those underlying issues” (Manufactured Housing Research Alliance 2000).

The combination of whole-house and “air seal tight, ventilate right” best practices will help mitigate significant condensation and other moisture-related problems under roof decking that might result in long-term durability issues.

Ice Dams

Ice dams and snow buildup in cold-climate manufactured homes can also lead to roof leaks and potential moisture durability issues. Unlike site-built codes, low-slope HUD-code manufactured home roofs do not have self-adhered ice dam membranes (per International Residential Code for One- and Two-Family Dwellings Whole-Building Approach) installed in roof valley areas or at roof eaves to protect against roof leaks.

Manufactured homes might have significant variations in installed R-values and ceiling-to-attic air leakage in localized areas, which might result in localized melting of snow and the formation of ice dams. The HUD State Administrative Agency consumer Manufactured Home Dispute Resolution Program and industry discussions suggest that ice dams are a common consumer complaint and potential service issue (conversations with manufactured housing stakeholders involved with the HUD State Administrative Agency). State Administrative Agency-related information from cold-climate State Administrative Agencies might be useful in exploring ice dam and other moisture-related manufactured home issues.

Some CAPs might forgo roof-related work to avoid responsibility for future roof failures, including ice dams, although attic insulation and air sealing will typically reduce the frequency and severity of ice dams by decreasing heat flux from conduction and air leakage. Using self-adhered ice dam membranes might also reduce leaks from snow buildup in roof valleys. Many CAPs install these self-adhered membranes when reroofing a home as part of the weatherization activity to reduce the probability of future roof leaks. HUD MHCSS has yet to consider this requirement for new HUD-code homes, although discussions are underway with the HUD Manufactured Housing Consensus Committee federal advisory committee, which supports recommendations to improve MHCSS.

Inaccessibility

CAPs reported that they try to insulate all areas that they can access, but that there are limitations in the field associated with roof truss gable details, vault-to-flat-truss transitions, penetrations of flues, non-insulation contact light fixtures, and so on. Most CAPs reported that they typically insulate over the eave vents, if they are encountered. Those CAPs reported that they are not concerned about this and believe that their actions improve the attic insulation quality.

CAPs identified situations where homeowners have added canopies, awnings, or site-built structures that might provide additional logistical challenges to adding attic insulation. CAPs have also noted challenges associated with blowing insulation and retaining clearance around HVAC systems, woodstove flues, and some recessed (can) light fixtures. Some CAPs use light-emitting diode recessed light retrofits that can reduce air leakage and allow for insulation coverage. Clearly, there are situations where the entire roof cannot be insulated. In these cases, CAPs using attic insulation do the best they can in areas they can access and insulate.

Quality-Assurance Tools Can Reduce Perceived Risks

Many CAPs use blower door-guided testing before and after air sealing. They also employ flow-measuring equipment to ensure that the ceiling is tight and the mechanical ventilation systems are adequate to remove moisture generated by occupant activities before it can condense in the attic during cold weather. Using air sealing checklists can help the CAP identify where the leaks are, how to seal them, what to seal them with, and how to confirm that they have been adequately sealed to last throughout the home's useful life. CAPs tend to use a blower door to help determine the location of ceiling air leaks and effectively seal them to minimize entry of interior-generated moisture into the attic. Some CAPs use the blower door as both a training tool and a quality-assurance tool and might also use smoke sticks and/or infrared thermography for training and/or quality assurance. Some discussion focused on using infrared thermography in conjunction with blower doors. Some stakeholders have questions regarding the ability to interpret infrared thermography imaging and usefulness as a quality-assurance tool to assess insulation voids and compression quality-control and/or moisture issues in the attic. Most agree that infrared thermography might be useful as a tool to help identify air leakage paths from the house to the attic via the ceiling in conjunction with blower doors.

2.2 Findings from Stakeholder Engagement

Based on stakeholder needs assessment discussions and WAP research, the installation of attic insulation is not typically occurring for a variety of reasons:

- No attic hatch and available work space make it more difficult to access attic spaces to insulate. This work requires manufactured home-specific training, experience, and commitment to implementing attic insulation retrofits as part of a whole-house approach.
- WAP activities associated with getting onto the roof might lead to roof leak complaints. Most CAPs that currently access the attic from the roof do not see this as a significant real-world issue.
- The fixed cost associated with accessing manufactured home attics, low natural gas prices for manufactured homes (typically located in parks), and climate severity can negatively impact the SIR.
- Installing insulation might block eave venting design required in HUD MHCSS after 1994 and for compliance with some asphalt shingle manufacturer installation manuals. At least one state has identified this HUD MHCSS issue and other issues related to alterations to HUD-code manufactured homes. This has eliminated opportunities for weatherization if the measures impact the original HUD-approved engineering design per MHCSS.
- The SWS has not specifically addressed details related to how to access and insulate HUD-code manufactured homes built after 1976, typically with high-low venting and sloped composition roofs with OSB or plywood decking. Most of the current SWS focus has been on pre-HUD homes with typically bow truss and metal roofs.

3 Cost-Benefit Challenges Associated with Attic Insulation Retrofits

This effort included conducting energy modeling using WAP-approved Targeted Retrofit Energy Analysis Tool (TREAT) software. This was done to provide a target installation cost for attic retrofits in typical single- and multi-section prototypes in various climates (Appendix B). CAPs with many manufactured homes in communities and/or trailer parks that are served by natural gas noted difficulty meeting the SIR for using attic insulation. WAP stakeholders reported that they can typically meet the criterion of no less than 1.0 SIR for attic insulation retrofits in many cold climates once they have experience with various retrofit approaches to access the attic to blow insulation. Some CAPs reported that finding, training, and retaining crews is challenging and can be an issue in achieving SIR goals.

3.1 Simulation Approach

WSU conducted two efforts to assess the SIR by employing:

- TREAT software, which is typically used by CAPs to evaluate the SIR
- A Pacific Northwest National Laboratory (PNNL) model that is typically used for energy code assessments.

These efforts involve energy modeling of a typical 66-ft-by-14-ft single-section and 56-ft-by-28-ft double-section manufactured home. PNNL used these prototypes for the 2012–2014 rulemaking evaluation of energy-efficiency improvements from current 1994 manufactured home requirements in MHCSS. The analysis estimated per-house energy savings associated with insulating the attics of existing HUD-code manufactured homes for various climate zones and HVAC/fuel types. The PNNL and TREAT modeling assumptions used in the analysis are provided in Table 1. Additional information on the PNNL analysis assumptions is provided in Appendix B. The TREAT analysis used the same assumptions except it used software default insulation measure U-value assumptions.

Table 1. Input Assumptions for Energy Savings Modeling Analysis

Building Component	HUD-Code Baseline: WAP (1976–1993)	Advanced Case *(Nominal R-38 Ceiling Insulation)*
Wall insulation R-value (h-ft^2-F/Btu)	11	11
Ceiling insulation R-value (h-ft^2-F/Btu)	R-14 or R-20	38[a]
Floor insulation R-value (h-ft^2-F/Btu)	22	22
Window U-factor (Btu/h-ft^2-F)	1.08	1.08
Window solar heat gain coefficient	0.70	0.70
Envelope leakage limit (ACH50)	NR (8)[b]	NR (8)[b]
Duct leakage limit (cfm25/100 ft^2 CFA)	NR (12)[b]	NR (12)[b]
High-efficacy lighting percentage (%)	NR (34%)[b]	NR (34%)[b]

[a] Nominal. R-38 at attic peak with tapering at eaves

[b] *See Appendix B for notes.*

Attic energy savings are computed using a base case of measures (e.g., wall, floor, and windows) that are based on the 1994 MHCSS typical levels. Attic savings analysis assumes a whole-house approach where other weatherization measures are also installed, resulting in a more conservative energy savings attribution than if only the attic measure were used without other measures.

Two analyses were conducted, assuming either an R-14 or R-20 base case insulation level. The economic assumptions used in Table 2a, Table 2b, Table 3a, and Table 3b are based on DOE assumptions (provided in Appendix B) and assume a 3% discount of present value energy savings and a 30-year useful life for attic insulation. The analysis assumed a 76°F cooling set point and 72°F heating set point, with no setback (based on DOE guidance on modeling assumptions). The two right-hand columns provide a comparison of the TREAT and PNNL analyses of energy savings in Mbtu/y. The difference between savings estimates from the PNNL and TREAT modeling shown in these tables might be a subject of future research, but it does not seem to have as big an impact on the SIR as other factors, such as climate and fuel type.

