Improving the Quality, Performance, and Operation of Manufactured Home HVAC Systems Through Plant Installation

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Prepared for

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Foreword

Manufactured housing plays a crucial role in meeting the diverse housing needs of our nation, and it is imperative that we continually strive to improve the quality, efficiency, and affordability of these homes. The integration of high-quality heating and air conditioning (H&AC) systems in the factory directly addresses these objectives, offering benefits not only to industry stakeholders but also to the customers who rely on manufactured homes for safe and comfortable living. Today, most manufactured homes are shipped from factories without air conditioning installed, leaving consumers to work with retailers to obtain air conditioning systems during the installation process of the home or install after-market air conditioning systems after occupancy. Either option can increase costs and reduce performance compared to factory-installed systems. HUD's Manufactured Housing Construction and Safety Standards (MHCSS) only require a manufactured home to be equipped with a heating system. Cooling systems are an optional feature under the MHCSS due to the nationwide applicability of the MHCSS and the more regional needs for air conditioning.

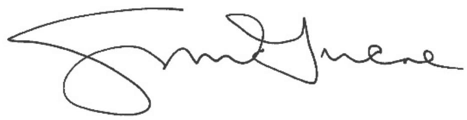
This study, *Improving the Quality, Performance, and Operation of Manufactured Home HVAC Systems Through Plant Installation*, was undertaken by the Systems Building Research Alliance (SBRA) and the Electric Power Research Institute (EPRI). The collaborative effort involving technical and commercialization experts aims to revolutionize the current practices in H&AC system design and installation within the manufactured housing sector. By leveraging HUD's quality control regime and partnering with industry stakeholders, the project aims to streamline the production process and enhance the overall performance of manufactured homes.

The report outlines the comprehensive research undertaken by the SBRA-EPRI team, from identifying deficiencies in current practices to developing and prototyping innovative H&AC solutions. Through rigorous evaluation and collaboration with key stakeholders, the team has successfully demonstrated the feasibility and benefits of plant-installed, commercially competitive, and fully integrated H&AC systems.

Of particular significance are the findings showcasing the successful implementation of various H&AC system types within production facilities. The insights gained from this study could pave the way for manufacturers to adopt alternative systems that not only improve energy performance, but also elevate the quality and comfort of manufactured homes.

This report serves as a valuable resource for industry stakeholders, policymakers, and researchers alike, providing detailed insights, recommendations, and avenues for future exploration. I commend the diligent efforts of all involved in this endeavor, and express my gratitude to the SBRA, EPRI, and dedicated professionals who contributed to this important initiative.

It is my hope that the findings presented herein will inform and inspire further advancements in the manufactured housing industry, ultimately benefiting both industry stakeholders and the individuals and families who call manufactured homes their own.



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Executive Summary

This report explores the potential benefits that the manufactured housing industry and its customers could gain from plant-installed, commercially competitive, and fully integrated heating and air-conditioning (H&AC) solutions.[1][2] This study's focus is to revise the current H&AC system design and fabrication processes in the manufactured housing industry by moving the installation of all H&AC components into the plant under the HUD-required quality assurance and quality control regime. To carry out this goal, the team from Systems Building Research Alliance (SBRA) and Electric Power Research Institute (EPRI) recruited technical and commercialization panel members and selected the most promising options on the basis of metrics, evaluated the commercial arrangements associated with the proposed solutions, and constructed three prototype homes with different H&AC systems.

The technical and commercialization panels included engineering experts and marketing professionals. The SBRA-EPRI team collaborated closely with the panels to identify deficiencies and find ways to improve current practice. During prototyping, the team explored three hardware integration and product configuration options that improved home performance and quality. It also explored changes to commercial arrangements, including the equipment distribution, inventory, and servicing necessary to align commercial interests.

The team partnered with production facilities in southern Georgia and northern California to integrate the three H&AC system options into newly constructed manufactured homes. In the Georgia plant, two whole-home options emerged—a ducted, packaged unitary system and a ducted (central air handler) mini-split heat pump. A nonducted packaged unitary system (one system per room) emerged in the California plant.

The findings demonstrate that home production facilities can successfully implement all three system types, and they can operate as intended after transport. The packaged unitary systems can be installed without additional work and skills. The ducted mini-split system requires more training and labor to install but is less costly and has other benefits. By piloting these alternative systems, this study is a steppingstone for manufacturers seeking options to improve energy performance and quality without significant impacts to labor, skill, and equipment costs.

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[1] In this document, *manufactured homes* means homes built to comply with the HUD Code, formally known as the Manufactured Home Construction and Safety Standards. These homes are built on permanent chassis and designed to be used as dwellings with or without permanent foundations when connected to required utilities and include plumbing, heating, air-conditioning, and electrical systems.

[2] This study's primary emphasis is on heating and cooling. Ventilation systems are already fully installed at the plant or could be integrated with the new H&AC system.

The report provides a background introduction and problem statement describing the need for the effort. Next, it outlines the research conducted to develop viable technical and commercial approaches to achieve the project goals. It describes the critical technical and commercial considerations identified from interviews and a shortlist of the most promising options based on a list of metrics. This report then details the technology development and prototyping process, hardware integration options, findings and lessons learned, and proposed commercial arrangements. Finally, it concludes with recommendations based on the key findings and suggestions for future research.

Chapter 1. Introduction

A defining characteristic of the manufactured housing industry is the consistency in construction method, design, and approach to sales among the 143 plants producing about 105,000 homes per year nationwide (MHI, 2022). Furthermore, many building and design practices that typify the industry have changed little in decades. Several studies note that the Manufactured Home Construction and Safety Standards (MHCSS), commonly referred to as the HUD Code, have changed little for many years and mandate minimum energy standards less stringent than state codes (Lubliner, Ueno, and Burkett, 2019; Talbot, 2012). Furthermore, the 2021 updates to the code made no changes to energy efficiency provisions. Low consumer demand and limited manufacturer offerings add to the lethargy of building more energy efficient homes. In some cases, manufacturing only to MHCSS minimums and using historical design and construction practices have stymied innovation and resulted in system inefficiencies. One of the most glaring examples of an antiquated practice that systemically degrades performance is installing the heating and cooling system (H&AC) components in two stages. The home manufacturer installs the required elements, such as heating and some distribution components, in the factory, and a technician installs other parts, such as the cooling and other parts of the distribution system, in the field (Dentz and Zhu, 2021). According to interviews with multiple industry experts, this bifurcation has resulted in reduced system operating efficiency, service issues, poor comfort, and increased homeownership costs. This research project seeks to reengineer the heating and cooling system design and fabrication, with all components installed in the plant under the existing regulated quality control regime.

The project concept evolved from discussions among industry experts to identify meaningful research that addresses the complex challenge of improving performance and affordability at the same time. The solutions and innovations build on existing industry practices and promising technologies not currently in use in the manufactured housing industry. The project team conducted a vetting process that required collaborating and partnering with stakeholders, resulting in a list of preferred solutions. The project also builds on recent advances in heat pump technology not available previously.

The project aims to achieve two core industry goals: (1) making homes more affordable on a sustainable basis by lowering energy costs and (2) improving quality. The work also aims to drive down the cost of installing space conditioning heat pumps, an important energy-efficient technology. Key aspects of the current heating and cooling system selection, design, and installation process will likely change as project results deploy. In the future, home manufacturers may take on most of the equipment installation responsibilities, such as installing the outdoor unit (whether air-conditioner or heat pump) and refrigerant line connections, thereby revamping and replacing steps currently under the purview of the heating, ventilation, and air-conditioning (HVAC) distributors and site technicians. Heating and cooling systems installed in the manufactured home plant could also provide opportunities for quality assurance on duct leakage and airflow testing in homes before shipment, ensuring system quality and functionality. Plant-installed heating and cooling systems could also provide a more standardized set of operating instructions, helping to educate occupants on operations, maintenance needs, and the economic and environmental values of the installed systems.

These research efforts, led by a team of engineers and marketing professionals and guided by a group of manufactured housing stakeholders, were based on applying an integrated and multidisciplinary approach to heating and cooling system design. The team sought to change deeply ingrained practices in manufactured home production, delivery, and installation methods. The resulting recommendations include proposed technical changes and new marketing, sales, and service approaches. For this project, HUD is the critical vehicle to bring together otherwise competing industry members to address a common set of goals and provide publicly available, independently verified results and data. The results provide the basis for improving home quality, reducing energy use and, ultimately, providing value, comfort, and convenience to manufactured home consumers and occupants.

Problem Statement

It is not uncommon in any industry for common practices to become standard without evolving over time, even when those practices are ineffective, inefficient, or even counterproductive in the current environment. Homebuilding is no exception. A glaring example of a practice that has outlived its utility is the traditional design, selection, and installation processes and the equipment used for heating and cooling systems in manufactured homes. By far, the most common scenario for heating and cooling design (about 90 percent of the annual number of manufactured homes produced each year) begins with home manufacturers selecting inventory and installing heating, distribution (typically air ducts), and ventilation systems components in the plant. The second step is for a separate, unaffiliated, and independent entity—an HVAC distributor and installer—to design, select, and install other major system components (typically the cooling system) at the home site. Even though system efficiency and operating effectiveness require heating and cooling components to be integrated, the manufactured housing industry has made this bifurcated arrangement work. The reason for this bifurcation is because HUD Code requires homes to include heating at the factory but not cooling. Cooling is usually an optional, aftermarket addition. It continues that way because the least costly way to add central cooling has been to install the outdoor unit and indoor coil on site. Experience has shown that fragmenting heating and cooling system decisions and outsourcing important component installation to contractors outside the quality control reach of the plant (for manufactured homes, the quality control process is under HUD's purview) has a corrosive effect on system operational efficiency and durability, with corresponding negative effects on affordability (that is, energy costs) and equipment service life.

Performance degradation resulting from a fragmented heating and cooling system is neither modest nor uncommon. The following is a partial list of concerns and inefficiencies in heating and cooling system performance stemming from a split design and installation process. This list comes from interviews with and comments from the expert panelists.

- **Oversized Cooling Equipment.** The HVAC distributor working for the home retailer typically selects cooling capacity, with no input from the home manufacturer. The negative consequences of this disconnect are legion. Home manufacturers make decisions about other system components (for example, duct sizing) without knowing the capacity of the cooling equipment, and distributors tend to oversize cooling capacity, not knowing the efficiency of the envelope, wanting to avoid customer complaints about undercooling. Too often, antiquated rules of thumb and undertrained or misinformed HVAC installers are used in selecting cooling capacity. When cooling equipment is oversized, energy bills go up, and the system is less capable of controlling humidity levels, increasing the likelihood of moisture problems (Levy and Dentz, 2003).
- **Mismatched Outdoor and Indoor Components.** Nearly all manufactured homes with the optional cooling system are provided with a system consisting of multiple site-assembled parts, including an evaporator "A" coil installed atop the furnace and an external compressor placed on a pad outside the home. The indoor and outdoor units must be matched to achieve the listed system efficiency. It is possible to physically combine indoor and outdoor products that are not meant to operate together. A conversation with an industry member revealed that mismatched products can lower operating efficiency (often significantly); create comfort issues; fail to manage indoor humidity enough to prevent indoor air quality problems, especially in shoulder seasons; or cause system malfunctions, leading to callbacks and costly equipment replacements.[3] Data collected from a utility-sponsored rebate program by the Systems Building Research Alliance determined that about 10 percent of cooling system components are mismatched (Levy, 2022).

[3] *Shoulder season* is a term referring to nonpeak heating and cooling seasons. Spring and autumn are shoulder seasons.

- **Incorrect Refrigerant Line Charge.** Achieving the listed efficiencies requires the technician to install and charge the refrigerant lines properly and ensure that the lines are free of leaks. Lacking formal oversight, site installations may be under- or overcharged with refrigerant. Line charge issues reduce operating efficiency and capacity, and leaks emit harmful greenhouse gases into the atmosphere.
- **Wrong Thermostat for Equipment Type.** The type of heating and cooling system dictates the type of thermostat to be installed in the home. The home manufacturer may install one type of thermostat, and the field technician may install one for a different product type. For example, the manufacturer expects an air-conditioning system thermostat, but the technician installs a heat pump thermostat. The result is extra work, increased and unnecessary material costs, and, often, reduced functionality and energy waste.
- **Bottom Board Tears.**[4] Site installers may find it most convenient to run refrigerant lines through the flexible membrane covering the bottom of the home, creating tears. This damage happens late in the installation process, and the penetrations may never be discovered and, therefore, left unrepaired. If not repaired, the holes are pathways for air leakage and can create condensation inside the home. Leaks at penetrations between the floor decking and bottom liner can introduce contaminated air from crawlspaces into the home, reducing the efficiencies of the heating and cooling systems and creating paths for moisture. Any condensation or associated mold in the belly or crawlspace can migrate into the home.
- **Misalignment of Service Responsibilities.** Callbacks, regardless of the cause, currently fall to the home manufacturer to address. In the case of the heating and cooling system, the HVAC installer is generally not directly held accountable. This lack of accountability is problematic in two respects. When failures occur, the feedback to the manufacturing plant is, at best, indirect. As a result, systemic issues are difficult to pinpoint and resolve. Lacking commercial ties to the HVAC installer, home manufacturers have few options for enforcing quality installation procedures. Fragmenting the H&AC installation process also creates consumer confusion when a repair is needed because determining the responsible party whose warranty covers the repair work can be difficult.
- **Improper Configuration of Fresh Air Intake.** The fresh air intake duct is the ventilation system for many manufactured homes. The HVAC installer typically sets the intake position when the cooling coil is added in the field. Improper configuration compromises ventilation.

[4] *Bottom board* is the woven fabric underneath the home, protecting the underfloor components and separating the space from the elements during transportation and after home installation. It is also commonly called "belly wrap" or "belly board."

Like previous examples, the ventilation system is more prone to improper setup when performed outside the plant's quality control process.

Objectives and Significance of the Work

The goal of this study is to develop manufactured home heating and air-conditioning (H&AC) system designs that can be completely installed during the homebuilding process in the factory to avoid the problems the bifurcated installation process can cause. The strategy for achieving this goal is vesting all decisions and actions related to the H&AC systems in the hands of a single entity, the home manufacturer. To achieve this goal, the study group took several steps to (1) consider which decisions and installation operations are currently performed outside the control of the home manufacturer; (2) develop options for moving those operations to the plant's purview; (3) make changes in design and commercial practices that would facilitate factories installing H&AC systems; (4) recommend other changes (business relationships, marketing, servicing, and so on) that support the design and process changes; (5) test the concept by building and evaluating prototype designs; (6) identify and recommend changes in the HUD Code that will facilitate the use of the designs (if any); and (7) broadly disseminate the results to the industry. The results and key findings covering the design, construction, and commissioning will provide guidance to the manufactured housing industry on the integration of innovative H&AC systems.

Three related considerations make this effort significant:

1. The project concept was the result of an industry consensus process seeking important research and development that would benefit the industry and the customers it serves. This project was an industry top research priority identified by companies responsible for more than 85 percent of all manufactured homes.[5]
2. The solution to the problem that this study addresses, if incorporated into the current homebuilding process, will have a huge effect on manufactured home performance and affordability. Making systemic changes requires a multipronged and interdisciplinary response and collaborative effort.
3. The project aims to accomplish two core industry goals: making homes more affordable (both on a first-cost and sustained basis, the latter mainly by lowering energy costs) and

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[5] Panel members included key stakeholders from Clayton Homes, Cavco Industries, and Skyline-Champion Homes, which together are responsible for more than 85 percent of manufactured home production in the United States.

markedly improving quality and resilience. The work demonstrated the potential to drive down heat pump installation costs, an important technology for improving energy efficiency.

Chapter 2. System Design

This chapter provides background information, hurdles, technical and commercial considerations, and proposed solutions for plant-installed heating and air-conditioning (H&AC) systems. Information was gathered via interviews and meetings with panel members—manufacturing, retail, and heating, ventilation, and air-conditioning (HVAC) stakeholders—and onsite observations from other projects.[6]

This project's technical panel, consisting mainly of leading home manufacturer senior engineering staff, provided input for the design phase. The team assessed related market acceptance considerations in interviews with the project's commercialization panel, emphasizing costs, servicing, and other business-related criteria. The project team then navigated through information gathered from the interviews and identified the critical technical and commercial considerations, including associated advantages and barriers to their adoption when placing the H&AC system fully under the control of the homebuilding facility. Initially, the focus was on identifying options and assessing technical merits. A metric list was formed and used to select potential options. The final selection of three H&AC system designs was then promoted to the next stage to be prototyped.

Background

Current industry heating and cooling practices consist of installing gas or electric furnaces in manufactured homes at the plant, with cooling components installed at home sites (exhibit 1). Air distribution is typically accomplished by placing ductwork in the attic or the conditioned floor cavity. For multisection homes, an externally installed crossover duct beneath the home usually connects the trunk ducts in each section (TLP, 2020). Cooling components are typically added at the site, usually consisting of an A-coil placed in the furnace cabinet connected with refrigerant lines running to an outside condensing unit (TLP, 2020). A local HVAC contractor performs the field installation. As noted previously, this configuration is susceptible to potential quality and performance degradation.

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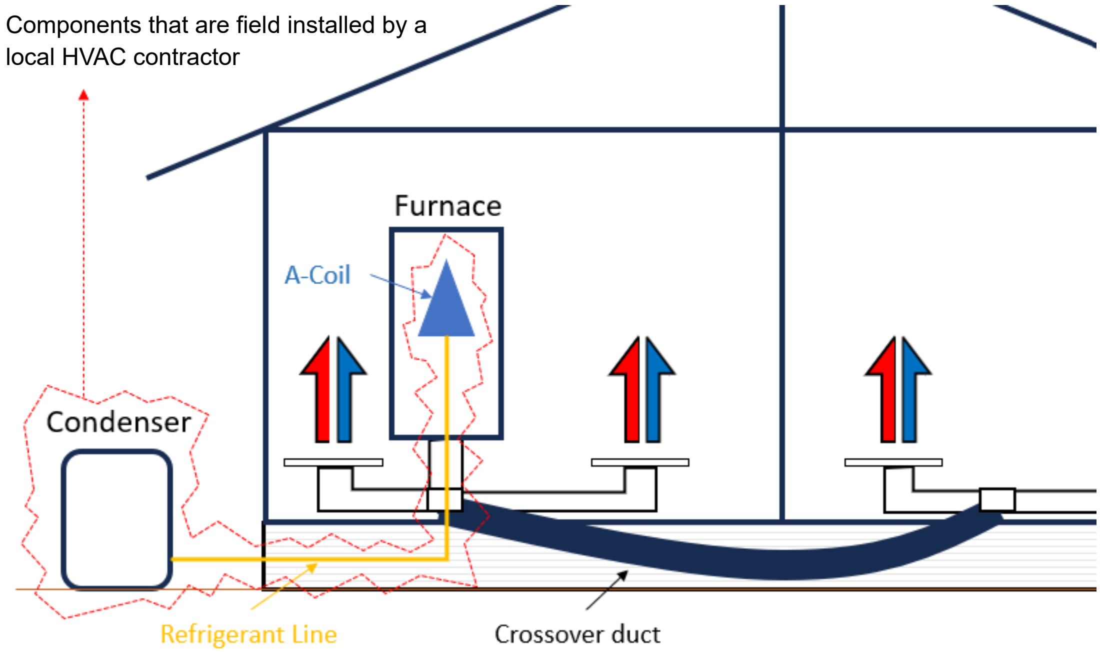
[6] These projects include *Title 24 Manufactured Homes*, a California Energy Commission-funded project, and *Getting to Zero Energy Ready: A Plan for Transforming the Manufactured Housing Market*, a U.S. Department of Energy-funded project.

Exhibit 1. Current Typical Heating and Air-Conditioning Setup in Manufactured Homes



Source: Systems Building Research Alliance

However, experimenting with fully plant-installed H&AC systems is not unknown in the manufactured housing industry. Several manufactured home plants have accomplished full mechanical equipment in-plant installation for certain niche markets, including—

- Park models and other small, single-section homes using mini-split heat pumps.[7,8]
- Homes going to remote locations where HVAC contractors are sparse.
- Emergency manufactured housing units built for the Federal Emergency Management Agency (FEMA).[9]

The sales process for these home types is atypical of the manufactured home industry, and aesthetics is a lower priority. Therefore, the production of such home types has avoided the major technical and commercial barriers to in-plant H&AC installation. This chapter describes these hurdles facing most of the industry and explains how the proposed solutions overcome them.