Annual heating and cooling energy savings are also presented for typical centrally ducted electric resistance, natural gas, and propane furnaces with air conditioning and heat pumps. Energy savings values are provided for both PNNL and TREAT modeling. PNNL analysis was also conducted for additional climate cities. The occupant annual utility savings associated with increasing attic insulation from a base case assumption of R-20 to R-38, assuming PNNL modeled energy savings, are shown in Figure 11. Using those savings, an analysis of the SIR was conducted for each climate and fuel case to determine a target attic insulation cost for each prototype and fuel case that would yield a SIR of 1.0 or more. The data that yield a SIR of 1.0 are presented for each case. As expected, the higher cost is justifiable for the higher cost of energy with more heating degree days and/or reduced efficiency of HVAC equipment.

Table 2a. Energy Savings and Maximum Allowable Cost for R-14–R-38 Attic: Single-Wide

Heating Type	Location	PNNL		TREAT	
		Mbtu/y	SIR = 1	Mbtu/y	SIR = 1
Electric	Duluth, MN	7.27	$ 4,584	7.31	$ 4,612
Electric	Burlington, VT	5.84	$ 6,246	6.02	$ 6,445
Electric	Salem, OR	5.04	$ 2,841	3.84	$ 2,168
Electric	Baltimore, MD	4.37	$ 3,196	3.95	$ 2,891
Heat pump	Duluth, MN	4.93	$ 3,108	6.07	$ 3,828
Heat pump	Burlington, VT	3.52	$ 3,770	4.47	$ 4,787
Heat pump	Salem, OR	2.28	$ 1,286	2.16	$ 1,221
Heat pump	Baltimore, MD	2.07	$ 1,516	2.53	$ 1,849
Propane	Duluth, MN	9.63	$ 3,189	9.52	$ 3,123
Propane	Salem, OR	6.49	$ 2,412	5.67	$ 2,350
Propane	Baltimore, MD	5.61	$ 2,005	5.37	$ 1,995
Natural gas	Duluth, MN	9.63	$ 1,824	9.52	$ 1,745
Natural gas	Burlington, VT	7.67	$ 2,577	7.81	$ 2,340
Natural gas	Salem, OR	6.49	$ 1,737	5.67	$ 1,420
Natural gas	Baltimore, MD	5.61	$ 1,727	5.37	$ 1,508
All types	Average	5.76	$ 2,801	5.69	$ 2,819
All types	Maximum	9.63	$ 6,246	9.52	$ 6,445
All types	Minimum	2.07	$ 1,286	2.16	$ 1,221

Table 2b. Energy Savings and Maximum Allowable Cost for R-14–R-38 Attic: Double-Wide

Heating Type	Location	PNNL		TREAT	
		Mbtu/y	SIR = 1	Mbtu/y	SIR = 1
Electric	Duluth, MN	11.85	$ 7,475	11.73	$ 7,398
Electric	Burlington, VT	9.53	$ 10,195	9.41	$ 10,083
Electric	Salem, OR	8.25	$ 4,652	6.31	$ 3,558
Electric	Baltimore, MD	7.31	$ 5,218	6.56	$ 4,798
Heat pump	Duluth, MN	8.06	$ 5,085	9.52	$ 6,007
Heat pump	Burlington, VT	5.37	$ 5,742	6.79	$ 7,281
Heat pump	Salem, OR	3.76	$ 2,121	3.40	$ 1,916
Heat pump	Baltimore, MD	3.42	$ 2,499	4.05	$ 2,962
Propane	Duluth, MN	9.26	$ 5,221	14.51	$ 5,462
Propane	Salem, OR	6.27	$ 3,958	8.46	$ 3,508
Propane	Baltimore, MD	5.41	$ 3,299	8.46	$ 3,161
Natural gas	Duluth, MN	9.26	$ 2,989	14.51	$ 2,649
Natural gas	Burlington, VT	7.38	$ 4,240	11.98	$ 3,596
Natural gas	Salem, OR	6.27	$ 2,855	8.46	$ 2,129
Natural gas	Baltimore, MD	5.41	$ 2,845	8.46	$ 2,397
All types	Average	7.12	$ 4,560	8.84	$ 4,460
All types	Maximum	11.85	$ 10,195	14.51	$ 10,083
All types	Minimum	3.42	$ 2,121	3.40	$ 1,916

Table 3a. Energy Savings and Maximum Allowable Cost for R-20–R-38 Attic: Single-Wide

Heating Type	Location	PNNL		TREAT	
		Mbtu/y	SIR = 1	Mbtu/y	SIR = 1
Electric	Duluth, MN	4.77	$ 3,009	4.85	$ 1,956
Electric	Burlington, VT	3.83	$ 4,098	3.85	$ 4,117
Electric	Salem, OR	3.39	$ 1,909	2.22	$ 1,254
Electric	Baltimore, MD	2.89	$ 2,115	2.39	$ 1,749
Heat pump	Duluth, MN	3.24	$ 2,040	4.11	$ 2,590
Heat pump	Burlington, VT	2.37	$ 2,531	2.82	$ 3,014
Heat pump	Salem, OR	1.54	$ 866	1.25	$ 708
Heat pump	Baltimore, MD	1.37	$ 998	1.51	$ 1,108
Propane	Duluth, MN	6.31	$ 2,092	6.60	$ 2,239
Propane	Salem, OR	4.35	$ 1,622	3.38	$ 1,371
Propane	Baltimore, MD	3.70	$ 1,329	3.55	$ 1,299
Natural gas	Duluth, MN	6.31	$ 1,200	6.60	$ 1,167
Natural gas	Burlington, VT	5.03	$ 1,698	5.03	$ 1,402
Natural gas	Salem, OR	4.35	$ 1,173	3.38	$ 786
Natural gas	Baltimore, MD	3.70	$ 1,456	3.55	$ 972
All types	Average	3.81	$ 1,876	3.67	$ 1,166
All types	Maximum	6.31	$ 4,098	6.60	$ 4,117
All types	Minimum	1.37	$ 866	1.25	$ 708

Table 3b. Energy Savings and Maximum Allowable Cost for R-20–R-38 Attic: Double-Wide

Heating Type	Location	PNNL		TREAT	
		Mbtu/y	SIR = 1	Mbtu/y	SIR = 1
Electric	Duluth, MN	7.38	$ 4,655	7.88	$ 4,970
Electric	Burlington, VT	5.94	$ 6,352	6.46	$ 6,621
Electric	Salem, OR	5.28	$ 2,979	3.74	$ 2,110
Electric	Baltimore, MD	4.48	$ 3,278	4.02	$ 2,939
Heat pump	Duluth, MN	5.04	$ 3,179	6.41	$ 4,044
Heat pump	Burlington, VT	3.38	$ 3,613	4.51	$ 4,837
Heat pump	Salem, OR	2.41	$ 1,361	1.95	$ 1,099
Heat pump	Baltimore, MD	2.14	$ 1,563	2.45	$ 1,796
Propane	Duluth, MN	5.76	$ 3,246	10.00	$ 3,731
Propane	Salem, OR	4.00	$ 2,532	5.36	$ 2,176
Propane	Baltimore, MD	3.39	$ 2,078	5.35	$ 1,962
Natural gas	Duluth, MN	5.76	$ 1,868	10.00	$ 1,765
Natural gas	Burlington, VT	4.59	$ 2,664	8.04	$ 2,247
Natural gas	Salem, OR	4.00	$ 1,835	5.36	$ 1,251
Natural gas	Baltimore, MD	3.39	$ 1,795	5.35	$ 1,470
All types	Average	4.46	$ 2,867	5.74	$ 2,869
All types	Maximum	7.38	$ 6,352	10.00	$ 6,621
All types	Minimum	2.14	$ 1,361	1.95	$ 1,099

3.2 Cost Inputs for SIR Calculations

Costing is typically done using a fixed cost of labor for setup and installation, plus a per-bag cost multiplied by the number of bags (typically fiberglass installed at a target density).

Table 4 shows estimated costs for single- and double-wide blown fiberglass insulation, provided by four northern state CAPs (personal communications with Glen Salas 2017 in May 2017). A few CAPs reported that material and labor costs were roughly split. Although these are limited-source cost data, they allow a comparison to targeted costs for a SIR greater than or equal to 1.0. The cost of attic insulation retrofits is site-specific, based on what is encountered in baseline insulation (assumed here to be R-20 or R-14).