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[7] *Park models* are temporary residences with floor plans of 400 square feet or less, built on a metal frame with wheels. They are built to American National Standards Institute, or ANSI, A-119.5-15 standards, a construction standard the Recreation Vehicle Industry Association created.
[8] *Mini-split heat pump* typically refers to a ductless, compact, and high-efficiency heat pump unit that can have one or multiple indoor heads and one or more outdoor compressors.
[9] *FEMA* is a U.S. Department of Homeland Security agency that is responsible for preventing and responding to natural disasters or man-made incidents.

Technical and Commercial Considerations

As a first step, a survey of industry experts and stakeholders was conducted to learn from prior efforts to integrate H&AC solutions in the plant, identify opportunities to advance practices, and select the most promising factory-complete heating and cooling system ideas for further development. The survey focused on prior experience with plant-installed H&AC systems, the associated advantages, and the major barriers to their adoption.[10]

The following key considerations provide a detailed characterization of the issues and barriers that researchers navigate in developing market-ready HVAC designs that are entirely or mostly plant installed.

- **Design Flexibility.** Most manufactured homes are either one home section (single-section) or two sections joined together (two-section). Heating and cooling systems must work with both home types. Ductwork is also a key design consideration. Most manufactured home plants in the United States, especially in northern climates, use underfloor ductwork, whereas in the South, attic ductwork is often used. Some heating and cooling equipment can accommodate both airflow configurations, with a conversion kit for downflow to underfloor ducts.
- **Sizing.** Manufactured home sizes typically range from 800 to more than 2,500 square feet. Systems' heating and cooling capacities must cover the range of home sizes and diverse climate locations.
- **Efficiency.** Inefficient system operation is a major factor contributing to high energy bills. Improving system efficiency can help homeowners save money.
- **Ease of Installation and New Skill Requirements.** Speed of installation is critical to maintaining a factory's production rate. A simpler installation process requires less time and labor. New skills might require additional investment in training staff and buying tools. The complexity and difficulty of the installation procedure may also increase the risk of system failure or underperformance due to improper installation.
- **Balanced Air Distribution.** The heating and cooling system must distribute conditioned air evenly across all bedrooms and main living areas.
- **Transportability.** Completed homes might have to ship more than a thousand miles without damage. The heating and cooling system, in a fully installed state, must be durable to avoid damage during transport. The HVAC equipment is not only heavy but also expensive, and it

[10] See appendix A for technical survey questions, appendix B for commercial survey questions, and appendix C for a list of interviewees.

can be exposed to vibration and shock during manufactured home transport. It is made up of delicate components such as compressors, pipes, coils, evaporators, and condensers. These components can be easily damaged and may leak if they are not secured properly to the manufactured home in a way that absorbs vibrations and shocks.

- **(In-Plant) Testing and Commissioning Procedures for Systems.** Heating and cooling system testing and commissioning will fall under the plant's purview. The complexity and difficulty of the procedure may require new skill training and added labor during production. However, the in-plant quality control process may reduce service calls. Savings from improved quality and operational efficiency may partially offset the added testing and commissioning costs.
- **Meeting Associated Building Needs.** Some heating and cooling systems may have additional features that can satisfy other needs—for example, a built-in dedicated ventilation system.
- **Noise.** Noise from indoor or outdoor units should be satisfactory for occupants.
- **Changes to Manufactured Home Construction and Safety Standards.** Given the range of technical options under consideration, technological changes will likely be accommodated in the short term through applying for Alternative Construction letters.[11] If the standards restrict using a proposed heating and cooling system change, a process must be initiated to propose changes in the regulations through the normal standards update process. In this study, only the Ephoca-made single-packaged heat pump required an Alternative Construction letter because of abridged Air-Conditioning, Heating, and Refrigeration Institute (AHRI) certifications and safety listing to an alternate Underwriters Laboratories standard.[12]
- **Aesthetics.** The heating and cooling system's appearance and location must be acceptable to homeowners. The market prefers aesthetics comparable with site-built homes.
- **Costs.** Affordability is key to manufactured housing. Manufactured homes provide a homeownership opportunity for lower-income individuals and families. A substantial

[11] The manufacturer submits Alternative Construction (AC) letters for homes that do not conform to the requirements of the Manufactured Home Construction and Safety Standards (the Standards) at the time of shipment. AC letters are intended to encourage innovation and the use of new technology in the manufactured housing industry. Please see HUD Regulations (3282.14) titled "Alternative Construction of Manufactured Homes" for more information.

[12] Ephoca is certified to AHRI Standard 390 instead of HUD's requirement of AHRI Standard 210/240 as of the time of writing this report.

increase in material costs, labor, service fees, and energy bills can adversely affect affordability.

- **Availability of Component Parts From Multiple Suppliers.** Home manufacturers buy materials in bulk and store them at the production facility. Having multiple suppliers of components reduces the risks of shortages and delays that may result in having to rely on only one supplier. It improves the industry's negotiating position with suppliers.
- **Effect on Existing Business Relationships.** In the current process, the HVAC distributor or a local HVAC contractor is typically responsible for installing cooling equipment and handling any customer service issues that arise. The manufactured home retailer's sole responsibility is to sell the home, including the HVAC equipment. A commercial arrangement that will not harm existing business relationships within the HVAC and home distribution chains is a key consideration.
- **System Maintenance and Servicing at Home Sites.** If the H&AC system is preinstalled and a customer service issue arises, neither the plant nor the retailer may want to be responsible for the service because of the added cost and time to resolve the issue on a home that may be far away from either party. A service agreement with HVAC manufacturers may be preferable.

Based on panel interviews, the most common plant-installed H&AC system in manufactured homes is a ductless mini-split unit installed at the plant, with the compressor mounted on the home's exterior wall. Still, this configuration is atypical in manufactured housing plants. It is used only in smaller, single-section manufactured homes and park models built to American National Standards Institute, or ANSI, A119.5 Park Model RV Standard. Some plants ship compressors and condensers loose with the home, which requires unit installation on a pad on site, but the method allows the indoor and outdoor sections to be properly matched and sized for a specific geographic area.

On the basis of the panel's feedback, the group brainstormed and discussed system options. Seven system configurations were included in the initial stage of assessment:

- Type 1. Split system with duct distribution; compressor mounted on frame.
- Type 2. Split system with duct distribution; compressor shipped loose, placed on pad at site.
- Type 3. Packaged unitary system (interior) with ducted air distribution.
- Type 4. Packaged unitary system (exterior) with ducted air distribution.
- Type 5. Ductless mini-split heat pump.
- Type 6. Ducted mini-split heat pump.
- Type 7. Nonducted packaged heat pump.

An H&AC design and commercial arrangement cost-benefit analysis was developed and used to select the most promising solutions.

Short List of Solutions

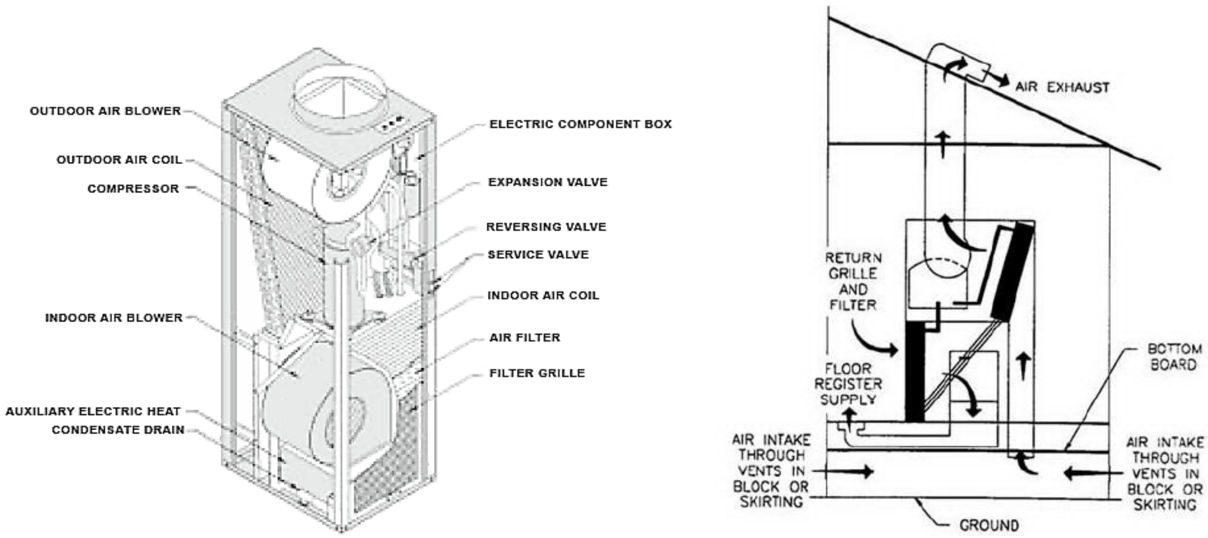
The panels met and held several discussion sessions to establish common ground and move toward consensus. The goal was to select the options, with the expectation that two or three would be promoted for prototyping. The system requirements and highly preferred attributes are the following:

1. Capacity in the 2- to 4-ton range.
2. Easily connected with ducts.
3. Provides sufficient airflow (operated at an external static pressure of more than 0.3 inch of water column).
4. Compatible with space constraints of existing manufactured home floor plans.
5. No electrical and wiring requirements beyond the skills of existing plant staff.
6. No noise issues (outdoor units with less than 79 A-weighted decibels [dBA] and indoor units with less than 68 dBA).
7. Can be hidden out of sight (aesthetics issues).
8. In-plant installation that does not require out-of-plant skills.
9. Can be transported without damage.
10. Does not require changes to the HUD Code.
11. Manageable equipment inventory arrangement.
12. Cost competitive.

On the basis of an evaluation of the advantages and challenges of each of the seven options identified and with panel input, the project team selected three options for continued consideration.

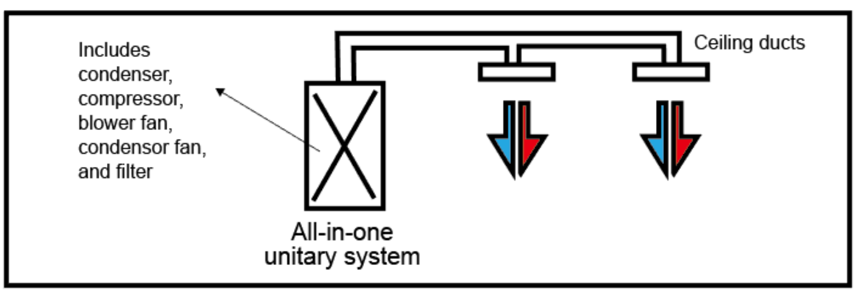
- A **packaged unitary system (interior) with ducted air distribution** is a fully self-contained unitary heat pump system inside the thermal envelope. These systems are popular in modular construction and hospitality buildings. Many years ago, manufactured homes used a version of this concept (the “Insider” heat pump; exhibit 2). However, due to technical issues, low demand, and the amount of development needed to meet higher seasonal energy efficiency ratio (SEER) and heating seasonal performance factor (HSPF) ratings, the concept was abandoned (Lubliner, Hadley, and Parker, 2007).[13,14] The technical panel was interested in revisiting this approach with today's technology (exhibit 3).

Exhibit 2. Insider Heat Pump



Sources: Insider Service Manual (left); Lubliner, Hadley, and Parker (2007; right)

Exhibit 3. Packaged Unitary System (Interior) With Ducted Air Distribution



Note: Colored arrows indicate conditioned air—red for heating and blue for cooling.

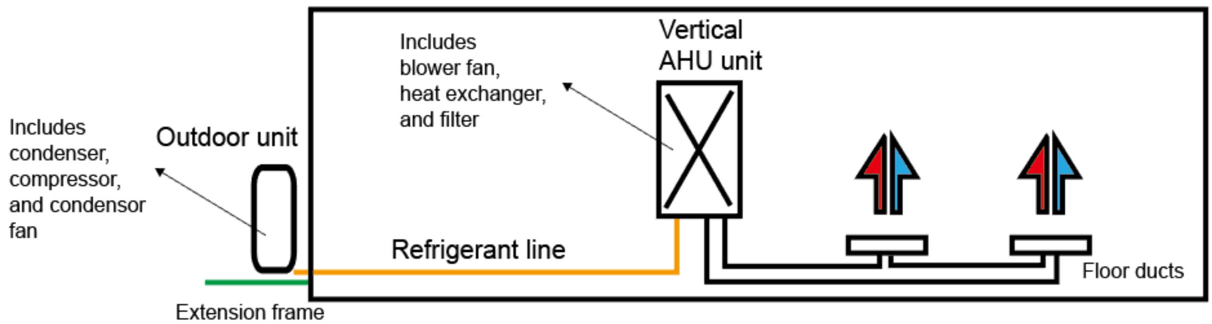
Source: Systems Building Research Alliance

- **Ducted Mini-Split Heat Pump: Frame-Mounted Compressor.** The decision was made to use a ducted mini-split system paired with a central indoor electric furnace instead of a conventional air-conditioner or heat pump. Mini-split systems are more energy efficient, and certain industry market segments already use them, making them valuable to investigate. Ducted mini-split systems use inverter-driven compressors and variable-speed fans to

13 SEER is a metric to measure equipment energy efficiency during the cooling season.
14 HSPF is a measure of a heat pump's energy efficiency during one heating season.

optimize performance. The mini-split outdoor units are slimmer than those for conventional systems, which improves aesthetics (exhibit 4).

Exhibit 4. Frame-Mounted Ducted Mini-Split Heat Pump With Compressor



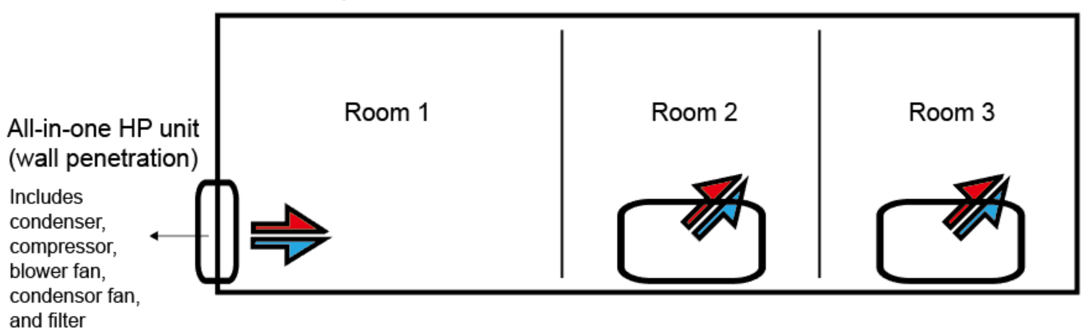
AHU = air handling unit.

Note: Colored arrows indicate conditioned air—red for heating and blue for cooling.

Source: Systems Building Research Alliance

- **Nonducted packaged heat pump** systems eliminate the design and installation of ductwork, which can be points of failure in current practice (exhibit 5). The unit demonstrated that it has high energy efficiency due to its variable-speed, inverter-driven technology and, therefore, can provide lower monthly operating costs for homeowners. One unit is installed in each zone so the occupants can fully control which zone or room they would like to heat or cool.

Exhibit 5. Nonducted Packaged Heat Pump



HP = heat pump.

Note: Colored arrows indicate conditioned air—red for heating and blue for cooling.

Source: Systems Building Research Alliance

Each proposed system was incorporated into homes during factory production for testing purposes with industry partners. Chapter 3 focuses on the processes and findings of prototyping the three H&AC systems that are completely plant installed and not currently used in the manufactured housing industry.

Chapter 3. Prototyping

After selecting the heating and air-conditioning (H&AC) solutions, the project team distributed a request for information regarding the products to six U.S. heating, ventilation, and air-conditioning (HVAC) equipment manufacturers and a request for expression of interest regarding plant demonstrations to about 40 manufacturing home facilities. Three HVAC equipment manufacturers consented to provide equipment and technical assistance to the project. Two home manufacturing plants were recruited to demonstrate the three prototyped homes. The project team helped the plants obtain engineering approvals from the Design Approval Primary Inspection Agency (DAPIA) services.[15] The first two homes were constructed in March 2022. The third home (with a nonducted packaged heat pump) was constructed in October 2022.

The following sections include detailed descriptions of the prototyping process of the three homes with H&AC systems. Each section begins with the home design and floor plan, followed by the modifications required to accommodate the new systems. Next, results from a short-term performance evaluation and lessons learned are documented to verify if the systems met the expected metrics. Finally, each section ends with a summary of the benefits and challenges identified during preparation and production. Throughout the prototyping process, the team encountered some hurdles. These findings provide an opportunity to rethink current practices and potentially open new revenue opportunities for factories.

Home Production Facilities

The packaged unitary and ducted mini-split systems were prototyped in March 2022 in partnership with the Clayton Homes plant in Waycross, Georgia. The home with the packaged unitary system was a two-section home shipped to Jesup, Georgia, in HUD climate zone 1.[16] The home with the ducted mini-split system was a single-section home shipped to Ooltewah, Tennessee, in HUD climate zone 2. The home with the nonducted packaged system was prototyped in October 2022 at the Karsten-Clayton Homes plant in Sacramento, California, and shipped to Visalia, California, in HUD climate zone 2.

Like some other plants in the southern United States, the Clayton Waycross plant installs duct work, furnace, and air handler per the Manufactured Home Construction and Safety Standards for heating, but the system does not include factory-installed air conditioning. Rather, a local HVAC contractor typically installs the packaged heat pump outside the home after it is delivered

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[15] *DAPIA* is a HUD-approved third-party agency responsible for reviewing and approving the design and construction packages for all manufactured homes.

[16] Climate zones refer to the "U_o value" zones in the HUD Code.

to the site. When an air handler is factory installed, it is a gas or electric heating system. If the homebuyer selects, a third-party contractor may also install the air-conditioning equipment (coil and outdoor unit) at the home site.

Most of the Clayton Waycross homes are constructed with overhead ductwork in the attic. The Waycross plant sells homes primarily to the cooling-dominated southern climate zone, where overhead ducts are more efficient than floor ducts for cooling. Floor ducts may also create restrictions on furniture placement for homeowners. The two prototype homes constructed at Waycross used overhead ducts. In the Sacramento plant, 100 percent of the homes are constructed with floor ducts.

The production sequence in manufactured home plants is designed to maximize throughput. Designated staff at each station ensure a smooth workflow. Appendix D provides descriptions of the work performed at each station in the Clayton Waycross plant. The production workflow is similar in the Sacramento plant.

The following section discusses the added work associated with integrating plant-installed heating and cooling systems, ease of system installation, short-term performance evaluation, transport to a site, servicing arrangements, and cost for each system.

Prototype Process, Short-Term Testing, and Lessons Learned

Exhibit 6 summarizes information on the three prototyped homes and their heating and cooling systems used for the demonstration.