Pre-1994 HUD-code homes might have lower base insulation levels (R-14) than post-1994 homes, especially in warmer climate zones. The SIR will benefit from the lower base case assumptions. Costs were provided by CAPs and can vary based on the attic insulation approach that is used. Cost challenges still exist to access the entire attic area requiring insulation. CAPs report that the costs for this measure are reduced as they become familiar with manufactured home attic insulation approaches. One CAP reported that having a few good manufactured home attic insulation contractors under contract to CAPs provides improved SIRs and increases the number of homes receiving this weatherization measure. Figure 11 shows the average estimated cost compared with the SIR target costs for adding attic insulation based on Table 4.

Table 4. Cost of Adding Attic Insulation from WAP CAPs

State Costs ($)	Cost/ft² R-14–R-38	Cost/1x R-14–R-38	Cost/2x R-14–R-38	Cost/ft² R-20–R-38	Cost/1x R-20–R-38	Cost/2x R-20–R-38
Montana	$4.00	$3,696	$6,272	$3.50	$3,234	$5,488
North Dakota	$1.20	$1,109	$1,882	$1.82	$1,682	$2,854
Washington	$1.30	$1,201	$2,038	$1.50	$1,386	$2,352
Michigan	$1.02	$942	$1,599	$1.46	$1,349	$2,289
Average	$1.88	**$1,737**	**$2,948**	$2.07	**$1,913**	**$3,246**

Legend:	R-14–R-38 single-wide = $1,737	R-20–R-38 single-wide = $1,913	Shown as (blue line)
	R-14–R-38 double-wide = $2,948	R-20–R-38 double-wide = $3,246	Shown as (red line)

Figure 11. Utility cost savings (vertical bars) and maximum measure cost (horizontal lines) to achieve SIR ≥1 by fuel type. Bars extending above horizontal lines indicate attic insulation is cost-effective (SIR ≥1).

4 Research and Technical Resources Needed to Advance the Insulation and Moisture Management of Manufactured Home Attics

Three main technical resources and areas of future research have been identified to address the issues that hinder attic insulation measures in manufactured housing. These recommendations are based on the input received from CAPs and other stakeholders and the analysis performed in this needs assessment.

4.1 Conduct Field Evaluation of Moisture Issues in Insulated Manufactured Home Attics

Reports from CAPs in Washington, Montana, North Dakota, Colorado, Wisconsin, and Vermont that have insulated manufactured home attics for many years suggest that no anecdotal complaints about attic moisture condensation have been received, although those in Washington noted some observations of under-decking condensation before attic installation retrofits. Thousands of homes in these states combined are believed to have been weatherized; in some cases, eave venting was reduced or eliminated as a result of the attic insulation. A rigorous field evaluation should be undertaken to determine whether or not attic insulation that reduces low eave venting leads to significant moisture issues. The proposed observational test plan seeks to open roofs, investigate, and provide field observations, which might be useful for future heat, air, and moisture modeling, if and when accurate input assumptions are known.

The goal of the field evaluation is to further investigate if significant moisture-related roof condensation is occurring by observing manufactured home attics where WAP CAPs have installed attic insulation. Field investigations will help characterize durability issues associated with roof deck condensation that might result from increasing attic R-value and/or eliminating attic eave venting in attic insulation retrofits. To help assess longer term impacts, consider selecting manufactured homes where CAPs installed attic insulation a number of years ago.

A potential field evaluation protocol was developed with stakeholder input, including thorough discussions held at the Building Science Corporation (BSC) Westford Symposium in August 2017. This preliminary "starting point" protocol is included in Appendix D for further review, refinement, and implementation by interested stakeholders. The plan will likely require significant commitment from those interested in CAPs to identify and recruit candidate homes that have received attic insulation with and without venting 2–5 years ago. This effort will then evaluate issues resulting from roof deck condensation and identify other typical roof moisture-related issues, such as bulk moisture intrusion (e.g., roof leaks), that are of concern.

The field evaluation should also include assessing field-testing (blower door and infrared) to determine if the ceilings of the previously insulated homes were effectively air sealed to limit moisture entry into the attic before adding attic insulation and to evaluate potential correlation between this air leakage and roof deck condensation.

4.2 Address Low (Eave) Venting Requirements

Manufactured housing industry stakeholders involved with the MHCSS suggest that reducing low venting by increasing attic insulation might pose code-compliance issues. Discussions with other CAPs in the field and some building science moisture expert stakeholders suggest that efforts to reduce moisture pathways from the house to the attic, and the installation and operation of whole-house ventilation systems, will mitigate any significant increased frequency and magnitude of under-decking moisture-related problems impacting the long-term durability of the roof decking as a result of the reduced low venting.

The field evaluation of insulated manufactured home attics, described in Section 3.3.2 and related research, would help determine whether a reduction in low eave venting results in moisture issues and which related measures (air sealing at ceiling plan or installation of mechanical ventilation per ASHRAE Standard 62.2) can mitigate these issues. The results will inform how to proceed in addressing the following research and resource gaps associated with current MHCSS and SWS requirements for roof venting:

- Address potential MHCSS code issues associated with modifying attic venting design.
- Promote systems shown to effectively mitigate moisture condensation in the attic that might satisfy WAP SWS and/or HUD MHCSS concerns about current attic venting code requirements.
- Develop SWS specifications for HUD-code manufactured homes.

Historically, the SWS focused on pre-HUD-code 1976 vintage manufactured homes. The SWS has not addressed details related to how to access and insulate HUD-code manufactured homes built after 1976, typically with high-low venting and sloped composition roofs with OSB or plywood decking. Most current SWS focus has been on pre-HUD homes with typically bow truss and metal roofs.

4.3 Evaluate Gable End Wall Insulation Approach and Develop Training Tools

Observe, document, and develop training tools for a gable end wall attic insulation system that could address installation and SIR challenges identified in the needs assessment. This approach to provide access to the attic via the end wall lends itself to HUD-code construction more than to pre-HUD-code construction. It might reduce costs that can improve the SIR. The approach addresses the key issues that affect the CAP's ability to insulate the attic by eliminating the need to cut holes in the roof decking or in the ceiling and not requiring installation from inside the home. This approach, being promoted by some CAPs to reduce costs and stay off the roof, is under discussion by the DOE WAP technical committee for potential inclusion in the DOE SWS.

4.4 Other Stakeholder Recommendations

These recommendations are based on feedback received during the needs assessment and on information provided in the bibliography and reference materials reviewed as part of the needs assessment.

Whole-house weatherization: Air sealing combined with controlled mechanical ventilation is recommended before insulating the attic. A systems approach should include blower door-guided air sealing to limit house air from entering the attic, effective mechanical ventilation to reduce occupant-generated moisture in the home, and resolution of all underlying moisture source issues in manufactured homes when using attic insulation. The whole-house approach is believed to be beneficial to SIR cost-effectiveness, occupant comfort, indoor air quality, and future useful life and durability of the home.

Community-scale measures: Meeting SIR requirements is challenging in manufactured homes heated by natural gas because of today's low natural gas fuel costs. Manufactured homes with natural gas typically exist in communities and might provide some economy of scale to reduce the cost of attic insulation (and other weatherization measures). Potential community-scale approaches can be explored and evaluated in terms of meeting SIR requirements despite low natural gas cost.

Attic insulation best practices: Some CAPs do not install attic insulation because of perceived risks, although the CAPs that regularly perform this measure do not report experiencing these risks in the field. Best practices can be developed based on the experience of CAPs that have used a whole-house approach about what works, how it is cost-effective, and how it mitigates moisture issues.

Develop quality-assurance tools: Guidance and potential testing protocols are needed to determine if a manufactured home's ceiling is tight enough to blow insulation into the attic. Development of this guidance can explore various methods using blower door-related house and fan pressure measurements to assess if the attic and house bypass have been reduced to a point where attic insulation can be added without concern of increasing roof deck condensation.

Durability analysis using unoccupied manufactured home test homes: The stakeholder feedback suggests a need and opportunity to use manufactured home test labs for implementation of unoccupied and controlled attic insulation experiments. Test labs (such as those at the National Institute of Standards and Technology, Florida Solar Energy Center, and PNNL) represent a broad range of climates for heat, air, and moisture analysis. Controlled field experiments, based on observational findings from the proposed field evaluations, would provide useful data needed to answer key research questions and to further inform modeling. Stakeholders from the manufactured housing, insulation, and roofing industries; CAPs and government agencies; and MHCSS can collaborate to address gaps in fundamental hygrothermal roof moisture research in manufactured homes needed to improve understanding of this issue.