Exhibit 6. General Information for Three Prototyped Homes

Heating and Air-Conditioning System Type	Packaged Unitary Ducted System	Ducted Mini-Split Heat Pump	Nonducted Packaged Heat Pump
Brand and Model Number	Friedrich, model VRP36K10	LG Electronics, model LUU249HV (outdoor), LVN241HV4 (indoor)	Ephoca, model DP91HDSO
Unit Counts	One unit	Single outdoor unit and single central air handler indoor unit	Four units
Production Facility	Clayton Waycross, Georgia	Clayton Waycross, Georgia	Karsten-Clayton Sacramento, California
Single or Double Section	Double section	Single section	Double section

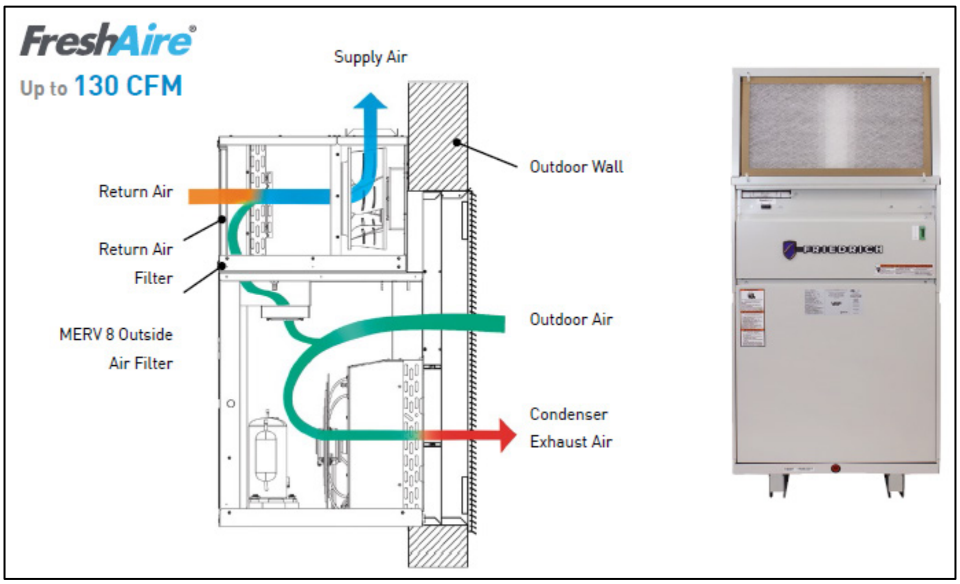
Heating and Air-Conditioning System Type	Packaged Unitary Ducted System	Ducted Mini-Split Heat Pump	Nonducted Packaged Heat Pump
Home Size	3 beds, 2 baths, 1,800 feet^2	3 beds, 2 baths, 990 feet^2	3 beds, 2 baths, 1,050 feet^2
Home Location (after shipment)	Jesup, Georgia	Ooltewah, Tennessee	Visalia, California
HUD Climate Zone	Zone 1	Zone 2	Zone 2

The following sections document the modifications required in each home to integrate the new H&AC systems.

A. Interior Package Unitary System With Attic Air Duct Distribution

A high-efficiency packaged unitary heat pump (Friedrich VRP36K10) was installed in a double-section home at the Clayton Homes plant in Waycross, Georgia. The system configuration is similar to the Insider heat pump but with an air grille on an exterior wall (exhibit 7).

Exhibit 7. Friedrich VRP Heat Pump



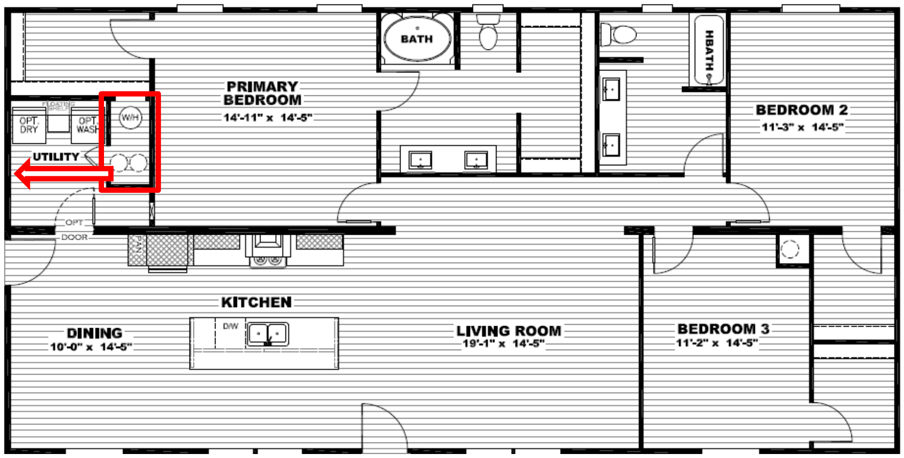
CFM = cubic feet per minute. VRP = Variable Refrigerant Packaged.

Source: Friedrich VRP Heat Pump Installation & Operation Manual

Home and HVAC System Design

The floor plan was modified from the standard model plan because the Friedrich VRP® heat pump must be installed against an exterior wall to exchange air and heat with the outdoors. The end wall of the home was preferable to a side wall because the attic had adequate clearance for connecting to the attic trunk duct. The utility room was rearranged to place the water heater and HVAC closet on the exterior end wall (exhibits 8 and 9). The door to the HVAC closet was widened to 36 inches to ensure that the heat pump could be moved in and out for installation, repair, or future replacement.

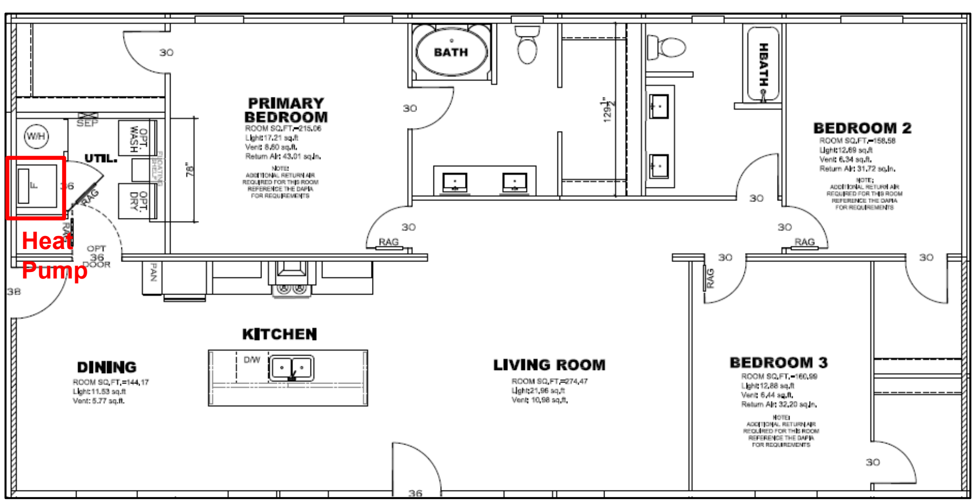
Exhibit 8. Original Floor Plan Layout for Home With Packaged Unitary System



Notes: The highlighted part is the original location of the water heater room. It was moved to the end of the home, so the heat pump can be placed adjacent to an exterior wall.

Source: Clayton Homes

Exhibit 9. Revised Floor Plan Layout for Home With Packaged Unitary System



Note: The highlighted part is the final location for the packaged unitary system.

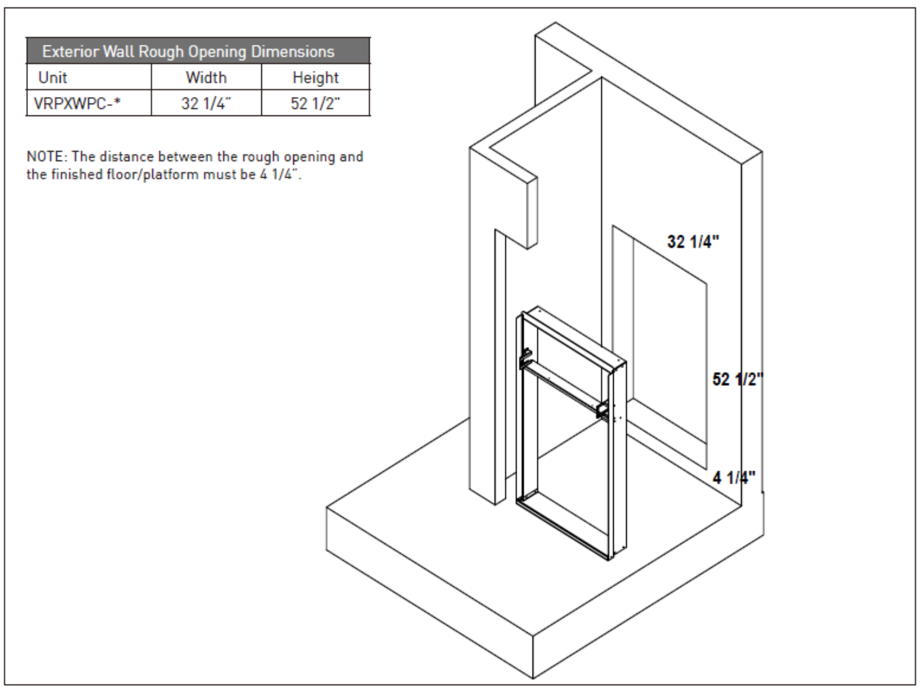
Source: Clayton Homes

Home Production Modifications

The following describes changes to the production process for the Friedrich heat pump installation.

1. **Exterior Wall Rough Opening for Heat Pump.** A rough opening on the exterior end wall was made at the wall construction station (offline). The height from the finished floor to the bottom of the rough opening was approximately 1.25 inches too high and did not align with the heat pump, which was resolved by placing oriented strand board sheets under the VRP unit to create a platform. If this home were to go into production, the wall rough opening location would be adjusted, and no platform would be needed (exhibits 10, 11, and 12).

Exhibit 10. Friedrich VRP Exterior Wall Opening Dimensions



Source: Friedrich VRP36K Installation Manual

Exhibit 11. Construction of the Friedrich VRP Exterior Wall Opening

The end wall is prefabricated at the wall construction station. The exact measurement and drawing must be provided to the staff for opening accuracy. The wall is 2x4 16-inch on center construction with R-11 kraft backed insulation, built to comply with the ENERGY STAR Manufactured Home program. Photo credit: Systems Building Research Alliance (2022).

Exhibit 12. Oriented Strand Board to Elevate the Friedrich VRP

A 1.25-inch oriented strand board platform was placed under the unitary heat pump unit so that the grille aligned with the prefabricated wall opening. Photo credit: Systems Building Research Alliance (2022).

2. **Friedrich VRP Heat Pump Installation.** The Friedrich VRP was placed on the floor deck before wall installation. Because the net weight of the unit is 330 pounds, a forklift was used

to lift it into place (exhibit 13).

Exhibit 13. Friedrich VRP in Utility Room Closet

A forklift placing the Friedrich VRP in the home's utility room closet. The oriented strand board platform was later added. Photo credit: Systems Building Research Alliance (2022).

3. **VRP Wall Plenum Sleeve.** The VRP wall plenum sleeve was installed in the exterior wall rough opening. First, the exterior frame and then the interior piece were installed. Pilot holes were drilled in the side of the metal plenum sleeve, and it was screwed to the rough opening wood frame. The exterior air louver would also typically be installed at this point**.** However, the louver was not available and was installed post-production offline (exhibit 14).

Exhibit 14. Friedrich VRP Wall Plenum Sleeve Installation

Staff installing the exterior portion of the wall plenum. The interior plenum piece is shown in the background and is not yet installed. Photo credit: Systems Building Research Alliance (2022).

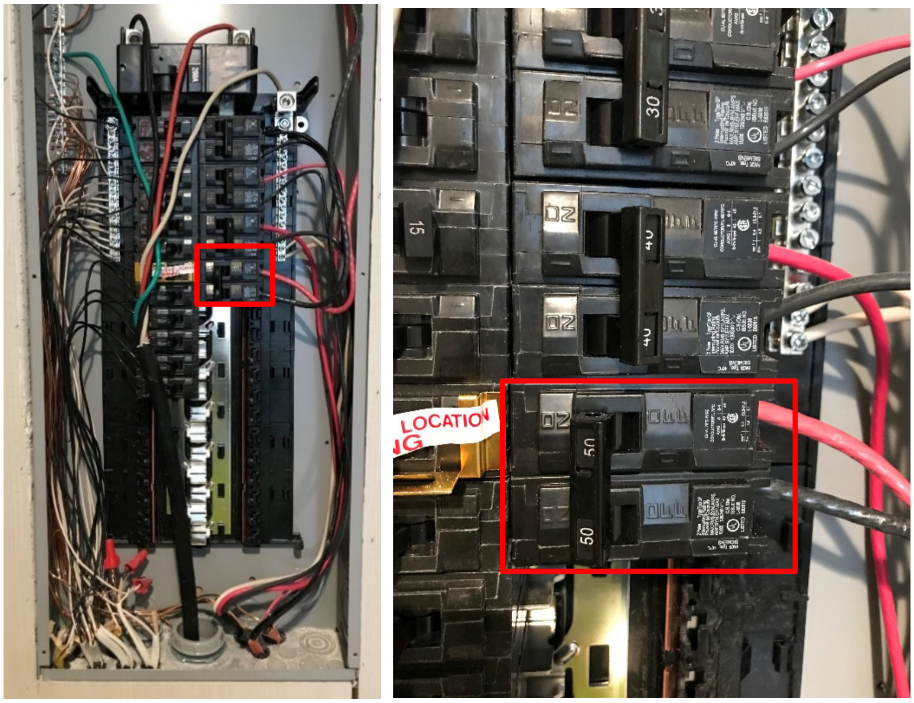
4. **Supply Air Connection to Attic Ductwork.** A short, insulated plenum box was fabricated to connect to the supply air opening on top of the VRP heat pump. A flexible duct was attached to the top of this plenum box and then extended into the attic air-mixing plenum. The new plenum box typically would be taped to the top of the heat pump with foil tape at this point, but it was left loose so the VRP could be moved later to install the exterior air louver. Again, if this home were to go into production and all parts were available on site, the foil taping step would have been completed at this point (exhibit 15).

Exhibit 15. Supply Ductwork Connection for Friedrich VRP Heat Pump

Staff installing the duct board plenum box at the top of the Friedrich VRP. The plenum box is the transition from the heat pump discharge to the flexible ducting above. Photo credit: Systems Building Research Alliance (2022; left); Electric Power Research Institute (2022; right).

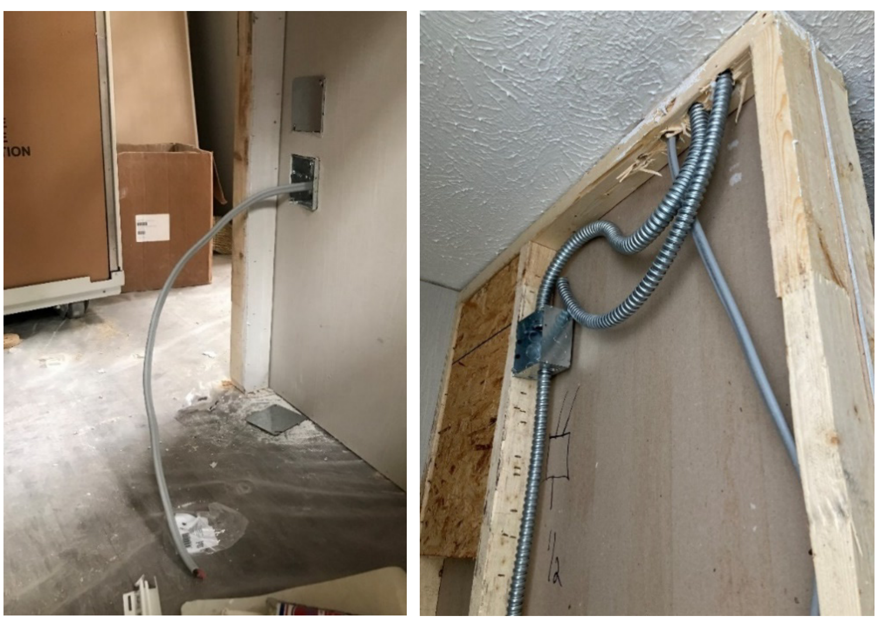
5. **Electrical and Plumbing.** Because the heat pump has a 10 kilowatt (kW) backup heat strip, the required branch circuit size for the system is 50 amperes, or 50A, at 6 gauge (copper conductors only). Electrical wires were connected to the terminal block within the VRP and to the electrical panel. The condensate water is collected at the bottom of the VRP unit (in a drain pan). The condensate outlet was connected to a polyvinyl chloride, or PVC, pipe routed through the floor and then turned 90 degrees laterally to the outside edge of the home (exhibits 16, 17, and 18).

Exhibit 16. Electrical Circuit Panel—Home With Friedrich VRP Heat Pump



The 50 amperes dual-pole 240-Volt type circuit breaker for the Friedrich VRP. A 110-Volt option is not available. Photo credit: Systems Building Research Alliance (2022).

Exhibit 17. Electric Power Wiring for Friedrich VRP Heat Pump



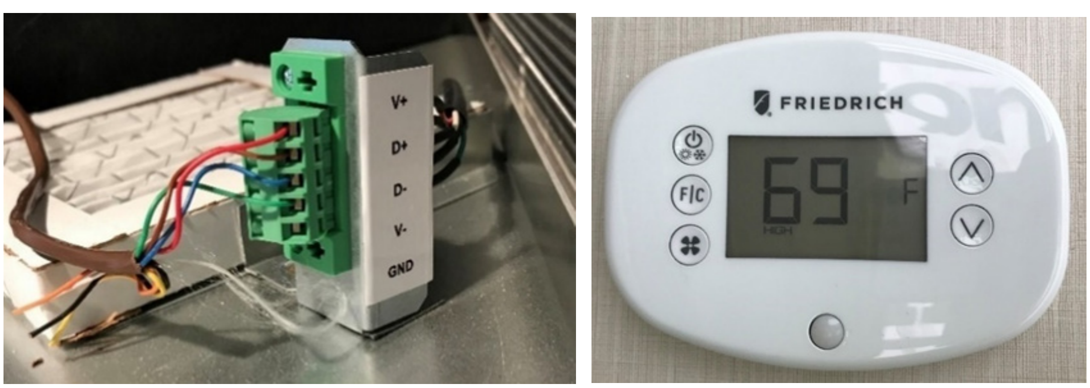
Electric power wiring from the breaker via the ceiling to the Friedrich VRP heat pump. Photo credit: Systems Building Research Alliance (2022; left); Electric Power Research Institute (2022; right).

Exhibit 18. Condensate Pipe for Friedrich VRP Heat Pump

The supplied ¾-inch drainpipe is connected to the right side of the heat pump unit base pan and elbowed out through the floor to the outside. Photo credit: Systems Building Research Alliance (2022; left); Electric Power Research Institute (2022; right).

6. **Thermostat.** Clayton typically installs an Ecobee programmable thermostat in its ENERGY STAR®-labeled manufactured homes. For this home, a Friedrich VRPXEMRT2 thermostat was used. The Friedrich thermostat instructions specify using Category 5e (Cat 5e) cable because hotels widely use the unit, and Cat 5e wire is less prone to interference from other smart devices. However, during the prototyping of the home, Cat 5e wire was not available, so standard thermostat wire was used (exhibit 19).

Exhibit 19. Thermostat Setup in Double-Wide Home

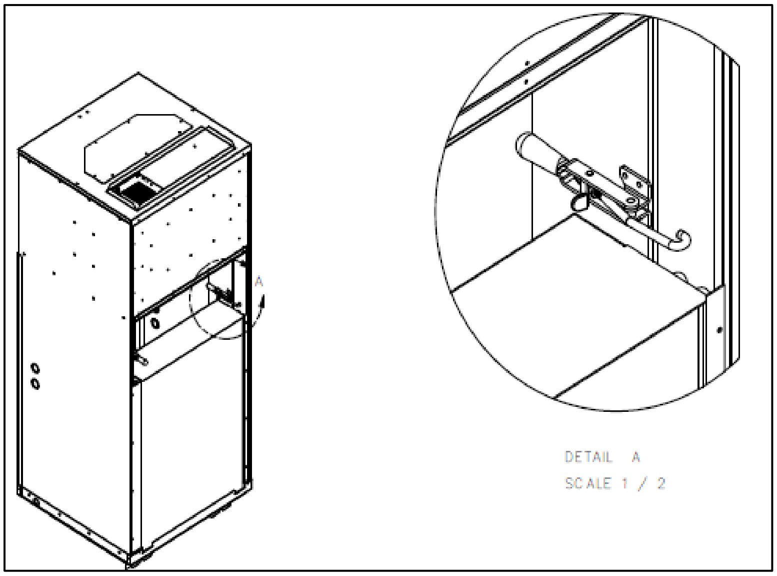


The screw terminal in the VRP unit to wire to the wall controller. Each colored wire should be paired to the corresponding terminal (left). The wall controller after powering up (right). Photo credit: Systems Building Research Alliance (2022).