One key challenge is quantifying how increases in roof deck condensation impact the magnitude of the plywood and OSB roof decking mold index and/or wood decay and the impact this has on associated roof life expectancy and decking repair costs at the time of reroofing. Such research efforts are likely necessary to justify potential MHCSS code issues and help improve future MHCSS code changes. This might include research to avoid lost opportunities with attic insulation and ventilation. Research on MHCSS code gaps might focus on eave venting and, to a lesser extent, weight of additional ceiling insulation; issues associated with additional snow loads; potential reduction of ice dams; and the decrease in bulk moisture-related problems by using a whole-house WAP approach to weatherization.

Cellulose insulation: CAPs do not typically use blown cellulose in attics, partially because of concerns about weight and moisture absorption. Research on the ability of ceilings in manufactured homes to support the weight of the insulation could determine whether cellulose is a viable alternative that might help CAPs meet SIR requirements.

Bag counts for low-slope attics: More specific guidance from insulation manufacturers is needed regarding bag counts for attic insulation in manufactured homes compared with standard bag count charts for site-built homes, where full attic insulation depth is easier to achieve. Research on the energy impact of displaced insulation in low-slope attics in manufactured homes would help inform how CAPs should determine the installed R-value based on bag count. This should include real-world installation issues related to achieving installed densities where access to the attic is limited.

HVAC research, development, and deployment: Discussions with some HVAC and manufactured housing industry stakeholders suggest interest in improving the effectiveness of current HUD-approved whole-house mechanical ventilation systems. Refinements to these systems might seek to improve temporal effectiveness (e.g., run time) of furnace-based whole-house supply ventilation systems.

Engage industry to reduce lost opportunities: Coordination with the manufactured housing industry is needed to consider offering voluntary standard options for R-38–R-49 attics instead of R-20 minimum to R-30 typical. This will help avoid the future need for WAP-funded retrofits. Doing it right initially is a win-win situation that might save costs for low-income manufactured home owners and taxpayers in the long run and reduce the future need to weatherize.

Opportunities with electric utility co-ops: Partnering with co-ops, especially those serving rural areas, could help CAPs identify manufactured home occupants with high utility bills. Getting electric co-ops to work with CAPs would be beneficial but might not happen easily without partnering with a state energy office and/or a generation and transmission co-op. Co-ops are getting interested in beneficial electrification and might find good opportunity in converting propane-heated manufactured housing to heat pumps or dual fuel systems. The National Rural Electric Cooperative Association has information about beneficial electrification on its website and is working with other stakeholders to save energy for their electric-heating manufactured homes customers and reduce peak loads for utilities. A report on weatherization of manufactured homes for South Carolina co-ops explains the impact assessment (personal communications with Pat Keegan in 2016). CAPs in this area have had a high level of success in installing attic insulation in a milder heating climate, in part by leveraging utility support.

5 Conclusions

This needs assessment set out to identify the barriers that prevent attic insulation upgrades from being implemented as part of weatherization work in manufactured homes. In existing site-built homes, attic insulation is a common cost-effective measure for improving comfort and efficiency of the home. Manufactured homes, conversely, are less likely to have attic insulation installed because of the inaccessibility of manufactured home attics and the related concerns about obstructing some of the attic ventilation and possibly causing or being held responsible for future moisture issues.

Based on input from various stakeholders, as well as energy modeling and cost analysis, several recommendations for how to address these issues have been compiled in this report. Three key technical resources and areas of future research have been identified that would best meet the needs related to these issues: (1) Conduct a field evaluation to assess attics that have previously been insulated by CAPs for moisture issues, (2) evaluate a gable end access approach and develop associated training tools, and (3) address low eave venting requirements through research on the effectiveness of alternative mitigation measures, such as a whole-house approach that includes air sealing the ceiling plane and installing appropriate mechanical ventilation.

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Appendix A. Needs Assessment Stakeholder List

Arnold, Tom	Liu, Bing
Baechler, Michael	Mendlen, Rick
Ballew, Johnathan	Mendon, Vrushali
Barbour, Ed	Merrigan, Tim
Bianchi, Marcus	Metzger, Cheryn
Blandford, Michael	Peeks, Brady
Blasnik, Michael	Nelson, Gary
Boisvery, Cory	O'Leary, Tim
Brooks, Howard	Olsen, Josh
Brown, Joan	Olson, Collin
Brown, Rodney	Parkhurst, Robert
Carter, Bruce	Pederson, Pete
Cichowski, Ben	Peterson, Janice
Clay, Chris	Pfeiffer, Bob
Conner, Craig	Pigg, Scott
Cox, Anthony	Raymer, Paul
Councilman, Brad	Robertson, Jake
Crawford, Roy	Ryan, Doug
Cutchin, Kelly	Salas, Glen
Daniels, Scott	Salzberg, Emily
Danner, Pamela	Schneider, Peter
Davies, John	Schrock, Gene
Dorsi, Chris	Schroeder, Derek
Dymond, Christopher	Schueler, Vince
Eckhart, Tom	Sedlacek, Craig
Ekman, Tom	Sivigny, Don
Epperson, Stacey	St. Onge, Richard
Ezzo, Mark	Starkey, Lois
Francisco, Paul	Steiner, Cal
Garcia, Robert	Stuart, Michael
Hagen, Bruce	Tempos, David
Hagerman, Joe	Thomas, Greg
Halverson, Rick	Turnes, Mark
Hood, Timonie	Unger, Lowell
Hourahan, Glenn	Vogt, Randy
Garcia, Robert	Walker, Iain
Karagiozis, Achilles	Werling, Eric
Karg, Rick	Weston, Theresa
Keefe, David	Wilcox, Geoff
Keegan, Patrick	Wilson, Mark
Kirkpatrick, Doug	Wingate, Peter
Kornbluth, Dick	Wolf, Michael
Krigger, John	Zabriskie, Paul
Laemmel, Bart	Zieman, Mike
Levy, Emanuel	

Appendix B. Summary of Key Inputs for PNNL Energy Analysis

The purpose of this simulation is to compare the energy savings from using R-38 ceiling insulation over R-20 (post 1994) and R14 (1976–1993 U.S. Department of Housing and Urban Development [HUD]) baselines in all climate zones.

Table A-1. Prototype Modeling Assumptions

Building Component	WAP HUD Code Baseline	R-38 Ceiling Insulation
Wall insulation R-value (h-ft^2-F/Btu)	11	11
Ceiling insulation R-value (h-ft^2-F/Btu)	20	38
Floor insulation R-value (h-ft^2-F/Btu)	22	22
Window U-factor (Btu/h-ft^2-F)	1.08	1.08
Window SHGC [a]	0.70	0.70
Envelope leakage limit (ACH50) [b]	NR (8)	NR (8)
Duct leakage limit (cfm25/100 ft^2 CFA) [c]	NR (12)	NR (12)
High-efficacy lighting percentage (%)[d]	NR (34%)	NR (34%)

[a] In the absence of a solar heat gain coefficient (SHGC) requirement, the SHGC corresponding to the window meeting the U-factor requirement based on ASRAC Cost Analysis Summary Table (ASRAC 2014) is selected for use in simulations.
[b] In the absence of HUD-code requirements for envelope leakage limit, a baseline is created using the 2006 International Electrotechnical Commission (IECC) assumptions in Mendon et al. 2013.
[c] In the absence of HUD-code requirements for duct leakage limit, a baseline is created based on Lucas et al. 2007.
[d] The lighting baseline is created based on the benchmark defined in Wilson et al. 2014.
[e] The whole-house ventilation rate for all cases is set per the HUD-code, which requires a continuous whole-house ventilation rate of 55 ft^3/min for the double-wide prototype specifications and 50 ft^3/min for the single-wide prototype specifications.

Following is a detailed description of PNNL's energy simulation analysis.

Energy Simulation Analysis

The present analysis leverages the analysis conducted by the U.S. Department of Energy (DOE) in support of the proposed rulemaking pertaining to the energy conservation standards for manufactured housing (DOE 2016a) and detailed in the energy simulation analysis chapter of the associated technical support document (DOE 2016b). The energy analysis focuses exclusively on single- and double-wide manufactured homes because they constitute the majority of the manufactured homes purchased in the United States and because multi-section homes are expected to be similar to the double-wide homes. This appendix describes the energy modeling software, climate locations, and details of the overall modeling methodology used in the analysis.