7. **Transportation Protection.** After all connections to the VRP were complete, it was secured

to the exterior wall plenum sleeve using a built-in locking mechanism (exhibit 20). No additional measures were taken to secure or protect the unit.

Exhibit 20. Locking Mechanism for Friedrich VRP Heat Pump



Source: Friedrich VRP36K Installation Manual

Short-Term Testing

Basic testing was conducted off the production line when connected to power (exhibit 21).

Exhibit 21. Friedrich Home Testing After Factory Assembly (One-Half of the Two-Section Home)

The prototype homes were moved to the plant yard to be tested (left). The power supply enables functional testing of the HVAC systems (right) Photo credit: Systems Building Research Alliance (2022).

1. **Power and Controls.** The VRP unit was powered on successfully. All controls and fans operated as intended. The thermostat had to be turned on first before the heat pump would run. The thermostat interface and functions are very basic: power (on or off), display in Fahrenheit or Celsius, three fan power levels (high, medium, and low), and a temperature setpoint from 82°F (highest) to 64°F (lowest). When the room temperature reached the setpoint, the unit shut off as expected, the thermostat screen displayed the room air temperature, and the fan icon disappeared, indicating that the heat pump fans were not operating.
2. **Measuring Heating and Cooling Capacity.** The supply and return air temperatures were measured when the heat pump was operating in heating and cooling modes. The thermostat setpoint temperature was set to a high value in heating and a low value in cooling, forcing the heat pump to operate near its maximum speed. The electric strip heat was turned off so that the heating performance of the heat pump alone could be evaluated. A temperature and humidity sensor, Vaisala HMT335, measured at plus or minus 1 percent relative humidity [0–90 percent relative humidity], plus or minus 1.7 percent relative humidity [90–100 percent relative humidity], and plus or minus 0.36°F.

   The airflow rate was not measured, so the manufacturer's performance data were used (exhibit 22). Only one side of the two-section home was tested. Therefore, the external static pressure (ESP) rise across the fan was assumed to be 0.3 inch, corresponding to 1,080 cubic feet per minute for the high fan speed used for testing.[17] With air temperature and humidity measurements and the assumed airflow rate, the heating capacity was calculated and compared with the manufacturer's published extended performance data. Exhibit 23 shows the results.

[17] *ESP* is the measurement of all the resistance in the duct system. It is the sum of the static pressure that is external to the equipment with the fan.

Exhibit 22. Manufacturer's Fan Performance for Friedrich VRP36K

Model	VRP36K	
Air Flow Data		
Indoor CFM	Low	High
.15" ESP *	1015	1200
.20" ESP	875	1160
.30" ESP (Max Low)	750	1080
.40" ESP	565	970
.50" ESP (Max High)	440	835

CFM = cubic feet per minute. ESP = external static pressure.

* Rated at 0.15-inch ESP, high and includes 0.08-inch ESP for a factory-installed 1-inch filter.

Source: Friedrich Variable Refrigerant Package Product Profile (2021)

Exhibit 23. Measured Air Conditions and Friedrich Heat Pump Capacity in Heating Mode

Parameter	Values
Supply Air Temperature and Humidity	95.6°F / 29% RH
Return Air Temperature and Humidity	70.6°F / 67% RH
Outdoor Air Temperature	61°F
Calculated Heating Capacity	28,930 Btu per hour
Manufacturer's Published Heating Capacity	33,310 Btu per hour

Btu = British thermal unit. RH = relative humidity.

The calculated heating capacity under these operating conditions was 28,930 British thermal units (Btu) per hour, 13 percent less than the manufacturer's published capacity of 33,310 Btu per hour.[18] The thermostat setpoint was used to force equipment to near-maximum capacity operation but may not have been operating at maximum. Given the uncertainty of whether the heat pump was actually operating at maximum capacity, the airflow assumption, and the accuracy of the temperature and humidity measurement, this variance is deemed acceptable. The measurements and capacity calculation were not expected to match the manufacturer's published performance data precisely but were instead meant to identify if any major differences (e.g., more than 20 percent) would warrant further investigation before transporting the home to its destination.

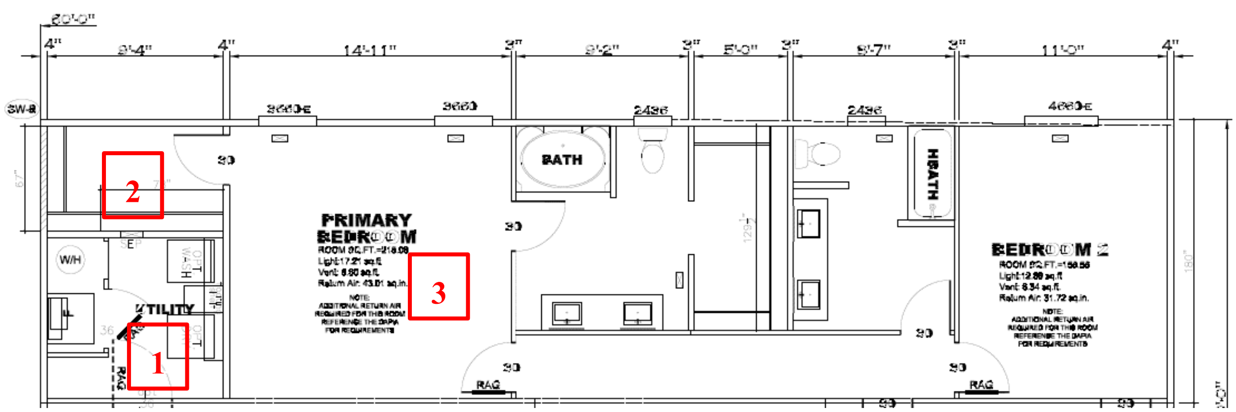
The process was repeated in cooling mode with supply air measured at 47°F, with 83-percent

[18] *Btu* is a measure of the heat content of fuels or energy sources. One Btu is the quantity of heat required to raise the temperature of 1 pound of liquid water by 1° Fahrenheit. Btu per hour measures the amount of heat removed from or added to a room in 1 hour.

relative humidity at 62°F outdoors. The compressor and fan speeds were not available for this test, and the manufacturer's published performance data were not available for the inlet air conditions measured. The air temperature drop through the air handler was measured at approximately 24°F, which is quite reasonable for these operating conditions, and no further testing was performed before home shipment.

3. **Noise Level.** Sound levels were tested using the EA Lab-developed National Institute for Occupational Safety and Health, or NIOSH, application for iPhone (NIOSH, 2018). Exhibits 24 and 25 show sound measurements within the Friedrich home and the locations where the measurements were collected.

Exhibit 24. Location of Sound Measurements Collected for Home With Friedrich VRP



Note: Numbering in exhibit 24 refers to the locations in exhibit 25.

Source: Clayton Homes

Exhibit 25. Sound Measurements for Home With Friedrich Heat Pump

Location of Measurement	Operating Mode	Fan Speed	LAeq[a]/ Maximum (dB)
Utility room (1)	Heating	High	65.8 / 66.7
Master bed closet (2)	Heating	High	50.7 / 64.5
Master bedroom (3)	Heating	High	44.6 / 48.8
Utility room (1)	Cooling	High	63.6 / 65.8
Master bed closet (2)	Cooling	High	50.1 / 52.5
Master bedroom (3)	Cooling	High	44.0 / 55.1

dB = decibels.

[a] LAeq, A-weighted equivalent continuous sound pressure level, is the constant noise level (averaged every second) that would result in the same total sound energy being produced over a given period

Note: Data collected March 24, 2022.

Source: NIOSH (2018)

Noise inside the utility room, the location of the VRP unit, was louder than in adjoining rooms. The sound-level test was conducted when the utility room louver door had not yet been installed. Installing this door might reduce the noise level in adjacent rooms. A slight vibration was noticed in the master bedroom floor while the unit was running. The home was resting on its running gear, not on a final foundation.

Onsite Performance

The home was set up in Jesup, Georgia, in June 2022. The ducted packaged unitary system suffered a series of malfunctions, with one possibly due to ice buildup on the bottom of the condenser coil. Although the actual cause of the ice buildup is unknown, possible causes include dusty coils, refrigerant leaks, or blocked condensate lines. Due to impending record-cold temperatures and delays in manufacturer repair services, the system was replaced with a standard packaged heat pump in December 2022. More details on field performance will be forthcoming in a separate report from the Electric Power Research Institute.

Lessons Learned

1. The location of the rough opening on the exterior wall is important, particularly the height above the finished floor.
2. The passage door to the utility room should be a minimum of 36 inches wide.
3. The thermostat currently available for the VRP unit is not programmable, so it does not comply with the ENERGY STAR Certified Manufactured Homes program. An energy model was prepared to demonstrate compliance in this case, but future installations should use the programmable thermostat planned by Friedrich to be available in the future.
4. For future improvement, use Cat 5e wire for the thermostat.
5. As an upflow unit, VRP is currently only suitable for overhead ducts. Future models may be available with side discharge that may be suitable for in-floor duct systems.
6. Clearance between the top of the VRP heat pump and the ceiling is only about 11½ inches, which poses challenges for connecting ductwork in this limited space. Other production sequencing, premade transitions, and configuration options should be considered to make this task easier.
7. Ordering and arranging plumbing for the heat pump with plumbing for the water heater resulted in a production delay. The sequencing of the heat pump and water heater made it hard to access connections at the water heater after the heat pump was installed. The plumbing connection was also the wrong size and had to be reordered. The team recommends

reviewing the installation sequence and confirming penetration sizes and drain line orientation.

Servicing Arrangements Summary

Based on a conversation with Friedrich VRP product manager, the firm can provide a 1-year parts warranty with labor fees included. Friedrich has a servicing network, but currently, it is not targeted to the VRP heat pump. They will need to have a stopgap measure to work with local representatives and train them to understand the product. For remote sites, they would get the closest person to travel to the site. If no certified contractors are available at remote sites, homeowners may use any licensed heating, ventilation, and air-conditioning contractor to do the repair. The homeowner should call the Friedrich customer center directly rather than the home manufacturer to resolve a service or maintenance request. Home manufacturers can add the service contact information to the package for the customer.

To make it more appealing to contractors from the HVAC servicing network to do the servicing work (because they would not be making a profit on equipment installation), Friedrich will need to find ways to incentivize servicing work. For other Friedrich models, representatives selling the equipment cover the labor costs for products under warranty. However, this incentive has not yet been set up for the VRP model.

Common issues for homeowners requesting service are the VRP control boards malfunctioning and refrigerant leaks due to transportation. The typical lifespan or replacement of the unit is at least 12 years. On component replacement, most parts have immediate availability. The control board is being redesigned, with better availability. Additional steps to check quality at the plant, such as powering up the home and commissioning testing in the factory before shipping the home, may reduce the need for field service. For training, Friedrich has a 3-day program in San Antonio, Texas, to certify contractors for Friedrich models other than the VRP. Servicers also could be trained in the homebuilding plant and provided with annual refreshers.

Benefits

1. **Little Additional Work Needed.** This packaged system requires little additional work because no separate outdoor unit is present. The entire system is mounted inside the home adjacent to an exterior wall, exchanging air and heat with the outdoors via an exterior wall penetration with a louver. Thus, the only additional work required is to provide an exterior wall rough opening and install a metal sleeve and louver to cover the opening. A drain pan and drip ledge are provided in the unit to direct any excess water driven from wind, rain, and ice through the louver.

2. **Does Not Require an Alternative Construction Letter.** Per HUD Code 3280.703, the Air-Conditioning, Heating, and Refrigeration Institute 210/240 listing (for the single-packaged air-source heat pump) held by this product is compliant. The U.S. Environmental Protection Agency could mandate that this system use low global warming potential refrigerants starting in 2025.

3. **Aesthetics.** This system uses a flat grilled louver on the end wall, which is aesthetically preferrable to an exterior-mounted condenser.

Challenges

1. **Floor Plan Design Inflexibility.** This system must be installed against an exterior wall to exchange air with the outdoors. The end wall of the home is preferable to a side wall because the attic has adequate clearance for connection to the attic trunk duct. At the Waycross plant, only 1 of their 10 floor plan designs could accommodate the packaged unit installation without significant modification.

2. **Limited Airflow Options.** The packaged system is limited to upflow configuration and, therefore, suitable only for overhead ducts (primarily used in southern homes). Future models may be available with side discharge, which may be suitable for in-floor duct systems.

3. **Narrow Capacity Range.** The maximum capacity for the packaged system is approximately 3 tons, which can be too small for homes larger than the prototyped two-section home (1,800 square feet) or homes in more extreme climates. The average multisection home built in 2021 was 1,794 square feet. If roughly one-half of multisection manufactured homes exceed this size, and no single-section homes do, then roughly 30 percent of the manufactured homes shipped in the United States in 2021 exceeded 1,800 square feet (MHI, 2022). About 20 percent of the manufactured homes shipped in the United States in 2021 were shipped to HUD climate zone 3—the coldest zone (MHI, 2022). Data cross-referencing size and location are unavailable, so this scenario (between 30 and 50 percent) is a worst-case estimate of homes unsuitable for a 3-ton system. Although an electric heat strip can be added to the system to compensate for the capacity limitation, such electrical resistance heating is not an ideal solution from an efficiency standpoint. Improving the thermal envelope U_o value might be a better way of mitigating the heating load in climate zone 3.[19]

[19] Uo is the overall coefficient of heat transmission.

4. **Higher Price.** Although easier installation means less labor, the equipment is more expensive than a standard split system—roughly a 40- to 50-percent, or $1,600 to $1,800, increase in equipment cost to the plant.

B. Attic-Ducted Mini-Split Heat Pump

A high-efficiency split heat pump, LG Electronics LV241HV4, was installed in a single-section home, with an outdoor portion mounted on a home chassis extension and the central air handler in an interior closet at the Clayton Homes plant in Waycross, Georgia (exhibit 26).

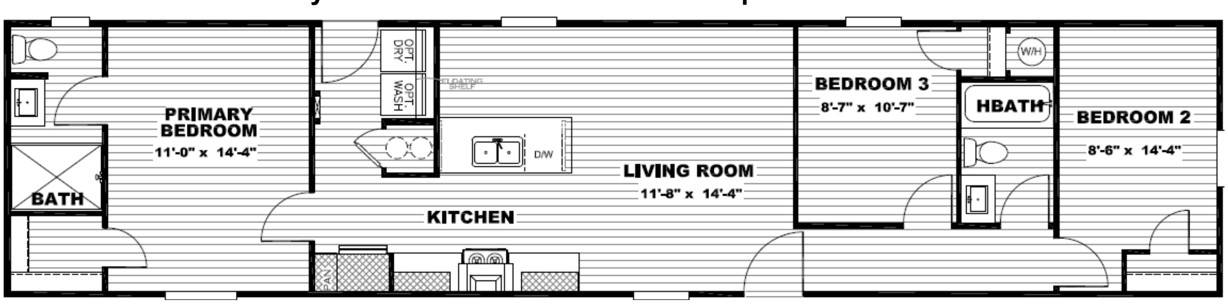
Exhibit 26. LG Electronics ThinQ LUU-LVN

Source: LG Electronics, Installation Manual Air-Conditioner

Home and HVAC System Design

The standard model plan needed no modification because the LG heat pump's air handler can be placed in the existing interior closet designated for a furnace (exhibit 27).

Exhibit 27. Floor Plan Layout for Home With Ducted Mini-Split



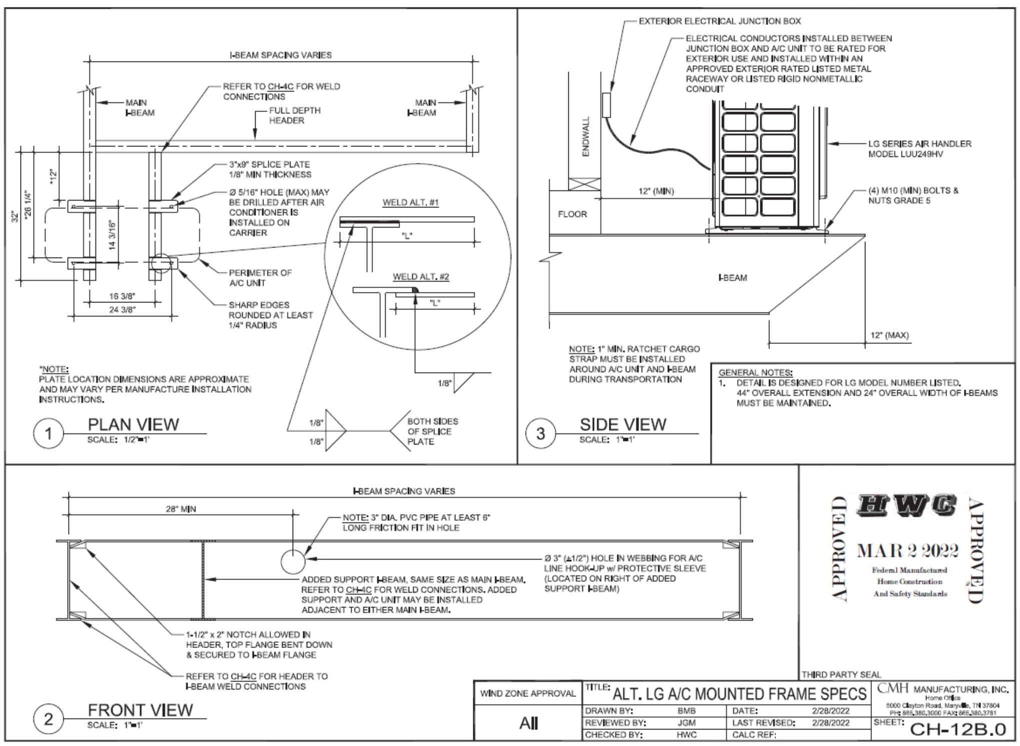
Source: Clayton Homes

Home Production Modifications

The following describes changes to the production process for LG heat pump installation.

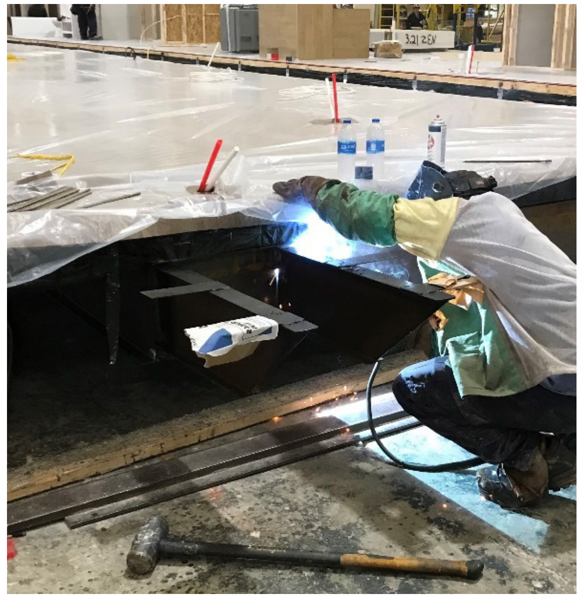
1. **Frame Extension.** Fabrication of a frame extension to support the LG outdoor unit (LUU249HV) and installation of an I-beam header on the rear of the home spanning the main I-beams was required. The redesign in exhibit 28 was submitted to the Design Approval Primary Inspection Agency services for approval. The two metal frame extension pieces were made at the chassis construction workshop and were welded to the rear frame header at the floor station (exhibit 29). A 4-inch diameter penetration in the rear header was made at the same station to allow a PVC pipe containing refrigerant piping and electrical wiring between the indoor and outdoor units, protecting these system components during home shipment. If this home were to go into full production, the frame extension and I-beam header additions would be completed during the construction of the home chassis (offline production).

Exhibit 28. Frame Extension Design Approval



Source: Clayton Homes

Exhibit 29. Welding Frame Extension to Rear Header for LG Electronics Outdoor Unit



The two added frame extension I-beams for mounting the outdoor unit (left). Welding the frame extension I-beam to the rear header. Photo credit: Systems Building Research Alliance (2022).