Simulation Tool

The simulation software used for this energy analysis is EnergyPlus® Version 8.0 (DOE BTO 2013). EnergyPlus is a whole-building energy simulation program capable of simulating detailed hourly and subhourly heating, cooling, and ventilation loads in a building. Since first introduced in 1996, EnergyPlus has been under continuous development by DOE. It has roots in the popular energy modeling software DOE-2 and the detailed heating, ventilating, and air-conditioning (HVAC) system modeling software Building Loads Analysis and System Thermodynamics (BLAST). EnergyPlus inherits the features of DOE-2 and BLAST and combines them with additional features of its own (DOE 2013).

Prototype Building Models

The present energy analysis is based on prototypical single- and double-wide manufactured homes, which constitute a majority of all manufactured homes in the United States. The single-wide home prototype is assumed to be 14-ft wide by 66-ft long with a floor area of 924 ft^2, and the double-wide home prototype is assumed to be 28-ft wide by 56-ft long with a floor area of 1,568 ft^2. Both prototypes are assumed to have a window area set to 12% of the conditioned floor area, with windows being equally distributed on all four walls to represent a solar-neutral configuration. Although equal window distribution is atypical in any individual manufactured home, the solar-neutral approach is designed to represent an average of all home orientations. For the purposes of energy modeling, the windows are modeled as a single large window on each side; however, this is not expected to impact the results because solar and conduction gains and losses are evenly distributed in the entire living space thermal zone. Figure A-1 and Figure A-2 show a graphical illustration of the two manufactured home prototype building models.

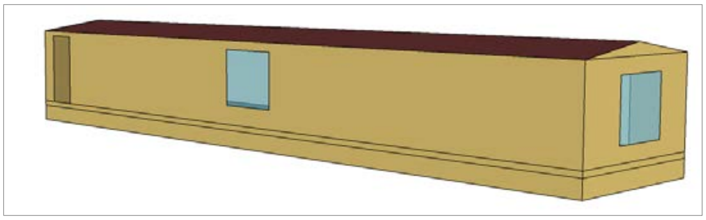


Figure A-1. Single-wide manufactured home prototype

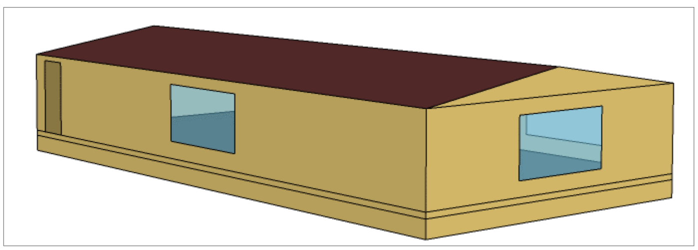


Figure A-2. Double-wide manufactured home prototype

Climate Locations

The energy analysis is conducted in all standardized climate zones and moisture regimes occurring in the United States, as defined by the International Codes Council (ICC) and ASHRAE. Because the ICC and ASHRAE incorporate 15 standardized climate zones (as shown in Figure A-3), and because the HUD-code for manufactured homes incorporates three (as shown in Figure A-4), the energy analysis is conducted in a total of 19 climate locations to provide adequate coverage between the ICC and HUD climate zones and to provide adequate consideration to states in the southeastern United States—Mississippi, Alabama, Georgia, and South Carolina—which account for a large portion of manufactured home sales.

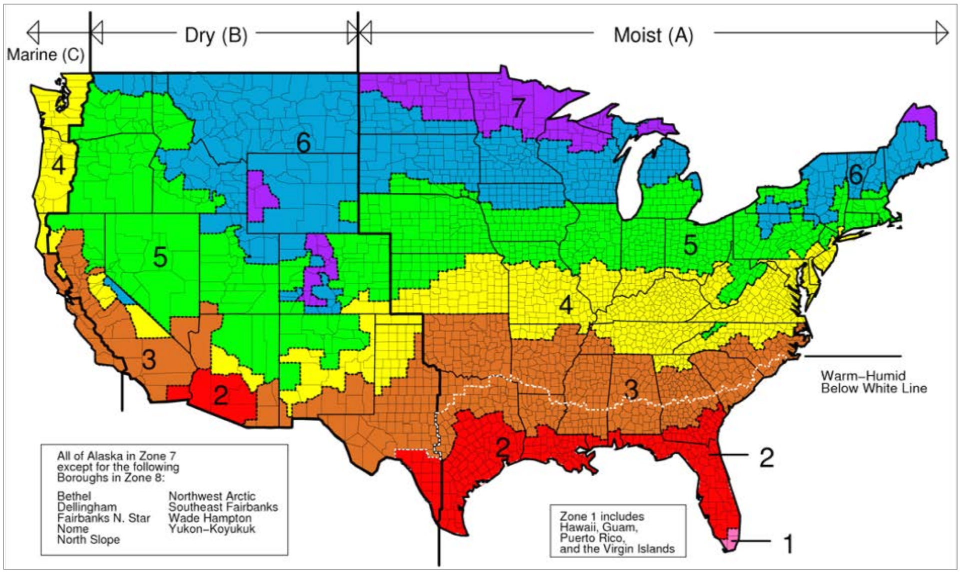


Figure A-3. IECC climate zone map

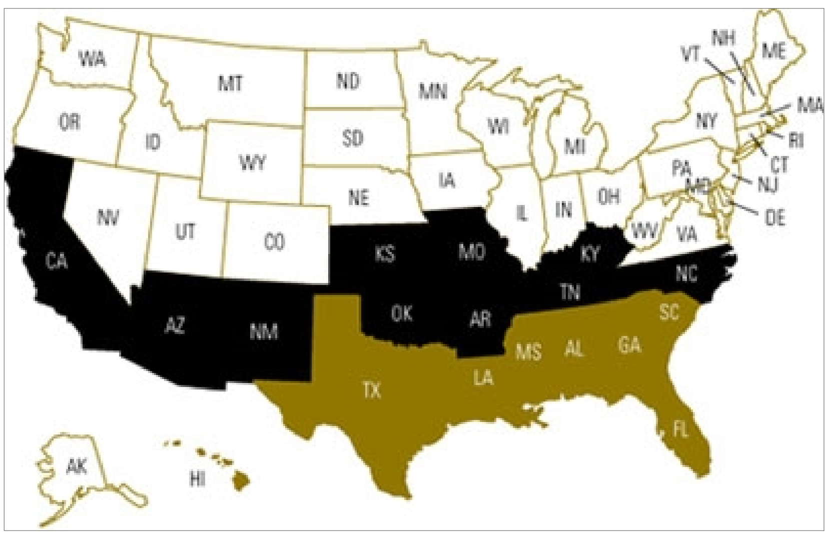


Figure A-4. HUD climate zone map

The climate locations used in the simulation analysis along with their respective HUD, IECC, and proposed climate zone designation as well as the typical meteorological year 3 (TMY3) weather file used in the simulations are listed in Table A-2.

Table A-2. Climate Locations Used in Energy Analysis

HUD Zone	IECC Climate Zone	Location	TMY3 Weather File Used in Simulation[5]
1	1A	Miami, Florida	USA_FL_Miami.Intl.AP.722020_TMY3.epw
1	2A	Houston, Texas	USA_TX_Houston-Bush.Intercontinental.AP.722430_TMY3.epw
2	2B	Phoenix, Arizona	USA_AZ_Phoenix-Sky.Harbor.Intl.AP.722780_TMY3.epw
1	3A	Atlanta, Georgia	USA_GA_Atlanta-Hartsfield-Jackson.Intl.AP.722190_TMY3.epw
1	3A	Charleston, South Carolina	USA_SC_Charleston.Intl.AP.722080_TMY3.epw
1	3A	Jackson, Mississippi	USA_MS_Jackson.Intl.AP.722350_TMY3.epw
1	3A	Birmingham, Alabama	USA_AL_Birmingham.Muni.AP.722280_TMY3.epw
1	3A	Memphis, Tennessee	USA_TN_Memphis.Intl.AP.723340_TMY3.epw
2	3B	El Paso, Texas	USA_TX_El.Paso.Intl.AP.722700_TMY3.epw
2	3C	San Francisco, California	USA_CA_San.Francisco.Intl.AP.724940_TMY3.epw
3	4A	Baltimore, Maryland	USA_MD_Baltimore-Washington.Intl.AP.724060_TMY3.epw
3	4B	Albuquerque, New Mexico	USA_NM_Albuquerque.Intl.AP.723650_TMY3.epw
3	4C	Salem, Oregon	USA_OR_Salem-McNary.Field.726940_TMY3.epw
3	5A	Chicago, Illinois	USA_IL_Chicago-OHare.Intl.AP.725300_TMY3.epw
3	5B	Boise, Idaho	USA_ID_Boise.Air.Terminal.726810_TMY3.epw
3	6A	Burlington, Vermont	USA_VT_Burlington.Intl.AP.726170_TMY3.epw
3	6B	Helena, Montana	USA_MT_Helena.Rgnl.AP.727720_TMY3.epw
3	7	Duluth, Minnesota	USA_MN_Duluth.Intl.AP.727450_TMY3.epw
3	8	Fairbanks, Alaska	USA_AK_Fairbanks.Intl.AP.702610_TMY3.epw