The location of the 4-inch hole turned out to be too low. The approval drawing showed it higher, but it was centered on the I-beam during production. In addition, the welding completed on the production line to attach the extension components to the I-beam was not optimal because the wooden floor had already been affixed to the chassis, and the concern was that heat from welding might damage the wooden floor. Again, these issues would have likely been avoided if the hole had been cut and all welding completed in the chassis fabrication area instead of on the production line.

2. **LG Indoor Vertical Air Handler (LVN241HV4).** The LG indoor vertical air handler (LVN241HV4) was placed on the floor deck before the installation of the mechanical closet walls. The unit weighs 123.5 pounds, and two people lifted and mounted it on a metal stand. HUD Code does not allow flammable material in mechanical closets; therefore, the mounting stand could not be constructed of wood (exhibit 30).

Exhibit 30. LG Electronics Air Handler in Interior Mechanical Closet

LG Electronics staff lifting the indoor vertical air handler to its location. A nonflammable metal frame is needed to mount the unit in the mechanical room. Photo credit: Systems Building Research Alliance (2022).

3. **Electrical and Plumbing.** The required branch circuit size for the heat pump is 30A (14-gauge wire size). A four-conductor cable powers the indoor air handler from the outdoor unit. An 8kW electric resistance heat strip was installed in the air handler on a separate breaker (a smaller heat strip size was specified, but it was unavailable at the time of system installation). The power and communication cables were connected from the outdoor unit to the indoor unit. An electrical disconnect box was installed adjacent to the outdoor heat pump section to comply with code requirements (exhibit 31). The condensate drain connection was at the bottom of the air handler and was connected to a PVC pipe routed through the floor and then turned 90 degrees laterally to the outside edge of the home (exhibit 32).

Exhibit 31. Electrical Wiring for LG Electronics Heat Pump

Power and communication cables connecting the outdoor unit to the air handler (left). The power and disconnect switch that will be connected to the outdoor unit (right). Photo credit: Systems Building Research Alliance (2022).

Exhibit 32. Condensate Pipe for Home With LG Electronics Heat Pump

The PVC pipe will drain the condensate from the indoor unit to the outside. Photo credit: Systems Building Research Alliance (2022).

The power cord and communication line between the outdoor and indoor units were routed through the attic. Optimal routing would be through the 4-inch PVC pipe beneath the floor that was used for the refrigerant lines (see the Refrigerant Line Protection section).

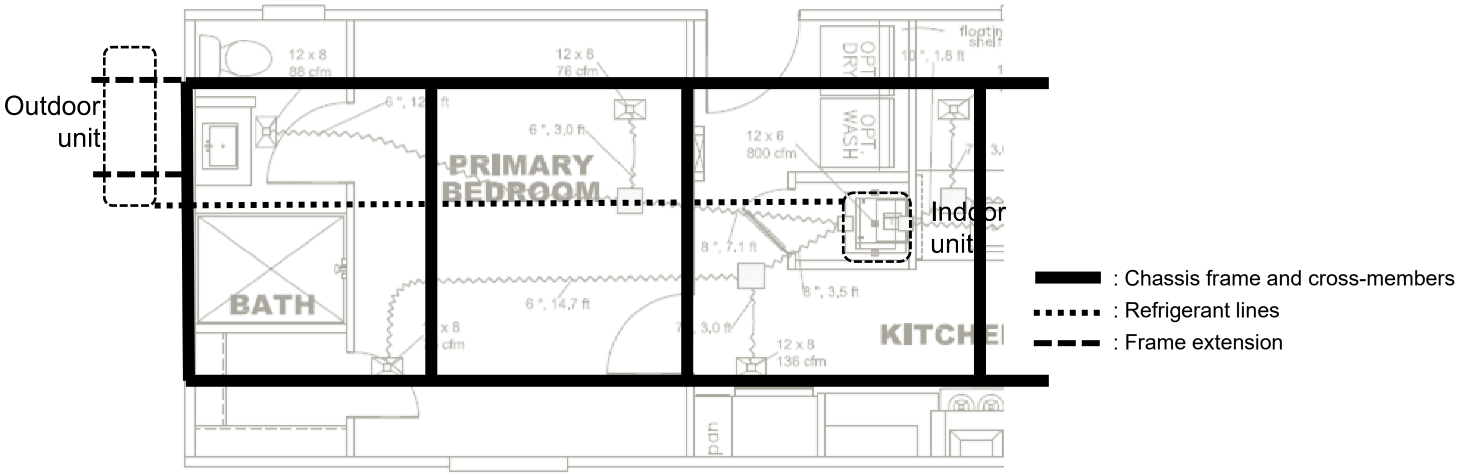
4. **Ductwork.** An insulated plenum box was fabricated to connect the supply air opening on top of the LG air handler to an insulated flex duct that passes into the attic supply air mixing box (exhibit 33). The space was adequate to complete this important ductwork transition.

Exhibit 33. Supply Air Ductwork Connection to LG Electronics Air Handler

A duct board plenum box connected to the top of the LG vertical air handler unit. The plenum box carries air from the heat pump discharge to the flexible ducting above. Photo credit: Systems Building Research Alliance (2022).

5. **Refrigerant Line Protection.** To minimize refrigerant line length and risk of damage during transport to the final home location, the line set was installed directly from the indoor air handler to the outdoor unit under the home through a straight (no elbows) 4-inch-diameter PVC pipe fastened to the chassis cross-members with steel straps (exhibit 34). To further secure the refrigerant lines and prevent air and water infiltration, the installers injected spray foam into each end of the PVC pipes.

Exhibit 34. Diagram of Refrigerant Line Set Run (not to scale)



Sources: Clayton Homes (floor plan); Systems Building Research Alliance and Electric Power Research Institute (overlaying diagram)

The total length of the refrigerant line was 28 feet. The outdoor section of the heat pump is shipped with enough refrigerant for 24.6 feet of line length. Therefore, additional refrigerant was added during the heat pump installation at the factory (0.43 ounces of refrigerant per additional foot). To keep within 24.6 feet, the air handler closet would have to be moved closer to the outdoor heat pump section. Twenty-five feet of refrigerant tubing is a standard length, so 24.6 feet would allow a single continuous piece of refrigerant tubing to be used without solder joints, which have the potential for refrigerant leakage. Although 35-foot line sets are available, the next-longest standard line-set length is 50 feet, which can be used but might result in wasted material (exhibit 35).

Exhibit 35. Four-Inch PVC Pipe Protection for Refrigerant Line Set for Home With LG Electronics Heat Pump

The 4-inch PVC refrigerant line protection pipe fastened to the chassis cross-members with steel straps (left). The end of the pipe was filled with spray foam to keep out water and animals (right). Photo credit: Systems Building Research Alliance (2022).

6. **Thermostat.** The LG programmable MultiSITE thermostat (PREMTBVC2) was used (exhibit 36). The thermostat is connected to the indoor air handler using regular multiconductor thermostat wire. Because this thermostat is programmable, it complies with the ENERGY STAR Certified Manufactured Homes program.

Exhibit 36. Thermostat for Home With LG Electronics Heat Pump

The LG wall thermostat mounted on wall (left). Closeup display of the thermostat (right). Photo credit: Systems Building Research Alliance (2022).

7. **LG Outdoor Unit.** The LG outdoor unit (LUU249HV4) was placed onto the chassis extension platform before connecting to the refrigerant line set and electrical power wiring. The outdoor unit weighs 130 pounds, and two people lifted it. Rubber pads were installed at each mounting foot to reduce vibration (exhibit 37).

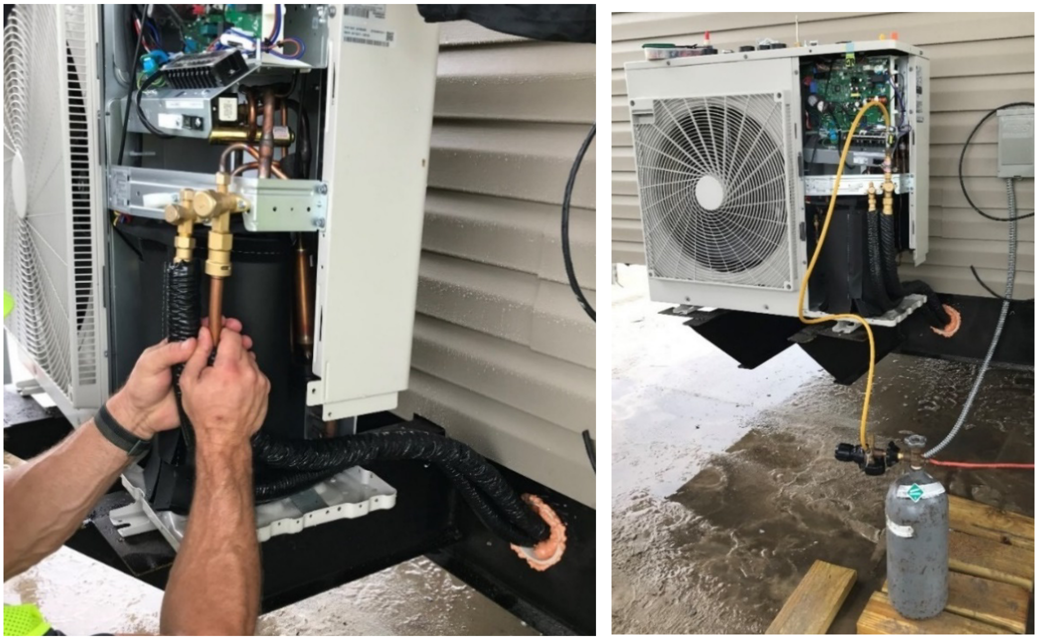
Exhibit 37. Rubber Mounting Pads for LG Electronics Outdoor Unit

Rubber pads reduce the outdoor unit vibration (left). The rubber pads are installed under each mounting foot (right). Photo credit: Systems Building Research Alliance (2022).

Even with the rubber pads on the footings, some vibration during operation was noticeable in the home close to the end wall. Adding rubber pads to the bolt connection on the bottom side of the chassis frame extension may be useful in reducing vibration. Another possibility is to drill the hole through the extension frame slightly larger than needed and add a rubber grommet to the hole with the connection bolt inserted through the grommet, thus avoiding metal-bolt-to-metal frame contact.

8. **Refrigerant Line Connection, Leakage and Evacuation Test, and Refrigerant Charging.** After securing the outdoor unit to the platform, the refrigerant line set was connected to the outdoor unit ports and indoor air handler. A leakage test was then performed using a pressure gauge and nitrogen gas (exhibit 38). The refrigerant lines were pressurized to 561 pounds per square inch gauge **(**psig**)** to check for pressure drops that could indicate leakage. The pressure test lasted 12 minutes, with the pressure dropping from 561 to 558.5 psig, then remaining stable. No leakage was detected using soap bubbles at each fitting. A vacuum pump was then used to evacuate any moisture and noncondensable substances (exhibit 39). A vacuum was pulled to approximately 350 micrometers of mercury and stabilized. At this point, additional refrigerant was added based on the factory-provided formula of 0.43 ounces per foot over the precharge length of 24.6 feet (exhibit 40).

Exhibit 38. Refrigerant Line Connection and Leakage Testing



Refrigerant line connections to the outdoor unit (left). Leakage and pressure tests are performed using a pressure gauge and nitrogen gas tank (right). Photo credit: Systems Building Research Alliance (2022).

Exhibit 39. Refrigerant Line Evacuation Set With Electric Vacuum Pump

A vacuum pump was used to conduct evacuation test (left). Reading from the pressure gauge during the evacuation test (right). Photo credit: Systems Building Research Alliance (2022).

Exhibit 40. Weighing and Adding R-410A Refrigerant to LG Electronics Heat Pump

Workers setting up to add R-410A refrigerant to the lines (left). The scale shows the amount of refrigerant being added (right). Photo credit: Systems Building Research Alliance (2022).

9. **Transportation Protection.** The indoor air handler was secured to the walls using steel straps (exhibit 41). The original cardboard box in which the LG unit was received was used to cover the outdoor unit. A 1-inch-wide ratchet strap was then wrapped around the box and underneath the mounting platform. The heat pump unit arrived intact at the site in southeastern Tennessee.

Exhibit 41. Securing LG Electronics Indoor Unit for Transport

Ratchet straps fasten the air handler to the wall and floor. Photo credit: Systems Building Research Alliance (2022).

Short-Term Testing

Basic testing was conducted off the production line when connected to power (exhibit 42).

Exhibit 42. Testing With LG Electronics Unit in Single-Section Home After Factory Assembly

The single-section home was moved to the yard to connect to power for functional testing. Photo credit: Systems Building Research Alliance (2022).

1. **Power and Controls.** The LG heat pump was powered on successfully. All controls and fans operated as intended. The thermostat had to be turned on first before the heat pump would run. The thermostat used for the heat pump was programmable, with multiple built-in modes. The temperature setpoint ranges from 60 to 86°F. When the heat pump was turned on in heating mode, the air handler waited 1 to 2 minutes before activating the supply air fan. This delay is intended to minimize "cold blow" of supply air to the space that can occur when heat pump compressors and fans start simultaneously. This operation is indicated on the thermostat interface as preheat mode.

2. **Measurement of Heating and Cooling Capacity.** The supply and return air temperatures were measured when the heat pump was operating in heating and cooling modes. The thermostat setpoint temperature was set to a high value in heating and a low value in cooling to force the heat pump into its maximum speed operation. The electric strip heat was turned off so that the heating performance of the heat pump alone could be evaluated. A temperature-humidity sensor (Vaisala HMT335) was used for the measurements (plus or minus 1-percent relative humidity [0–90-percent relative humidity], plus or minus 1.7-percent relative humidity [90–100-percent relative humidity], and plus or minus 0.36°F).

   The airflow rate was not measured, so the manufacturer's performance data for high speed were used (exhibit 43). With air temperature and humidity measurements and the assumed airflow rate, the heating capacity was calculated and compared with the manufacturer's published extended performance data. Exhibit 44 shows the results.

Exhibit 43. Supply Air Fan Performance for LG Electronics Split Heat Pump

Model Number	Air Volume*		
	High	Medium	Low
LVN181HV4	640	580	480
LVN241HV4	**710**	640	480
LVN361HV4	990	880	800

Air volume flow rate is measured in cubic feet per minute. The value in the bold rectangle is used for the calculation in exhibit 44.

Source: LG Single Zone Vertical Air Handler Unit Engineering Manual, EM_SZ_VAHU_07_21 Profile 2021

Exhibit 44. Measured Air Conditions and LG Electronics Heat Pump Capacity in Heating Mode

Parameter	Values
Supply Air Temperature and Humidity	112.3°F / 18% RH
Return Air Temperature and Humidity	70.3°F / 64% RH
Outdoor Air Temperature	61°F
Calculated Heating Capacity	31,495 Btu per hour
Manufacturer's Published Maximum Heating Capacity at 61°F outdoor and 70.3°F indoor.	31,530 Btu per hour

Btu = British thermal unit. RH = relative humidity.

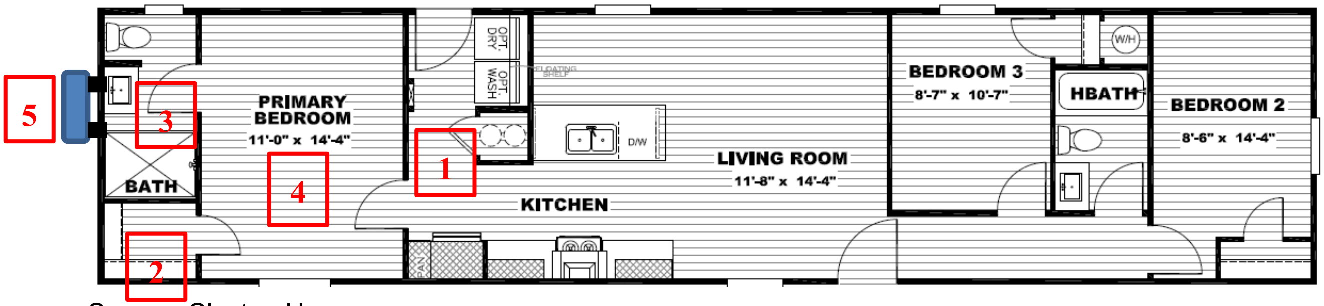
Note: Assumed 710 cubic feet per minute for capacity calculation (exhibit 41). Electric strip heat was not operating during data collection.

The calculated heating capacity under these operating conditions is 31,495 British thermal units per hour, virtually identical to the manufacturer's published capacity. The measurements and capacity calculation were not expected to match the manufacturer's published performance data precisely but were instead meant to identify if any major differences (e.g., more than 20 percent) would warrant further investigation before transporting the home to its destination.

The process was repeated in cooling mode with supply air measured at 49.7°F with 72-percent relative humidity at 62°F outdoors. The compressor and fan speeds were not available for this test. However, the air temperature drop through the air handler was measured at approximately 21°F, which is reasonable for these operating conditions, and no further testing was performed before home shipment.

3. **Noise Level.** Exhibits 45 and 46 show the locations of sound measurements collected for the home with the LG heat pump.

Exhibit 45. Location of Sound Measurements Collected for Home With LG Electronics Split Heat Pump



Source: Clayton Homes

Exhibit 46. Sound Measurements for Single-Wide Home With LG Electronics Split Heat Pump

Location of Measurement*	Operating Mode	Fan Speed	LAeq[a] / Maximum (dB)
Utility room hallway (1) air handler closet door open	Heating	High	50.1 / 51.1
Utility room hallway (1) air handler closet door closed	Heating	High	47.0 / 48.5
Master bed closet (2)	Heating	High	39.4 / 43.9
Master bed bathroom (3)	Heating	High	39.7 / 41.3
Master bedroom (4)	Heating	High	40.8 / 43.2
Outdoor unit (5)	Heating	High	62.6 / 70.0 (may include ambient noise)

dB = decibels.

* Data collected on March 24, 2022.

[a] LAeq, A-weighted equivalent continuous sound pressure level is the constant noise level (averaged every second) that would result in the same total sound energy being produced over a given period (NIOSH, 2018).

As expected, the noise near the indoor air handler closet was louder than in adjoining rooms. The sound level test was conducted with and without the air handler closet louvered door closed. The sound level per the International Organization for Standardization Standard 3745 testing of the LG LUU249HV (outdoor unit) is listed as a maximum sound pressure of 52 A-weighted decibels (dBA) in heating. The LG LVN241HV4 (indoor unit) is listed as 36 dBA in high-speed fan mode (laboratory tests are not directly comparable with field measurements).

A slight vibration was noticed in the master bedroom when the heat pump was running, seemingly transmitted from the outdoor section (mounted on frame extension) through the main longitudinal chassis I-beam. The home was resting on its running gear, not on a final foundation.

Onsite Performance

The LG ducted mini-split system was set up in June 2022 in Ooltewah, Tennessee (southeastern Tennessee near Chattanooga) and has been operating since without reports of complaints from the occupants. According to the Electric Power Research Institute (EPRI), during historic low outdoor temperatures in the winter of 2022, the indoor temperature briefly dropped from 72 to 69°F but soon recovered. The heat strip was deliberately shut off at the breaker, so only the compressor system provided heating.

Lessons Learned

1. Equipment was damaged during delivery to the factory. The 5kW electric heat strip was broken and could not be used. For full-scale production, the plant could have a small stock of heat strips to use when needed. A replacement heater was obtained the next day (only the 8kW heater was available). On the basis of heat load calculations, the team anticipated that little to no electric strip heat would be required for this home.
2. On arrival at the home production facility, the LUU249HV outdoor unit had a major oil leak due to failed seals, which was discovered after unboxing the unit. According to LG, this occurrence was highly unusual. LG provided a replacement unit the following day.
3. Because the HUD Code prohibits flammable material within the heating, ventilation, and air-conditioning closet, a metal air handling unit (AHU) stand was obtained from a local distributor.
4. The wire connecting the indoor AHU and the outdoor unit (L1, L2, C, G wire) should not have been routed from the AHU through the ceiling to the outdoor unit. It should run through the 4-inch PVC pipe, along with the refrigerant lines. Installation in the ceiling resulted from confusion when constructing this custom home configuration but would not have occurred if the system had been installed on the production line.
5. The outdoor unit holds refrigerant for up to 24.6 feet of line length. The test home required 28 feet, so additional refrigerant was required. Home designs keeping the line length within the 24.6 distance would avoid purchasing longer-than-needed line sets (25 and 50 feet are standard lengths), the extra process of adding refrigerant, and the U.S. Environmental Protection Agency (EPA)-required refrigerant handling training and licensing.
6. The 4-inch PVC pipe location might have to be adjusted if any obstructions are under the home between the AHU closet and the outdoor unit.
7. The 4-inch hole location should be raised to reduce bending of the refrigerant lines (exhibit 47), or the refrigerant lines should exit the outdoor unit in the downward direction rather than horizontally to minimize the number of sharp bends.