Building Geometry

For the energy analysis, the dimensions of the single-wide manufactured homes are set to 14 ft by 66 ft, thus yielding a floor area of 924 ft^2. The dimensions of the double-wide manufactured homes are set to 28 ft by 54 ft, thus yielding a floor area of 1568 ft^2. The floor-to-ceiling height for both homes was set to 7.5 ft. The roof is assumed to be gabled with the roof ridge along the long dimension of the homes. The window-to-floor ratio is set to 12%, thus yielding a window area of 111 ft^2 for single-wide homes and 188 ft^2 for double-wide homes. The window area is assumed to be distributed equally on all four facades to yield a solar-neutral orientation. Although equal window distribution is atypical in any individual manufactured home, the solar-neutral approach is designed to represent an average of all home orientations. The windows are assumed to have no overhangs to represent an average case. Both the single-wide and double-wide homes are assumed to have two

[5] TMY3 weather files are data sets of hourly solar radiation and meteorological elements for a period of 1 year. TMY3 files for more than 1,020 locations in the United States can be downloaded from http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_about.cfm.

exterior doors with a total door area of 36 ft^2. The manufactured homes are also assumed to have a vented attic and a vented crawl space.

Building Thermal Envelope

EnergyPlus is a detailed energy simulation program that requires detailed specifications of building components for simulation. This section describes the building component assemblies and the derivation of the resulting component heat transfer coefficients (*U*-factors) for the various component efficiency levels considered in the energy analysis. The methodology published as part of an earlier analysis conducted by the Pacific Northwest National Laboratory (PNNL) (Conner et al. 1992) and DOE (DOE 2016b) is adapted to calculate the *U*-factors of building assemblies to match the component-level *U*-factors.

This section describes the *U*-factor calculations for the ceilings, walls, and floors of a manufactured home. The heat-flow paths with and without insulation compression or reduction in thickness are computed separately for the ceilings, walls, and floors. The basic material properties used in the calculations are summarized in Table A-3, whereas the detailed ceiling, wall, and floor U-factor calculations are described in the following sections.

Table A-3. Building Material Properties

Component	*R*-value (h×ft²×°F/ Btu)[a]	Material Description
Framing members[b]	1.87	2 in. by 2 in. (1.5 in by 1.5 in. actual)
	4.38	2 in. by 4 in. (1.5 in. by 3.5 in. actual)
	6.88	2 in. by 6 in. (1.5 in. by 5.5 in. actual)
	9.74	2 in. by 8 in. (1.5 in. by 7.5 in. actual)
Air films	0.25	Exterior air film (7.5-mph wind speed)
	0.61	Horizontal air film, heat flow up
	0.92	Horizontal air film, heat flow down
	0.68	Vertical air film
Cladding and finishes	0.45	Gypsum board, 1/2 in.
	0.82	Particleboard, 5/8 in.
	0.00	Bottom board (thin material holding floor insulation in place)
	1.00	Interior floor covering[c]
Ceiling insulation (per inch)	2.5 to 3.7	Blown insulation[d]

[a] Except as noted, these data are from ASHRAE (2013, Chapter 26).
[b] Wood framing members have a range of *R*-values. The commonly used *R*-value for wood is 1.25 per inch, which is used here. This value is also used in the 2013 *ASHRAE Handbook—Fundamentals* (example 3, page 27.3).
[c] ASHRAE provides the *R*-value of linoleum as 0.51 and rugs as 1.59 (rug with rubber pad). An *R*-value of 1 is an intermediate value between these two.
[d] From DOE (2011, Table 5.1.3).

Ceiling *U*-factors

The methodology described in Conner et al. (1992) and DOE's previous analysis (DOE 2016b) is applied to the current calculation of ceiling *U*-factors. The calculations for each ceiling insulation *R*-value for single- and double-wide manufactured homes are detailed in tables Table A-4–Table A-9. Table titles use nominal R-values; calculations account for tapering as indicated in the note following each table. A summary of ceiling *U*-factors considered in this analysis is provided in Table A-10.

Table A-4. Ceiling U-factor for Single-wide Manufactured Homes with R-14 Ceiling Insulation[a]

Description	At Trusses (Bottom Chord)			Between Trusses	
Insulation	None	Full	Partial	Full	Partial
Fraction of ceiling	4.00%	4.85%	1.2%	72.70%	17.3%
R-value of non-insulation materials	3.55	3.55	3.55	1.67	1.67
Insulation *R*-value	0	14	Variable	14	Variable
Total path *R*-value	3.55	17.55	7.25	15.67	10.30
Path *U*-factor	0.282	0.057	0.138	0.064	0.097
Overall *U*-factor = 0.0788					

[a] Insulation thickness = 4.5 in.
Fraction of ceiling with reduced insulation thickness = 19.22% (ridge height = 23.5 in.; heel height = 2.5 in.)

Table A-5. Ceiling U-factor for Single-wide Manufactured Homes with R-20 Ceiling Insulation[a]

Description	At Trusses (Bottom Chord)			Between Trusses	
Insulation	None	Full	Partial	Full	Partial
Fraction of ceiling	4.00%	4.65%	1.4%	69.74%	20.3%
R-value of non-insulation materials	3.55	3.55	3.55	1.67	1.67
Insulation *R*-value	0	15.35	Variable	20	Variable
Total path *R*-value	3.55	18.9	9.18	21.67	12.46
Path *U*-factor	0.282	0.053	0.109	0.046	0.080
Overall *U*-factor = 0.0636					

[a] Insulation thickness = 6.5 in.
Fraction of ceiling with reduced insulation thickness = 25.51% (ridge height = 23.5 in.; heel height = 2.5 in.)

Table A-6. Ceiling U-factor for Single-wide Manufactured Homes with R-38 Ceiling Insulation[a]

Description	At Trusses (Bottom Chord)			Between Trusses	
Insulation	None	Full	Partial	Full	Partial
Fraction of ceiling	4.00%	4.43%	1.6%	66.44%	23.6%
R-value of non-insulation materials	3.55	3.55	3.55	1.67	1.67
Insulation *R*-value	0	33.35	Variable	38	Variable
Total path *R*-value	3.55	36.9	27.00	39.67	29.86
Path *U*-factor	0.282	0.027	0.037	0.025	0.033
Overall *U*-factor = 0.0377					

[a] Insulation thickness= 12.3 in.
Fraction of ceiling with reduced insulation thickness = 26.17% (ridge height = 28.5 in.; heel height = 7.5 in.)

Table A-7. Ceiling U-factor for Double-wide Manufactured Homes with R-14 Ceiling Insulation[a]

Description	At Trusses (Bottom Chord)			Between Trusses	
Insulation	4.00%	5.39%	0.6%	80.87%	9.1%
Fraction of ceiling	3.55	3.55	3.55	1.67	1.67
R-value of non-insulation materials	0	14	Variable	14	Variable
Insulation *R*-value	3.55	17.55	7.25	15.67	10.30
Total path *R*-value	0.282	0.057	0.138	0.064	0.097
Path *U*-factor	4.00%	5.39%	0.6%	80.87%	9.1%
Overall *U*-factor = 0.0757					

[a] Insulation thickness = 4.5 in.
Fraction of ceiling with reduced insulation thickness = 10.15% (ridge height = 44.5 in.; heel height = 2.5 in.)