Exhibit 47. Suggested Location for 4-Inch Pipe Opening

The opening on the rear header was too low. To avoid sharply bending the refrigerant lines, the hole should have been cut at the bold circled location. Photo credit: Systems Building Research Alliance (2022).

8. The right-hand frame extension was wobbly, which can be mitigated if an additional bar is welded between the two extensions for added rigidity, indicated by the thick red line in exhibit 48. In addition, welding of the frame extensions to the I-beam header was mistakenly performed on the factory production line instead of in the chassis fabrication workshop. Because the wood floor was already attached to the metal frame before welding, the team was concerned about overheating the wood floor when welding. Therefore, the weld length was shortened to avoid causing problems with the wooden floor. Properly welding it in the chassis fabrication area (offline) may strengthen the joint and reduce deflection.

Exhibit 48. Reinforcement of Extension Platform

A reinforcement bar (white line) could be added to increase the rigidity of the extension platform. Photo credit: Systems Building Research Alliance (2022).

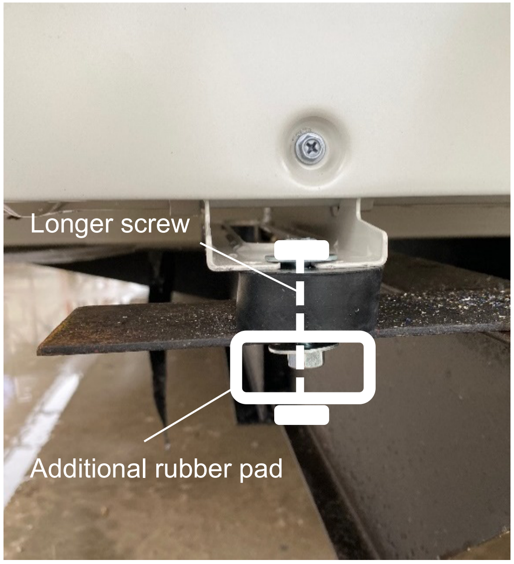
Four flat pieces of metal, connected to the two frame extensions, were used to mount the outdoor heat pump section. They were flexible and were bent several times on the production line. They could also cause damage during transport if the condenser rocks. These pieces can be eliminated by mounting the outdoor unit directly to the two I-beam extensions for a stiffer connection (exhibit 49). The frame extension location would have to be precise to match the outdoor unit mounting hole dimensions. Shorter tabs and more widely set frame extensions could be used as an alternative to mitigate bending.

Exhibit 49. Eliminate or Shorten the Four Metal Mounting Tabs

The four metal mounting tabs could be eliminated in the future because they lack stiffness, and the I-beams could be installed with wider spacing. Photo credit: Systems Building Research Alliance (2022).

9. Attaching an additional rubber pad to the bottom side of the extension platform might further reduce vibration transmission to the frame and home. It would require longer bolts and an additional rubber pad (exhibit 50). For even further vibration reduction, the mounting hole for the bolt could be widened slightly, and a rubber grommet could be installed with the mounting bolt placed through the middle of the grommet. With rubber pads on the top and bottom of the mounting bolt, plus the rubber grommet within the bolt hole, all metal-to-metal contact would be eliminated, which should significantly reduce vibration transmission.

Exhibit 50. Suggested Rubber Pad on Underside of Frame Extension



To mitigate the outdoor unit vibrating, additional rubber pads can be placed under the mounting frame.
Photo credit: Systems Building Research Alliance (2022).

Servicing Arrangements Summary

As determined in a conversation with the LG regional manager, the company can provide a 10-year warranty, including all parts and labor. LG has its own servicing network called the LG Pro Dealer Program. If no providers are in the area, an alternative option is to find a contractor via JB Warranties. LG prefers the homeowner to visit the LG website or call the LG customer call center to find an LG Pro Dealer based on ZIP Code. The LG Pro Dealer (or JB Warranties contractor) will perform full servicing at no cost to the homeowner for the 10-year warranty period.

To make it more appealing to contractors from the HVAC servicing network to do only servicing work, LG will pay a negotiated rate to Pro Dealers and JB Warranties contractors to cover the servicing work.

A common issue for which homeowners request servicing is the malfunction of control boards when the electrical voltage is more than 10 percent outside the high-low range, which can be avoided if a phase monitoring relay is installed at an added cost. The typical lifespan and anticipated need to replace the unit is at least 10 years. Most parts are available immediately. Additional steps to check quality at the plant, such as powering up the home and commissioning testing in the factory before shipping the home, could reduce the need for system servicing in the field. LG can provide training in the homebuilding plant.

Benefits

1. **Energy Performance.** The efficiency of the ducted mini-split system is superior to the standard code minimum split system heat pump that the plant typically uses—seasonal energy efficiency ratio (SEER) 14 and heating seasonal performance factor (HSPF) 8.2. The variable-speed LG unit has SEER of 18 and HSPF of 10 for a 3-ton unit and SEER of 19.5 and HSPF of 11 for a 2-ton unit. However, ducted distribution reduces efficiency and capacity somewhat compared with ductless units.
2. **Does Not Require an Alternative Construction Letter.** Per HUD Code 3280.703, this product's Air-Conditioning, Heating, and Refrigeration Institute (AHRI) 210/240 listing is acceptable for the air-source heat pump, and it is compliant. The EPA could mandate that this system use low global warming potential refrigerants starting in 2025.
3. **Quiet.** The indoor AHU operates very quietly at about 50 dBA compared with a traditional furnace air handler (61 to 68 dBA). The EPA identified an average 24-hour exposure limit of 45 dBA for indoor residential areas for comfort and to protect occupant health (EPA, 1974).
4. **Floor Plan Design Flexibility.** The ducted mini-split unit offers flexibility for floor plan designs. The central indoor unit fits into the typical furnace closet. The indoor AHU can be anywhere on the floor plan if the refrigerant line does not exceed a certain limit. However, if additional refrigerant is not added to the system, the lines can run only a limited distance of about 24.6 feet.
5. **Airflow Configurations.** The indoor AHU can be converted to serve in-floor ducts—the most common duct configuration in the industry—with a downflow kit costing from $150 to $200. Attic ducts are more typical in the South. The downflow configuration does not affect floor location or space requirements.

Challenges

1. **New Skills and Additional Work Needed.** A split system, such as the ducted mini-split unit, requires that the installer hold an EPA refrigerant handling license, which the plant does not typically hold. Additional work includes connecting the lines, evacuation and vacuum testing, charging, and protecting the refrigerant lines. Plants would also have to track inventory for the additional required parts and materials. Additional tools are necessary to complete those tasks (for example, a pressure gauge and vacuum pump).
2. **Adding Total Length to the Home.** Adding the frame extension to accommodate the outdoor unit increased the total home length by 32 inches. On a home already designed to the

maximum length allowable by shipping regulations or factory constraints, this increase is a limitation.

3. **Aesthetic Issues.** The frame extension and outdoor unit affect aesthetics because they are positioned higher than the typical outdoor unit equipment pad mounted on the ground. The elevation can be especially high on a sloped site and could affect serviceability. However, elevated outdoor units are typically less prone to floods, winds, and vandalism.

C. Nonducted Packaged Heat Pump

Four high-efficiency, nonducted unitary heat pumps were installed in three bedrooms and the living room of a double-section home at the Clayton Homes plant in Sacramento, California (exhibit 50).

Exhibit 51. Ephoca HPAC 2.0

1. EC Crossflow Blower Fan
2. Insulation
3. Inverter brushless DC compressor
4. Temperature sensors
5. EC condenser fan
6. Touch-screen display
7. Metal paintable cabinet
8. Electrical connection
9. Optional fresh air intake[2]
10. Condensate mister
11. Washable filter
12. Indoor heat exchanger
13. Adjustable air louver
14. Outdoor heat exchanger

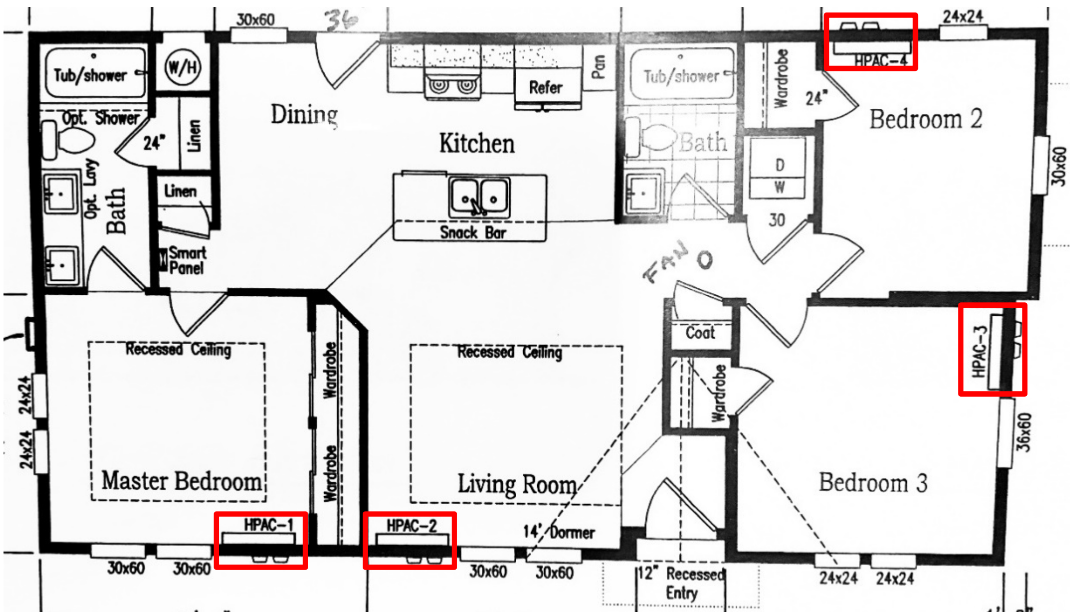
HPAC = heat pump air-conditioner.

Source: Ephoca HPAC 2.0 Installation Manual

Home and HVAC System Design

Exhibit 52 shows the final floor plan for the two-section home. The four units were installed in the home on external walls, one in each bedroom and one in the living room. The unit is slim and does not extend outdoors. Two vents through the wall draw in and exhaust air for the heat pump. The mounting location is flexible because it can be installed high or low on the wall or even perpendicular to the exterior wall with the addition of a side wall conversion kit. In this prototyped home, the units were placed high on the wall to provide more flexibility for furniture placement. This placement made the touchscreen controller inaccessible, but the heat pump also works with a remote control and smartphone application.

Exhibit 52. Floor Plan for Home With Ephoca HPAC



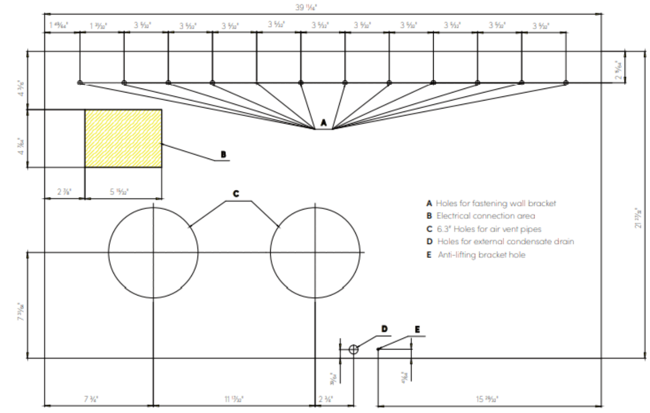
Source: Clayton Homes

Home Production Modifications

The following describes changes to the production process for the Ephoca unit installation.

1. **Exterior Wall Rough Opening for Heat Pump.** For each unit, two 6-inch-diameter openings were made on the external wall for the air vent pipes (exhibit 53). Although the home was not going to be in a California wildland urban interface (WUI) zone, the team wished to assess the potential for WUI compliance with this home. One of the WUI requirements specifies that exterior grilles be a 1/8-inch metal mesh to cover air intakes. However, the Ephoca vent grilles required a minimum free area of 0.21 square foot (for each supply and exhaust) and a more generous 0.68 square foot for optimum performance to maintain sufficient airflow. Applying a 1/8-inch mesh would reduce airflow, so vent grilles with larger openings were used (exhibit 54).

Exhibit 53. Construction of Exterior Wall Opening



The 6-inch air exchange openings on the exterior wall. The vent pipes were later wrapped in batt insulation (right). Photo credit: Ephoca Installation Manual (left); Systems Building Research Alliance (2022; right).

Exhibit 54. Dundas Jafine ProVent 6-Inch White Wall Vent Hood

Ephoca manufacturer approved vents were used. Photo credit: Systems Building Research Alliance (2022).

2. **Heat Pump Installation.** After the exterior walls were assembled, mounting brackets were fastened to the interior of the wall, and the Ephoca units were mounted on the brackets (exhibit 55). They were then covered in plastic before moving to the next station to paint the walls. Because the unit was mounted high on the wall, the underside is visible to occupants.

Exhibit 55. Wall-Mounted Ephoca HPAC Unit

The Ephoca units were mounted high on the walls to allow for flexibility in furniture placement (left). The underside of the Ephoca is not finished and is visible to the homeowner in this configuration. A cover is suggested to hide the bottom of the unit (right). Photo credit: Systems Building Research Alliance (2022).

3. **Thermostat.** A separate thermostat was not required because each Ephoca unit came with a built-in controller with four modes (cool, heat, dehumidify, and automatic) that could be accessed through an onboard touch controller or a smartphone application.
4. **Electrical and Plumbing.** The electrical wires were hardwired to the home's 100-ampere electric panel. The condensation is collected at the bottom of the unit with a condensate drain pan. The condensate outlet was connected to a PVC pipe routed through the floor and then turned 90 degrees laterally to the outside edge of the home (exhibit 56).

Exhibit 56. Condensate Pipe for Ephoca HPAC Unit

The condensate line is routed through the wall and turned to the outside edge of the home under the floor. Photo credit: Systems Building Research Alliance (2022).

Short-Term Testing

Basic functional testing was not conducted at the plant because the home was not connected to electrical power. The functional test was performed after the home was installed in Visalia, California. No damage or cracks around the Ephoca unit were visible after transporting. When powering up the unit via the onboard touch screen, it took a couple of seconds to start blowing air. The noise level was not measured, but per the product brochure, it is less than 51 A-weighted decibels when running at high speed. Infrared images were taken around the unit, and no noticeable leaks were found. The airflow rate and temperature at the air outlet for each unit were tested when running at maximum heating and cooling setpoints. To activate the warranty of an Ephoca unit, photographic documentation is required to ascertain that it was properly installed.

Onsite Performance

The Ephoca packaged heat pump system underwent onsite commissioning in Visalia, California, in May 2023. During commissioning, power, airflow, air temperature, and controls were checked, and the units functioned as intended. EPRI will conduct ongoing monitoring under a separate California Energy Commission project.

Lessons Learned

1. The opening for the air vent pipes should be increased to 8 inches so that a finer mesh screen can be used for WUI compliance. This consideration is important in California, where many homes are required to be WUI compliant.
2. When mounted high on the wall, accessing the onboard touch controller is difficult, and a remote control is needed. However, mounting the unit low on the wall restricts furniture

placement in the room because the supply air blows from the front and should not be blocked.

3. The units did not provide fresh air ventilation. Therefore, a separate ventilation system was required. Ephoca offers an optional fresh air heat recovery ventilator feature. However, the ventilation rate is only 15 cubic feet per minute (cfm), which does not meet the minimum ventilation-rate capacity in the HUD Code (0.035 cfm per square foot with a minimum of 50 cfm) unless at least five units were used for this size home.
4. An Alternative Construction letter was required to install the Ephoca unit because of abridged AHRI certifications. The Ephoca HPAC is certified to AHRI 390 instead of HUD's requirement of AHRI Standard 210/240. This unit was installed in accordance with the product manufacturer's installation instructions—Design Approval Primary Inspection Agency-approved designs, instructions, and specifications—and meets the intent of the Standards.
5. For this home in this location, the unit capacity greatly exceeds the thermal loads in the bedrooms. Smaller-sized units are not available, so oversized heat pumps in bedrooms are likely to be the case in most homes in most climates. Oversizing may negatively affect humidity control and can result in short cycling of equipment.

Servicing Arrangements Summary

As determined in conversations with Norman S. Wright's Business Development Department, the manufacturer's representative in California, the firm can provide a 10-year warranty that covers the cost of any replacement parts. Labor is also covered for the first year. Norman S. Wright requires the Ephoca system installer to complete training before purchase. Norman S. Wright has in-house technical support to help with system troubleshooting. However, because Ephoca is new to the U.S. market, the company currently has only 47 trained installers. Ephoca also provides homeowners with training on the product, but homeowners can always reach out to Norman S. Wright for technical support. The homeowner should work with the installer for maintenance issues. An alternative solution is to develop a network of servicing contractors in multiple areas to whom homeowners can reach out.

Benefits

1. **Energy Performance.** The efficiency of the through-wall packaged terminal heat pump system is superior to the standard split system heat pump that the plant typically uses (SEER 14, HSPF 8.2). The variable-speed Ephoca unit has a SEER of 16 and an HSPF of 10.3. The system is ductless; therefore, efficiency and capacity are not compromised.

2. **Little Additional Work Needed.** This packaged terminal heat pump system requires little additional work because no separate outdoor unit is present. The entire system is mounted inside the home on an exterior wall through which it exchanges air and heat with the outdoors. Thus, additional work is required to provide two exterior wall rough openings (6 to 8 inches in diameter, depending on the model), mount the unit on a wall bracket, and install manufacturer-approved external louvers to cover the two openings. The unit does not drain the condensate directly into a drainpipe. Rather, to prevent freezing, the condensate collects in a lightly heated collection pan, where a solenoid valve releases it to the drainpipe once the maximum level has been reached.
3. **Aesthetics.** This system has two small louvers on the outside of the exterior wall. It does not have an outdoor unit that negatively impacts the home's appearance.
4. **Quietness.** The heat pump unit provides quiet operation compared with a traditional furnace air handler (51 dBA versus 61 to 68 dBA). The U.S. Environmental Protection Agency identified an average 24-hour exposure limit of 45 dBA for indoor residential area comfort and to protect occupant health (EPA, 1974).
5. **Floor Plan Design Flexibility.** The packaged terminal heat pump offers flexibility in floor plan designs. Where an exterior wall exists, the unit can be installed without any disruption to the floor plan design.
6. **Ductless.** The elimination of ductwork can save some upfront costs related to duct material and installation. It also eliminates distribution losses and improves overall energy efficiency. The individual control of each zone may save energy use compared with a centralized system, but further monitoring data are needed to assess the effect of the oversized units.

Challenges

1. **Requires an Alternative Construction Letter.** The Ephoca unit requires an Alternative Construction letter because Ephoca is certified to AHRI 390 instead of HUD's requirement of AHRI Standard 210/240. Furthermore, the Ephoca product UL listing was pending official approval, which required nationally recognized testing laboratory documentation during HUD review at the time of the research. The EPA could mandate that this system use low global warming potential refrigerants starting in 2025.
2. **Additional Electrical Wiring Is Needed.** Three to four times as much wiring must be used for the Ephoca units compared with a traditional furnace air handler because one unit is installed in each room, and each is wired separately.

3. **Takes up Floor Space.** One unit must be installed in each thermal zone. The space in front of the unit (whether low or high on the wall) must be clear, with no furniture blocking airflow. This placement may be a critical consideration because rooms in manufactured homes tend to be small, and taking up usable space is not ideal. In large rooms, placement for optimal air throw must be considered.
4. **Oversized Capacity.** The maximum rated capacities are 8.1 one-thousand British thermal units (kBtu) per hour (heating at 47°F) and 8.1 kBtu per hour (cooling at 95°F) per heat pump (model DP91HDSO). However, the average load in HUD climate zone 2 for a manufactured home bedroom is only about 1 to 1.5 kBtu per hour for heating or cooling. The oversized equipment may result in the compressor's short cycling, reducing efficiency, equipment life span, and dehumidification performance.
5. **Higher Price.** The equipment cost per ton of heating and cooling capacity is higher than for a standard split heat pump system with a central air handler. In addition, one unit must be installed per room rather than a single unit for a central system.

Chapter 4. Commercial Practices

Key players in the heating and cooling system selection, design, and installation processes will likely change as the project results are deployed. In the future, the home manufacturer will take on most of the responsibilities, revamping and replacing steps currently under the purview of the heating, ventilation, and air-conditioning (HVAC) distributor or site technician.

Current State

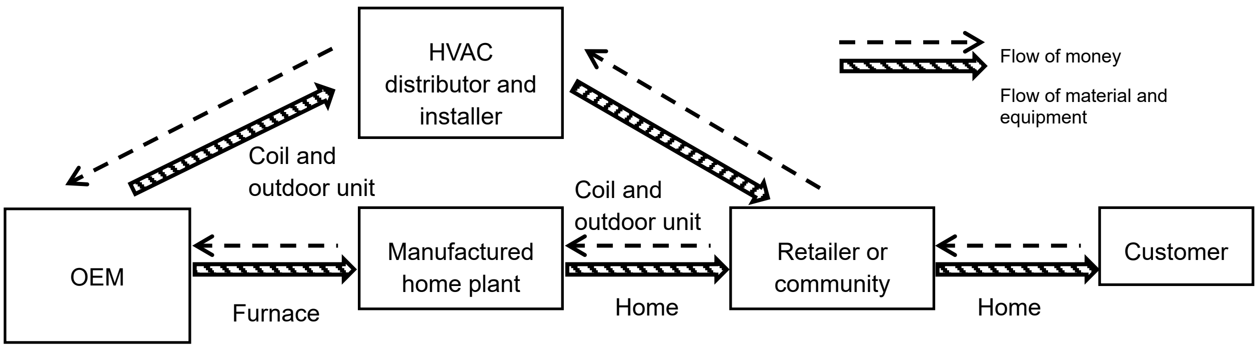
The current commercial process associated with heating and cooling system selection, design, and installation in the manufactured housing industry has stayed the same for decades. The plant installs only the indoor furnace (electric or gas) and ductwork, whereas the home retailer orders the outdoor unit (air-conditioning only or heat pump) from the HVAC distributor. The distributor then sends a technician or contractor to the site to install the indoor coil and outdoor unit. These affiliated contractors are also responsible for future servicing if the heating and cooling system fails. Using alternative heating and cooling systems fully installed at the home manufacturing plant will require commercial arrangement and business relationship changes, as the following sections describe.

At present, the two major paths to selling manufactured homes are via retailers or manufactured housing communities. In both scenarios, the HVAC distributor, home retailer, or HVAC contractor plays a critical role in providing, installing, and servicing the heating and cooling equipment. For servicing, the homeowner or resident calls the home retailer, and depending on the type of system failure, the retailer finds the right party to service the system. The following is a list of parties responsible for the various activities of the heating and cooling processes:

- Equipment Distribution: Original equipment manufacturer (OEM; indoor and outdoor equipment); HVAC distributor (outdoor equipment).
- Stocking of Equipment: Manufactured home plant (indoor); HVAC distributor (outdoor).
- Installation: Manufactured home plant (indoor); local HVAC contractor (outdoor).
- Service, Warranty, and Repair: Local HVAC contractor.

The diagram in exhibit 57 captures the current state of the relationships in the heating and cooling processes for homes in scattered lots and communities. The OEM sells some equipment (such as the furnace) to the manufactured home plant and the balance to an HVAC distributor. These parallel streams recombine at the site when the home retailer or community purchases the homes and the coils, along with the outdoor unit, and they are delivered to the customer.

Exhibit 57. Current-State Model (Scattered Lot and Communities)



HVAC = heating, ventilation, and air-conditioning. OEM = original equipment manufacturer.

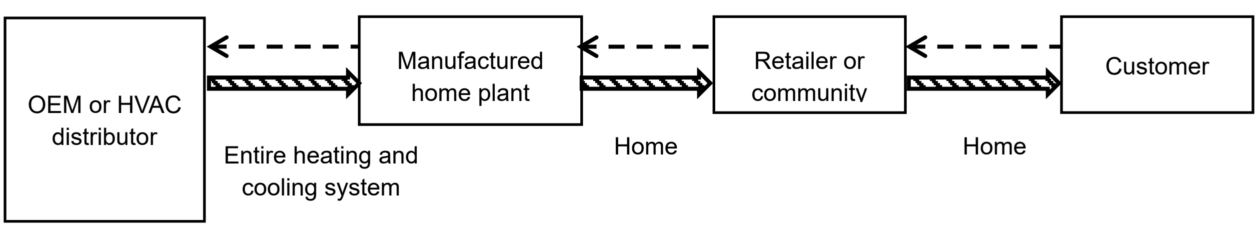
Future State—Home Manufacturing Plant-Installed Full Heating and Air-Conditioning System

In the future, most of the responsibilities will ideally be moved to the plant. All heating and cooling components would be provided directly to the plant. The in-plant quality control process may reduce service calls, and savings from improved quality and operational efficiency may partially offset the added cost. The following is a list of parties that would be responsible for the various activities of the heating and cooling processes:

- Equipment Distribution: OEM or HVAC distributor (indoor and outdoor).
- Stocking of Equipment: Manufactured home plant or HVAC distributor.
- Installation: Manufactured home plant.
- Service, Warranty, and Repair: Local HVAC contractor, manufactured home plant, or HVAC distributor.

Exhibit 58 captures the relationships of the heating and cooling processes of the future state. The flow is streamlined, with all heating and cooling equipment passing from the OEM manufacturer to the manufactured home plant to the site.

Exhibit 58. Future-State Model



HVAC = heating, ventilation, and air-conditioning. OEM = original equipment manufacturer.

Commercial Evaluation

To further understand the commercial benefits and liabilities of each approach, evaluation criteria were divided into **More Critical** (exhibit 59) and **Less Critical** (exhibit 60) categories to the industry on the basis of input from the marketing and commercialization panel, which includes manufactured home sales and marketing directors, home installation specialists, and HVAC sales representatives.

Exhibit 59. List of Evaluation Criteria—More Critical to the Industry

Market Considerations	Packaged Unitary, Ducted Unit	Mini-Split, Ducted Unit	Packaged Unitary, Nonducted Unit
Material and component costs	Approximately $3,700–$4,300 increase from current practice (cost to the home retailer).	Approximately $1,200–$1,500 increase from current practice (cost to the home retailer).	Approximately $8,000–$9,500 increase from current practice (cost to the home retailer).
Service costs	Warranty included but only up to 1 year. Labor included only for the first year.	Need to pay an upfront cost for a 10-year warranty (approximately $400).	Warranty included for up to 10 years (parts only). Labor included only for the first year.
New inventory procedure	Equipment stored in plant.	Equipment stored in plant.	Equipment stored in plant.
Regional marketability	Not flexible. Currently available only in homes with upflow air ducts (mostly produced for HUD climate zone 1).	Flexible. Air handlers can provide both up and downflow air (i.e., attic or underfloor ductwork).	Flexible. Zonal system.
Impact on existing business relationships	Large impact—will have to change supplier and possibly eliminate from the value chain HVAC distributors that currently have a close relationship with retailers. See the Future State section on business relationship changes.	Current suppliers (HVAC distributors or original equipment manufacturers) might be able to provide a similar product. See the Future State section on business relationship changes.	Large impact—will have to change supplier and possibly eliminate from the value chain HVAC distributors that currently have a close relationship with retailers. See the Future State section on business relationship changes.
Process for system maintenance and service at the site	National footprint might be limited because system type is less common. Needs skills and expertise for maintenance.	Might not be an issue. However, if local HVAC contractors were to service, they might be reluctant because they would be making less money, and installation would be removed from their contract.	National footprint will be limited because system type is new, and currently, only a handful of manufacturers produce this type of system. Skills and expertise are needed for maintenance.

HVAC = heating, ventilation, and air-conditioning.

Exhibit 60. List of Evaluation Criteria—Less Critical to the Industry

Market Considerations	Packaged Unitary, Ducted Unit	Mini-Split, Ducted Unit	Packaged Unitary, Nonducted Unit
Availability of parts from multiple suppliers	Parts from multiple suppliers might be limited because system type is less common.	Not an issue.	Parts from multiple suppliers might be limited because system type is less common.

Costs to the plant and retailer of the prototyped systems were compared with a baseline system, a conventional split heat pump unit, to highlight the system upgrade costs (exhibits 61 and 62).

Exhibit 61. Estimated Costs of the Prototyped Heating and Air-Conditioning Systems to the Plant

System Description	Cost to Plant	
	Materials	Labor
Baseline—Traditional system that includes indoor furnace, connection to ductwork, and thermostat. Procurement and installation of outdoor unit not included.	$796 (not including outdoor unit)	$105 (not including installation of outdoor unit)
Home that includes Friedrich packaged heat pump, connection to ductwork, and thermostat.	$5,952	$135
Home that includes LG Electronics indoor air handling unit, outdoor unit, connection to ductwork, and thermostat.	$4,109	$210
Home that includes four Ephoca ductless units, with control panel included in the units.	$10,115 (four in total); $2,959 (per unit)	$240 (four in total), $60 (per unit)

Exhibit 62. Estimated Retailer Costs of the Prototyped Heating and Air-Conditioning Systems

System Description	Cost to Retailer
Baseline—Traditional split system that includes indoor furnace, outdoor heat pump, connection to ductwork, and thermostat.	$5,050
Home that includes Friedrich packaged heat pump, connection to ductwork, and thermostat.	$9,345
Home that includes LG Electronics indoor air handling unit, outdoor unit, connection to ductwork, and thermostat.	$6,452
Home that includes four Ephoca ductless units, with control panel included in the units.	$15,881(four in total), $3,970 (per unit)

Technical panel members and the marketing and commercialization panel believe that the first cost to the homeowner is an important consideration. The heating and cooling equipment can add $2,000 to $6,000 to the home's retail price, which is challenging for an affordable housing product.

Discussions and Solutions

The panels agreed that to change the current state and adopt the plant-installed heating and air-conditioning (H&AC) system in manufactured housing, the entire process will have to be redesigned by developing new partnerships, staffing accordingly, and possibly providing new incentives to drive the transition process. Pushbacks are anticipated from home retailers unless the new process promises less responsibility and better incentives. Panel members discussed improvements that could solve some of the identified hurdles (exhibit 63).

Exhibit 63. Summary of Commercial Hurdles and Solutions

Hurdles	Solutions
1. Higher equipment cost	The current baseline system cost results from a years-long negotiation to reach the current price. Bulk purchase and further negotiations may be able to drive down the cost of the new systems.
2. Servicing arrangement and cost	A service network affiliated with the heating, ventilation, and air-conditioning (HVAC) manufacturers would provide servicing for the new proposed approach. National coverage is crucial because manufactured homes are shipped throughout the United States. Partnering with other servicing programs may also be a solution to expand the existing network. For example, LG Electronics has a partnership with JB Warranties, which provides certified servicing.

Hurdles	Solutions
3. Impact on existing business relationships	If HVAC original equipment manufacturers provide the equipment directly to the plant, the HVAC distributors may be removed from the business relationship because home manufacturers could assume those responsibilities. However, HVAC distributors could still sell the equipment to home manufacturers, and plants could install it. Home retailers have an established relationship with HVAC distributors, which they might be reluctant to change.
4. Availability of parts from multiple suppliers	For reliability, having multiple suppliers to provide the components is preferrable to relying on a single supplier.

Results

Each of the three prototyped systems has unique advantages and disadvantages. After the prototypes were completed, plant management and staff indicated that they appreciated the ease of installation of the packaged units (the ducted packaged unitary system and the nonducted packaged heat pump) but noted that the equipment cost for these two systems might be a barrier. The ducted mini-split system has superior energy performance and is competitive on cost, but the additional work associated with installation (primarily the work to connect and charge the refrigerant lines) and commissioning is a major drawback. Most other technical hurdles are secondary and can be resolved, such as redesigning floor plans to accommodate the system construction requirements or getting an Alternative Construction letter of approval from HUD. The following sections provide a summary of the results.

Cost

Initial or first cost plays a critical role in manufactured housing. A conventional split system typically costs approximately $5,000 to the home retailer. The three systems prototyped in this project had higher initial costs—approximately 28 percent higher for the LG Electronics ducted mini-split, 85 percent higher for the Friedrich ducted packaged unitary system, and 215 percent higher for the multiple Ephoca nonducted packaged heat pumps. However, these systems are more energy efficient and will have a lower operating cost compared with a traditional split system. Ekotrope energy modeling was conducted to estimate the operational cost for the three systems in typical single- and two-section manufactured homes in Waycross, Georgia. The result shows that compared with an electric-resistance heated HUD home, the Friedrich VRP® packaged unit has a 14.9-percent energy cost decrease in a single-section home and 9.8-percent decrease in a two-section home. The LG ducted mini-split has a 17.8-percent decrease in a single-section home and 16.8-percent decrease in a two-section. The Ephoca ductless packaged system has a 21.3-percent decrease in a single-section home and 24.4-percent decrease in a two-section home. These operational cost savings would offset some of the initial investment premium. In addition, the costs of the systems currently in use have been negotiated and optimized for many years, whereas the systems explored in this research are prototypes without the benefit of bulk purchase agreements and years of engineering refinements. Over time, the expectation is that new system types would decrease in cost as they are refined and scaled up.

Capacity

Equipment heating and cooling capacity is important in system design and selection. The capacity range available should cover the loads of different-sized homes in different climates in which manufactured homes may be located. When in full control of system design, home manufacturing plants can select equipment properly, considering heating and cooling load calculations and duct sizing. Of the three systems prototyped, the ducted mini-split offers the most comprehensive range of capacities (2 to 4 tons). The maximum capacity for the ducted packaged unitary system is approximately 3 tons, which can be too small for homes larger than the prototyped two-section home (1,800 square feet) or homes in cold climates. An electric heat strip can be added to the system to compensate for the capacity limitation; however, this addition will increase operational costs. The nonducted packaged heat pump, on the other hand, may be oversized in most applications because it is a zonal system, in which one unit (with a nominal capacity of 10 one-thousand British thermal units, or kBtu, per hour) is required for each room. Smaller packaged units will have to be developed for optimal performance, or a transfer fan could be installed to transfer air between rooms.

Zonal control may save energy compared with a centralized system because occupants can condition only occupied spaces. However, oversized equipment can lead to short cycling, which can reduce equipment lifetime and adversely affect comfort and energy efficiency.

Controls

Easy-to-use controls can help occupants best use H&AC systems and reduce the need for service due to improper system operation. Both the ducted packaged unitary system and the ducted mini-split have standalone thermostats with easy access to control temperature and airflow. The nonducted packaged heat pump has a built-in touch controller on the unit. In the prototyped home, because the unit was mounted high on the wall, access to the onboard controller is difficult, requiring a remote control. A programmable thermostat should be installed if the home is built to comply with the ENERGY STAR Certified Manufactured Home program. In this research, only the ducted packaged unitary system (Friedrich VRP) did not have a programmable thermostat in place.

Air Distribution

Another important consideration is the ability of ducted space conditioning units to accommodate the two major duct locations in manufactured homes: under the floor and in the attic. Most manufactured home plants in the United States, especially in northern climates, use downflow systems with ducts under the floor. In the South, upflow systems with ducts in the attic are more common. The ducted mini-split unit can convert between up and downflow configurations. The ducted packaged unitary system can provide only upflow. A side-discharge supply air configuration may become available, which could be used for under floor ducts. The nonducted packaged heat pump eliminated the need for ducts altogether.

Ventilation

HUD Code homes require mechanical ventilation, often provided by a system integrated with the air handler or a dedicated exhaust fan. Manufacturers may prefer a whole-house ventilation feature integral to the factory-installed H&AC system. The Friedrich VRP 3-ton unit in this research, with Fresh-Aire UV indoor air quality accessories installed, can condition 130 cubic feet per minute (cfm) of fresh air from outdoors without the need for additional ductwork or air inlets. This feature can help the home comply with the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 62.2 standard. However, the HUD Code requires that the ventilation system operate independently of heating or cooling modes, so unless the system has a designated control for ventilation (i.e., can operate the air handler fan only), it does not meet this ventilation requirement. The nonducted single packaged heat pump also provides the opportunity to supply fresh air. The Ephoca unit in this research can provide 15cfm of fresh air per unit with the addition of a heat recovery ventilator. The ducted mini-split in this research does not offer a ventilation function.

Floor Plans

Full-range applicability to home floor plans and requiring minimum interior space are important. The two packaged systems currently must be installed on an exterior wall. The ducted packaged unitary system takes up a regular-sized furnace closet if it weighs less than 2 tons (a 3-ton unit requires a larger footprint), but the closet must be on the end wall of the home to provide clearance in the attic to connect to the attic trunk duct, thus limiting design flexibility. The nonducted packaged heat pump is more flexible in accommodating different floor plans but takes up valuable space in each room because the space in front of the unit must be open for airflow. The length of the refrigerant line limits the floor plan design flexibility for the ducted mini-split if adding more refrigerant is to be avoided. Otherwise, the indoor air handling unit can be placed anywhere in the home.

Noise

Operational noise is a consideration for equipment placement. Results from the prototyped homes show that both the ducted mini-split and nonducted packaged heat pump have low operational sound levels. The ducted packaged unitary system is louder. The Friedrich VRP measured at 66.7 maximum level of decibels when operating at high speed in the plant, similar to a traditional furnace air handler.

Regulations

Another critical aspect to consider is Design Approval Primary Inspection Agency (DAPIA) approval. The plant's DAPIA services must approve all aspects of home design to ensure compliance with the HUD Code. In this research, several elements required DAPIA approval, including the frame mount for the ducted mini-split system, the thermal load calculations, and the specific equipment for use in manufactured homes. These reviews required the manufacturer to develop and provide additional documentation to the third-party DAPIA service providers. Because the nonducted packaged heat pump system in this research (Ephoca unit) was not certified under Air-Conditioning, Heating, and Refrigeration Institute Standard 210/240, an Alternative Construction letter was required. Although obtaining approval took several months, future use of the same systems will take less time to process.

Production

During production, the project team identified the following key takeaways:

1. The plants were concerned about any new skills required for installing the new systems. With the plant's current expertise and knowledge, most of the installation processes are manageable. However, connecting, evacuating, and charging refrigerant lines for the ducted mini-split are the most challenging. Although plants can have staff obtain an Environmental Protection Agency Section 608 Technician Certification (Type II for residential air-conditioning and heat pump), this solution is not deemed ideal. The plant would have to provide a staff training program to develop the required skillset and retain the trained staff.
2. An increase in labor due to additional work is also a key consideration. Plants operate at an intense production pace, and the production process and plant layout have undergone years of refinement to maximize efficiency. Adding steps to the production process must consider inventory storage space, parts and material tracking, inventory distance to the production line, labor, and material usage. Among the three systems considered, plant management

appreciated the ease of installation of the ducted packaged unitary system. Its implementation required minimal additional work and did not disrupt the overall production process. The ducted mini-split required more extensive changes, including fabricating an extension frame in the chassis workshop, running PVC piping underneath the home at the final station, and commissioning and charging the refrigerant lines in the yard. The installation process for the nonducted packaged heat pump was relatively straightforward. However, because one unit must be installed in each zone, labor still increased.