Table A-8. Ceiling U-factor for Double-wide Manufactured Homes with R-20 Ceiling Insulation[a]

Description	At Trusses (Bottom Chord)			Between Trusses	
Insulation	None	Full	Partial	Full	Partial
Fraction of ceiling	4.00%	5.31%	0.7%	79.64%	10.4%
R-value of non-insulation materials	3.55	3.55	3.55	1.67	1.67
Insulation *R*-value	0	15.35	Variable	20	Variable
Total path *R*-value	3.55	18.9	9.18	21.67	12.46
Path *U*-factor	0.282	0.053	0.109	0.046	0.080
Overall *U*-factor = 0.0599					

[a] Insulation thickness = 6.5 in.
Fraction of ceiling with reduced insulation thickness = 11.52% (ridge height = 47.5 in.; heel height = 5.5 in.)

Table A-9. Ceiling U-factor for Double-wide Manufactured Homes with R-38 Ceiling Insulation[a]

Description	At Trusses (Bottom Chord)			Between Trusses	
Insulation	None	Full	Partial	Full	Partial
Fraction of ceiling	4.00%	5.20%	0.8%	77.95%	12.1%
R-value of non-insulation materials	3.55	3.55	3.55	1.67	1.49
Insulation *R*-value	0	33.35	Variable	38	Variable
Total path *R*-value	3.55	36.9	27.00	39.67	29.86
Path *U*-factor	0.282	0.027	0.037	0.025	0.033
Overall *U*-factor = 0.0367					

[a] Insulation thickness = 12.3 in.
Fraction of ceiling with reduced insulation thickness = 13.39% (ridge height = 49.5 in.; heel height = 7.5 in.)

Table A-10. Ceiling U-factors

Insulation	*R*-14	*R*-22	*R*-38
Double-wide	*U*-0.0757	*U*-0.0599	*U*-0.0367
Single-wide	*U*-0.0788	*U*-0.0636	*U*-0.0377

Wall *U*-factors

The methodology described in Conner et al. (1992) and DOE's previous analysis (DOE 2016b) is applied to the current calculation of exterior wall *U*-factors. The wall U-factor calculation for the R-11 walls considered in this analysis is provided in Table A-11.

Table A-11. Wall U-factor for Homes with R-11 Wall Insulation

Description	Frame	Insulation
Fraction	25%	75%
Constant R-value	1.505	1.505
Wood stud	4.375	
Insulation R-value	0	11
Path R-value	5.88	12.505
Path U-value	0.17	0.08
Overall *U*-factor = 0.1025		

Floor *U*-factors

The methodology described in Conner et al. (1992) and DOE's previous analysis (DOE 2016b) is applied to the current calculation of floor *U*-factors. The detailed calculations for the floor *U*-factors considered in this analysis are provided in Table A-12 and Table A-13, and the overall floor *U*-factors are summarized in Table A-14.

Table A-12. Floor U-factor for Manufactured Homes with R-19 Floor Insulation

	Frame Insulation		Non-Frame Insulation	
	Full	Partial	Full	Partial
Fraction of floor area	0.00%	5.00%	50.00%	45.00%
Constant *R*-value		1.84	1.84	1.84
Roll insulation		4.75	19	16.625
Floor joists (2 in. by 6 in.)		0	0	0
Total path *R*-value		6.59	20.84	18.465
Path *U*-factor		0.1517	0.048	0.0542
Overall *U*-factor = 0.0560				

Table A-13. Floor U-factor for Manufactured Homes with R-22 Floor Insulation

	Frame Insulation		Non-Frame Insulation	
	Full	Partial	Full	Partial
Fraction of floor area	0.00%	5.00%	50.00%	45.00%
Constant *R*-value		1.84	1.84	1.84
Roll insulation		5.5	22	19.25
Floor joists (2 in. by 6 in.)		0	0	0
Total path *R*-value		7.34	23.84	21.09
Path *U*-factor		0.1362	0.0419	0.0474
Overall *U*-factor = 0.0491				

Table A 14. Floor U-factors

Insulation	*R*-19	*R*-22
U-factor	0.0560	0.0491

Lighting

The current analysis considers the lighting requirements of the HUD-code. Lighting is modeled as hardwired, plug-in, and exterior based on the *Building America Simulation Protocols* (Wilson et al. 2014). The corresponding lighting energy use for the baseline is calculated using Building America's equations, shown in Table A-15, and are based on conditioned floor area (CFA).

Table A-15. Baseline Lighting Energy Use for HUD and the 2006 IECC

Type		Energy Use
Interior hardwired	=	0.8 × (CFA x 0.542 + 334) kWh/y
Interior plug-in lighting	=	0.2 × (CFA x 0.542 + 334) kWh/y
Exterior lighting	=	CFA × 0.145 kWh/y

Building America assumes that 66% of all lamps are incandescent, 21% are compact fluorescent, and the remaining 13% are T-8 linear fluorescent in the baseline (when the energy code has no requirements for efficient lamps [compact fluorescent and fluorescent, not incandescent]). The HUD-code for manufactured housing does not require any high-efficacy lighting. Thus, the lighting energy consumption is calculated using fractions specified in Table A-16 and the simplified approach described in the *Building America Simulation Protocols* (Wilson et al. 2014).

Table A-16. Lighting Fixture Type Fractions for All Cases Considered in the Energy Analysis

	All Cases
Fraction incandescent	0.66
Fraction compact fluorescent	0.21
Fraction linear fluorescent	0.13

Internal Loads

Internal loads include interior equipment loads, such as televisions and computers, people loads, and lighting loads. The total internal heat gain for the baseline HUD-code is assumed to be 67.5 kBtu/d for double-wide manufactured homes and 48.1 kBtu/d for single-wide manufactured homes as calculated using the assumptions in Section R405 of the 2015 IECC (ICC 2014).

Envelope Leakage

In EnergyPlus, air leakage through the building envelope is specified using the effective leakage area (ELA), which is a measure of the total area of all sources of leakage in the building envelope. The input to EnergyPlus is the ELA at a 4-Pa reference pressure differential, whereas a standard blower door test as specified in the proposed rule is set in units of air changes per hour at a 50-Pa pressure differential (ACH50). This value is converted to the required EnergyPlus input of ELA using the methodology described in Mendon et al. (2013). Table A-17 lists the specific ELA values used in this analysis as input to EnergyPlus to model the ACH50 requirements in the proposed rule and alternatives.

Table A-17. ELA

Description	ELA (in^2)	
ACH50	Double-wide	Single-wide
8	86.06	50.72

Mechanical Systems

HVAC systems in new manufactured homes are commonly electric air-conditioning units with heating provided by a natural gas or liquid petroleum gas furnace, electric resistance heating, or electric heat pump heating. Hence, these four HVAC systems have been considered in this analysis. This section describes the details of the HVAC system.

Thermal Zoning and Thermostat Set Points

The manufactured home model is divided into three thermal zones for simulation purposes: a conditioned living zone, an unconditioned attic, and an unconditioned crawl space. The attic is assumed to be ventilated through soffit and ridge vents. The heating set point is assumed to be 72°F (22.22°C), and the cooling set point is assumed to be 75°F (23.88°C) (ICC 2014).

HVAC System Sizing

The size of the heating and cooling coils is obtained by running the EnergyPlus design day simulation for the purpose of this energy analysis. EnergyPlus allows users to specify a winter design day and a summer design day, which are used for determining the heating and cooling coil size. The winter and summer design days are selected based on the ASHRAE heating and cooling design day criteria (ASHRAE 2013).

HVAC Equipment Efficiency

The equipment efficiencies of all three systems analyzed in this energy analysis are summarized in Table A-18. These efficiencies are established in existing Federal Appliance Standards.

Table A-18. Equipment Efficiencies

System	Efficiency
Electric AC with natural gas or liquid petroleum gas furnace	Seasonal Energy Efficiency Ratio of 13; annual fuel utilization efficiency of 75%
Electric AC with electric resistance heating	Seasonal Energy Efficiency Ratio of 13; 100% heating efficiency
Electric heat pump	Seasonal Energy Efficiency Ratio of 13; heating seasonal performance factor of 7.7

Duct Leakage

EnergyPlus has the capability of simulating detailed duct losses with the AirflowNetwork model, which has been used in the present analysis to quantify duct losses. The ducts are assumed to be located in the crawl space. All ducts except the crossover duct for double-wide manufactured homes are assumed to be placed above the belly insulation under the floor such that they are surrounded by the floor insulation. Hence, the ducts are approximated to be insulated to the level of the floor belly insulation. The crossover duct for a double-wide home is assumed to be insulated by *R*-8 duct insulation in all cases. Duct leakage is modeled as leakage from the main supply duct into the crawl space.

The HUD-code requires sealing but does not specify duct leakage thresholds. Thus, duct leakage rates for the HUD baseline are assumed based on research conducted by Lucas et al. (2007) and as summarized in Table A-19.

Table A-19. Duct Leakage Assumptions

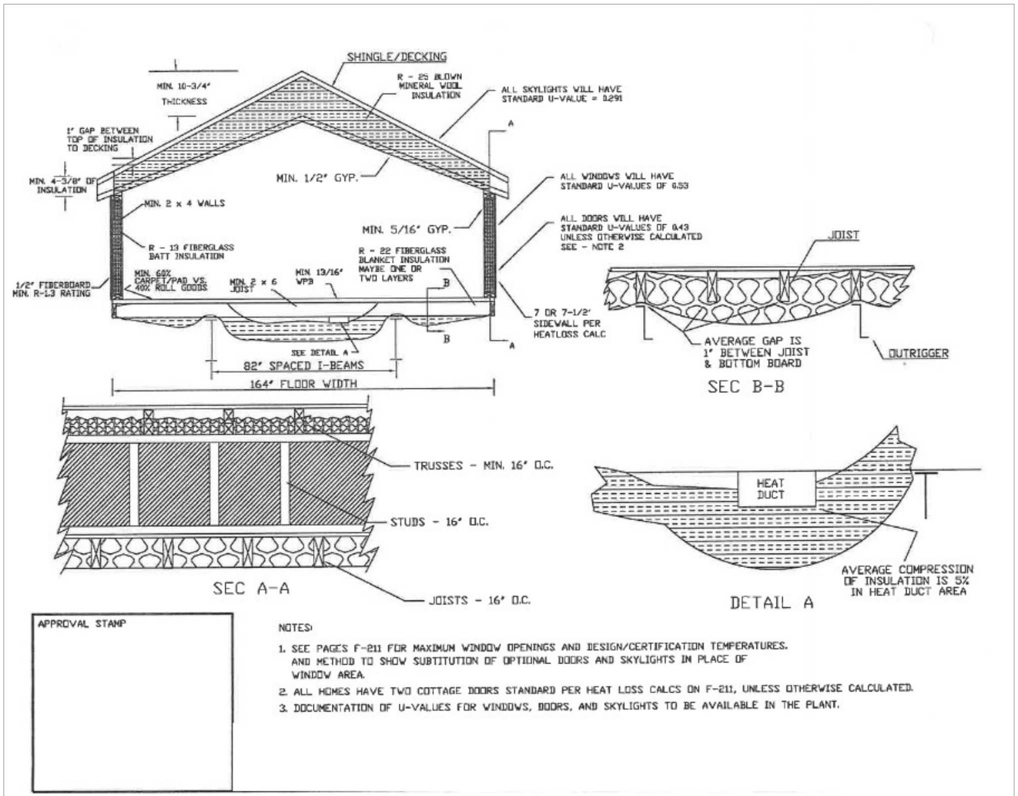
Code	cfm25 per 100 ft^2 of Floor Area	Double-Wide (cfm25)	Single-Wide (cfm25)
HUD	12	188	111

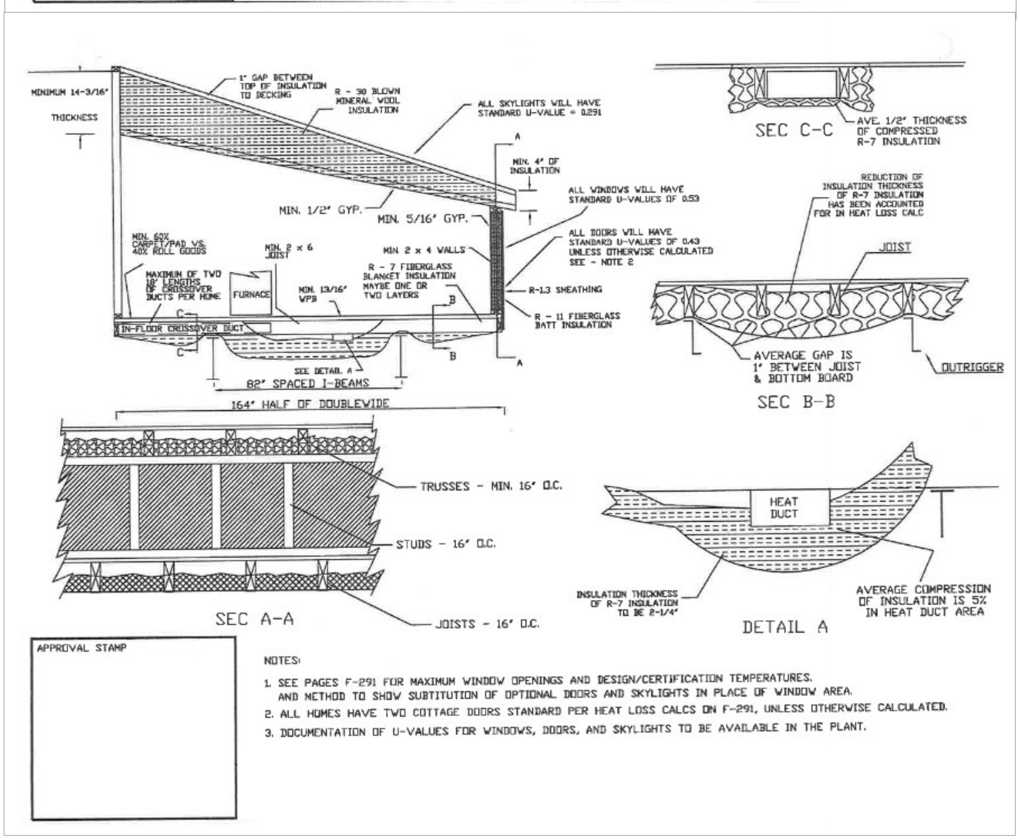
Domestic Hot Water System

The water heater in all cases is assumed to be a storage-type water heater with minimum efficiency levels established by Federal Appliance Standards.

Appendix C. Typical Truss Details: Flat and Vaulted

The following images were provided by Resources, Applications, Designs, and Controls (RADCO), Inc.





Appendix D. Field Evaluation Protocol

The following protocol provides an approach to evaluate the attics of U.S. Department of Housing and Urban Development (HUD)-code manufactured homes and assess any moisture issues associated with attic insulation retrofits. The approach involves conducting reviews of existing weatherization audit and work record data to help recruit target homes for follow-up evaluation.

This initial protocol is an outline of the potential requirements and is presented as a starting point for Community Action Partnerships (CAPs) or other interested parties to use when designing and conducting a field evaluation. It does not include the technical testing procedure and analysis methodology, which would be developed by the researchers in coordination with the funding organization.

1. Recruiting homes based on target home criteria:
    - Single- or double-section manufactured homes
    - Built after 1994 to HUD Manufactured Housing Construction Safety Standards
    - Single-owner-occupied since purchased new
    - Access to Weatherization Assistance Program audit, work scope records, etc.
    - Heating, ventilating, and air-conditioning certificate information available in home (panel or under sink)
    - Manufactured home never moved from original site address
    - Shallow pitch roof truss less than 3:12
    - Roof has oriented strand board wood decking and asphalt shingle
    - Roof approaching end of useful life
    - Attic insulated from R14-R22 to R38+ at least 2 years prior
    - Insulation blown fiberglass at >1.5 pcf
    - Blown fiberglass insulation touches underside of roof decking
    - Weatherization CAP employed whole-house approach:
        - Air sealing of ceiling bypass to attic
        - Installation of mechanical ventilation per ASHRAE 62.2
        - Measures to reduce of source of bulk moisture intrusion.
2. Developing and executing homeowner agreements indicating that occupants must be willing to participate according the terms of agreement, and allow the researcher to conduct the field evaluation, including:
    - Conducting before and after verbal phone/site survey with occupant
    - Pretest home to determine logistical and technical adequacy for sample selection
    - Roof removal and replacement
    - Conducting the moisture content test protocol
    - Collecting decking core samples
    - Taking photos from roof and in attic
    - Data logger deployment and retrieval

3. Developing and executing roofing contractor agreements
4. Coordinating and implementing field tests and data analysis:
    - Recruitment screening
    - Field-testing during reroofing
    - Deploying and retrieving data loggers measuring relative humidity and temperature.
    - Laboratory analysis of deck samples
    - Analyze field visit data, data logger measurements, and other information from existing weatherization audit and work record.

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