3. The preferred approach to ensuring the integrity of installed H&AC systems is to energize the home and conduct basic functional testing of the H&AC system before it leaves the plant. This approach will allow for early detection of any potential issues and reduce homeowner callbacks. However, in some cases, it may be difficult to have power readily accessible where and when needed in the plant. For the Waycross prototypes, the plant was able to energize the homes and conduct these checks in the yard. The Sacramento plant was unable to perform these checks, and as a result, a wiring flaw had to be corrected once the home was installed on site.

Transportation

All three prototyped homes were transported successfully from the plant to the home site. Using PVC pipe to protect the ducted mini-split refrigerant lines proved to be effective. However, the technical panel raised some concerns regarding the constraints the extension frame posed. If the home is already designed to the maximum length the factory allows, the length added to the end of the house may exceed the limitation of the production line. A solution to this issue is to weld the extension frame at the final station so the added length will not block the line. Another issue is that if the trailer shipping the home is going up a steep incline, the extension hitting the road surface is a risk. The two packaged systems pose no issue related to transportability because they are in the home envelope. One side note is that the Ephoca unit has a specific requirement. To avoid potential oil leaks and damage to the compressor welds, the Ephoca unit must be transported and kept upright at all times. The system seems to tolerate vibration during transport.

Aesthetics

Aesthetics are an important marketing consideration today because manufactured homes often compete with site-built single-family homes. The ducted packaged unitary system offers an advantage in this regard because it will be hidden in a mechanical room and, therefore, concealed from the rest of the home. However, the outdoor unit of the ducted mini-split is hard to conceal because it is mounted on the frame. If the home is on a sloped site, the outdoor unit may be high above the ground and unappealing visually. One possible solution is to use a bolt-on option and relocate the unit to the ground on site. An alternative solution is to install a screen or landscaping around the unit to hide it from sight. Despite this concern, the inverter-driven outdoor unit is slimmer than a traditional outdoor compressor. The nonducted packaged heat pump has two small louvers on the exterior, thus having the least visual effect of the three prototyped heating and cooling systems.

Floods, Other Damage, and Vandalism

The packaged units are fully within the home and, thus, are less prone to flood, fire, wind damage, and vandalism. The frame-mounted system is high off the ground, reducing the risk of flooding, but it would require specific protection to prevent wind damage and vandalism to the outdoor unit.

Conclusions

The building and design practices that typify the manufactured home industry have changed little in decades. In the case of heating and air-conditioning (H&AC) systems, the current practices have stymied innovation and resulted in inefficiencies. This research explored three innovative H&AC systems that can be fully installed in the factory before shipping and setting up at the home on site. These systems are seldom used in the manufactured housing industry today. The work provided insights into the potential benefits of these systems, or similar ones, and revealed challenges—both technical and commercial—that require further effort to resolve.

Manufactured homes differ from site-built or modular homes. Consistent and repeatable design is one of the reasons that manufactured homes provide one of the most affordable housing options in the United States (NAHB, 1998). Therefore, replacing current H&AC practice with a design that can fit seamlessly into the plant production while maintaining harmony between key stakeholders was a core consideration in vetting solutions. Two industry panels—technical and commercial—provided guidance and feedback to ensure that solution development was thorough and relevant.

The concept of an all-in-one unit that can be easily connected to ceiling ducts (the Friedrich VRP® system) proved to be appealing to the plant because of the simplicity of installation. However, the cause of the Friedrich VRP malfunctions is uncertain because whether they were due to a product design flaw or to a flaw only in the unit received is unclear. On the other hand, the ducted mini-split system may be more intricate to install but exhibited outstanding performance. The Ephoca packaged terminal system passed functional testing, but further monitoring will be critical to gain a comprehensive understanding of how the system performs. In a companion effort, project team member Electric Power Research Institute will continue to monitor the systems and gather data to evaluate their reliability and effectiveness in meeting the intended objectives.

The plant-completed H&AC systems have the potential to provide improved installation quality, such as avoiding mismatched outdoor and indoor components, installing and charging refrigerant lines properly, and installing the correct type of thermostat. Other benefits include the advantage of marketing the home as “heating, ventilation, and air-conditioning (HVAC) included” and facilitating heat pump information documentation for energy programs (e.g., ENERGY STAR or Zero Energy Ready Homes). The project team identified challenges that the proposed solutions face, including design flexibility, system capacity limitation, ease of installation, first costs, and methods of servicing in the field. These findings can inform potential further research. Appendixes E and F provide guidelines for industry members interested in adopting the prototyped solutions. These guidelines provide actionable instructions tailored toward engineering and production staff (the technical guideline, including fabrication details) and business managers (the commercial guideline).

To ensure the successful implementation of plant-installed H&AC solutions, plants should partner with H&AC manufacturers with dedicated research and development teams, a nationwide footprint, a commitment to the manufactured home market, and a willingness to embrace innovation.

Additional future research and fieldwork are needed to probe the technical hurdles. HVAC manufacturers and products also need to offer more competitive costs to incentivize plants to adopt the factory-installed heating and cooling components concept. Future discussions should also be held with HVAC distributors to explore collaboration possibilities further. The feedback and views of the consumers should also be investigated to broaden the perspective of this study. Resolving those problems can help make manufactured homes more affordable on a sustained basis and improve quality and resilience.

Appendix A. Interview Questionnaire—Technical

Background

Subjects: MH stakeholders/MH engineers

Survey goals:

- To reengineer the design and fabrication of the HVAC system to prevent common performance problems and encourage heat pumps over electric resistance heating through a strategy of making the plant responsible for a larger share of the HVAC system selection and installation
- To identify associated changes in production, home delivery, and installation method

Interviewee: ______________________________

Interviewer: ______________________________

Date of interview: ______________________________

I. Design

1. **Prior experience**
    a. What types of full plant-installed HVAC systems have you done in the past? (type of systems, type of house models, number of indoor/outdoor equipment, way of cooling distribution, supplemental heat, which facility, comfort issue, where to ship these models… etc.)
    b. Do you have photos/drawings/case studies that you can share with us?
2. **Other all-in-one HVAC systems**
3. **Tools needed for designing cooling system components**
    a. What tools are currently used for designing the cooling system? (software, specific skill sets…etc.)
    b. How do we provide or upgrade design tools used by the plant if the plant were to install heat pumps (HPs) as the norm?
4. **Locating the outdoor components**
    a. Is relocatable platform attached to frame a possible solution?
    b. What are other options for locating the outdoor unit? (end wall/side wall?) (placed on frame extension/mount on bracket on wall?)
5. **Avoidance of refrigerant line damage during transportation**
    a. What is the best way to run the refrigerant lines?
    b. Are the lines charged before shipment? If yes, are they checked at the site post-delivery? How do you do it and who will test them?

c. How do you design the refrigerant runs to avoid damage/leakage during transportation?
d. What other considerations are there for running, protecting, and charging the lines?

6. **Other HVAC design-related**
   a. What are other significant HVAC design issues when the systems are fully plant-installed? Are there any issues specific to single-section homes and double-section homes?

II. Inventory

1. **Past experience**
   a. Are there any specific provisions that need to be made in ordering and stocking the additional HVAC equipment/components?

III. Production

1. **Past experience**
   a. What are the impacts on production of full plant-installed HVAC systems?
2. **Plant staff training**
   a. Do plant staff currently possess the skills to do a full plant-install HVAC system?
   b. If not, how would these skills be delivered (training, etc.)?
   c. Are these tasks likely to be outsourced?

IV. Shipping

1. **Past experience**
   a. How do you typically ship HVAC equipment for full plant-installed HVAC systems?
2. **Protection during transport**
   a. How is equipment protected?

V. Onsite Quality Check

1. **Past experience**
   a. If components are site installed, how do you QC the HVAC components on site?
   b. Do you verify/commission systems that were installed in the plant, once on site?

VI. Other

a. What other significant design, installation, quality assurance, inventorying, testing, training, and other factors have we missed?
b. What are the five reasons not to plant install all HVAC components?
c. What are the five reasons to plant install all HVAC components?

Appendix B. Interview Questionnaire—Commercial

Background

Subjects: MH stakeholders/MH retailers

Survey goals:

- To identify and address the commercial hurdles to the adoption of the new HVAC solutions

Interviewee: ______________________________

Interviewer: ______________________________

Date of interview: ______________________________

I. Business Relationships

1. **Retailer to HVAC distributor relationship**
    a. How has this relationship change been handled in the past? What problems were encountered?
    b. In what other ways might the new distribution model face resistance by retail?
    c. What steps can be taken to overcome hurdles?
    d. Will retailers be able to maintain a relationship with HVAC distributors for parts and service? If not, how can these essential functions be maintained?
2. **Retail to plant ordering process**
    a. What obstacles or challenges will be faced when ordering equipment from the plants?
    b. What essential information needs to be conveyed to the plant (e.g., home location) during the purchase process and how does this impact the timing of the orders?
    c. Do you foresee any problems related to that change?
3. **Responsibility of service/warranty/repair**
    a. Who will be responsible for service/warranty/repair of the HVAC system if fully installed at plant?
    b. What added burden does this place on the retailer?
4. **Partnering with HVAC manufacturers**

II. Promotion and support

1. **Benefits of HPs**
    a. Do you think providing incentives for installing HPs (cost more than ACs) will be a feasible way to change the market? How much does the incentive need to be to meaningfully move the market?
    b. What support materials (e.g., literature, videos, web presence) will be needed and most effective in conveying the benefits to customers?

c. Is it necessary to sell the change to customers?

III. Other

a. What other significant sales, ordering, service, design, and installation factors have we missed?
b. What are the five reasons retail will cite for not to plant install all HVAC components?
c. What are the five reasons retail will cite for to plant install all HVAC components?

Appendix C. List of Interviewees

Exhibit C1. Technical Panel Members

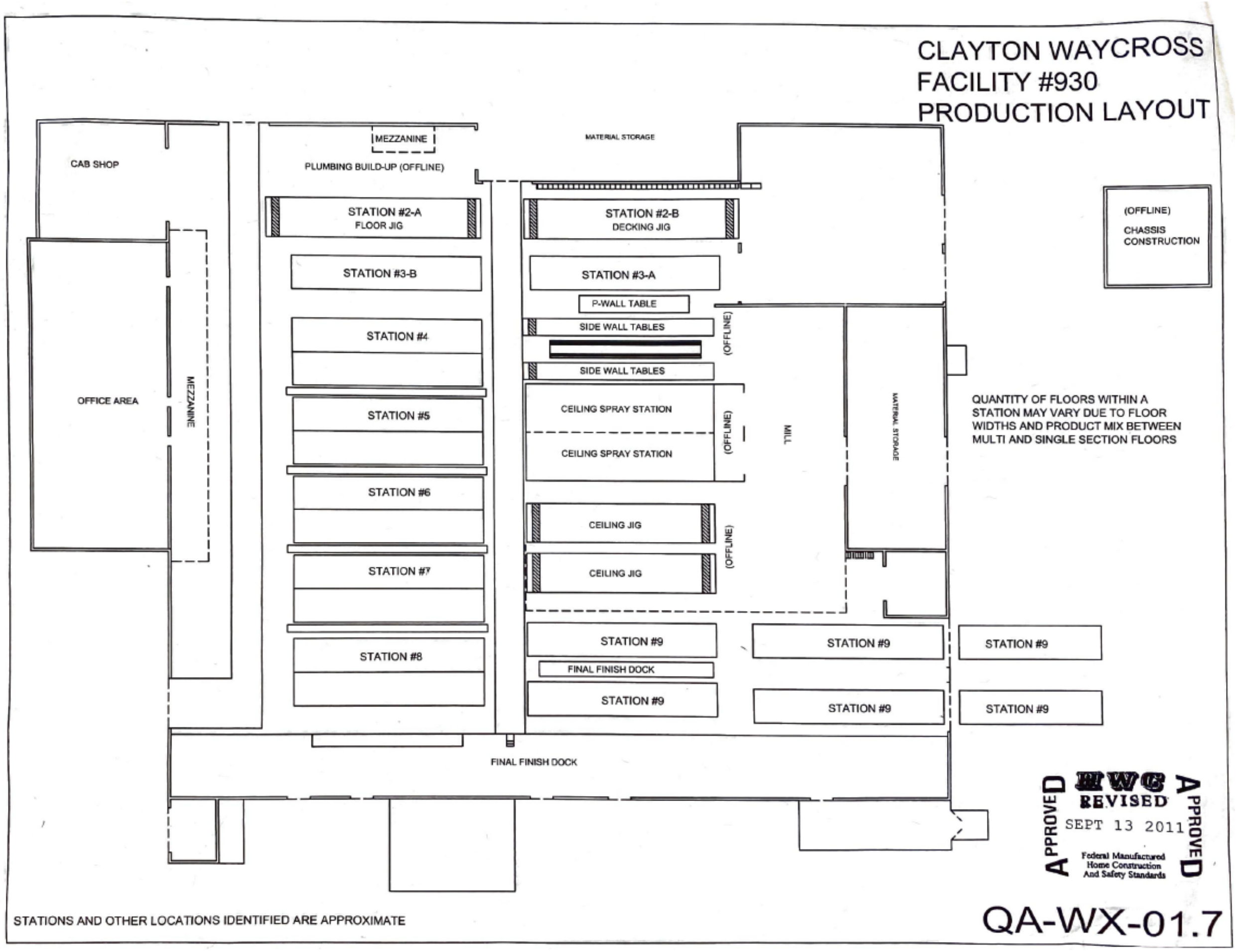
Panel Member (Interviewee) Title	Expertise
Director of Engineering	Manufactured home systems design and engineering
Vice President of Engineering	Manufactured home systems design and engineering
Chief Engineer	Manufactured home systems design and engineering
Vice President of Engineering	Manufactured home systems design and engineering
Director of Production	Production flow, home manufacturing efficiency
Vice President of Engineering and Design	Manufactured housing heating, ventilation, and air-conditioning systems and production

Exhibit C2. Commercialization Panel Members

Panel Member (Interviewee) Title	Expertise
Retail Regional Director	Manufactured home sales and marketing
Vice President of Site Construction	Home installation specialist
Associate Director	Heating, ventilation, and air-conditioning sales and marketing
Senior Manager of Product Management	Heating, ventilation, and air-conditioning sales and marketing

Appendix D. Production Station Layout and Production Sequence

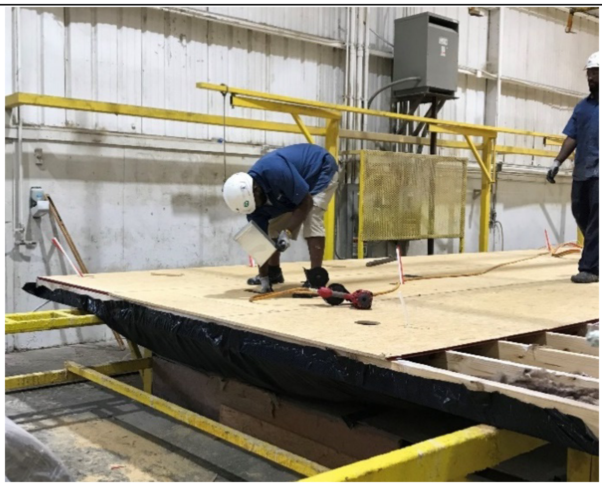
Exhibit D1. Production Layout for Clayton Waycross Facility



Source: Clayton Homes

Exhibit D2. Descriptions of Production Line Stations (Waycross Plant)

Station Numbers and Associated Work	Photos
Chassis construction (offline) • Construct and paint the chassis.	 Building a home chassis in the frame shop. Photo credit: Systems Building Research Alliance (2022).
Plumbing buildup (offline) • Assemble plumbing pipes (drainage and water supply pipes). • Manufacture floor ducts (rectangular metal downflow air ducts if used).	 Connecting plumbing lines according to the floor plans. The white pipes are sanitary lines. The smaller pipes in the foreground are hot and cold water supply lines. Photo credit: Systems Building Research Alliance (2022).

Station Numbers and Associated Work	Photos
Station 2-A: Floor jig • Install bottom belly wrap. • Construct perimeter wood frame. • Install R-22 fiberglass batt floor insulation. • Place underfloor wiring and plumbing above floor insulation. • Place floor ductwork (if any). • Construct the 2"x6" floor joists (16" on center.	 The belly wrap and floor insulation are laid prior to placing the electrical wiring, plumbing, and ductwork (if any). Floor joists are then added at the same station. Photo credit: Systems Building Research Alliance (2022).
Station 2-B: Floor decking jig • Attach plywood floor deck. • Cut penetrations for water lines, floor duct (if any), and electrical wires. • Place vertical branch duct (if any).	 The floor deck is installed at this station and holes are cut for plumbing, electrical, and ductwork. The staff is placing the register box under the floor deck. Photo credit: Systems Building Research Alliance (2022).

Station Numbers and Associated Work	Photos
Station 3-A • Floor deck sanding. • Add washers to secure the bottom belly wrap to floor frame. • Cut trunk duct and connection of the vertical branch duct (if any).	 Sanding the floor deck to make the surface even. Photo credit: Systems Building Research Alliance (2022).
Station 3-B • Place vinyl floor cover. • Install plastic wrap protection for the floor. • Cut through floor cover and plastic wrap for plumbing, electrical wires, and floor registers (if any). • Cut additional locations for floor ducts (if any).	 Plastic wrap is placed on top of the vinyl floor to protect it from construction damage and debris. Photo credit: Systems Building Research Alliance (2022).
Wall construction (offline) • Build 2"x4" exterior walls and 2"x3" interior partition walls. • Install R-11 fiberglass batt insulation in exterior wall cavities. • Construct interior walls with paper over gypsum wallboard.	 Building the exterior walls and interior partition walls. Photo credit: Systems Building Research Alliance (2022).

<table>
<tr><th>Station Numbers and Associated Work</th><th>Photos</th></tr>
<tr><td>Station 4
Install walls on the floor deck.
Add electrical wiring in the walls.
Place cabinets and bathroom fixtures.
Install door frames.
Apply foam to seal the penetrations.</td><td>
Walls are lifted into place using an overhead crane and track system. Photo credit: Systems Building Research Alliance (2022).</td></tr>
<tr><td>Attic jigs (offline)
Lay down ceiling gypsum board.
Place and secure roof trusses atop the ceiling gypsum.
Cut openings in the gypsum ceiling for air registers and lighting fixtures.
Install ductwork air-mixing boxes.
Use foam to attach attic trusses to the ceiling board.
Install attic flex ducts (R-8 insulation) and connect the ducts to the air-mixing boxes.</td><td>
A ceiling with flex ducts is installed. An air-mixing box is in the center of the photo to distribute air to the supply registers. Photo credit: Systems Building Research Alliance (2022).</td></tr>
</table>

Station Numbers and Associated Work	Photos
Attic spray station (offline) • Place attic electrical wires and conduits. • Spray fiberglass insulation (roughly R-33). • Paint inside surface of the ceiling.	 Fiberglass roof insulation was blown in. An electrician places the electrical wires and conduits. Photo credit: Systems Building Research Alliance (2022).
Stations 5 and 6 • Install oriented strand board (OSB) on exterior walls. • Install building air and moisture wrap on exterior walls. • Place roof and ceiling from the attic spray station on top of the walls. • Connect exterior walls to roof. • Install water flashing (below the roof gable and at the bottom of the floor) and soffit vent. • Install OSB roof decking.	 Exterior OSB sheathing being installed. Staff apply starter strips in preparation for installing the siding. Photo credit: Systems Building Research Alliance (2022).

Station Numbers and Associated Work	Photos
Station 7 • Install vinyl siding on exterior walls. • Install windows and trim. • Flash around windows to provide water protection and reduce air infiltration. • Install interior cabinetry, fixtures, doors, trim, and other finishes.	 Installing vinyl siding around a window. Photo credit: Systems Building Research Alliance (2022).
Station 8 • Raise home to install axles and wheels. • Install window shutters.	 Attaching wheels to the chassis. Photo credit: Systems Building Research Alliance (2022).
Station 9 • Complete interior finishes. • Install lighting fixtures and appliances. • Install thermostat for heating and cooling system. • Clean interior of the home.	 Home finishes are completed at this station. Photo credit: Systems Building Research Alliance (2022).

Appendix E. Technical Guideline for Manufactured Homes

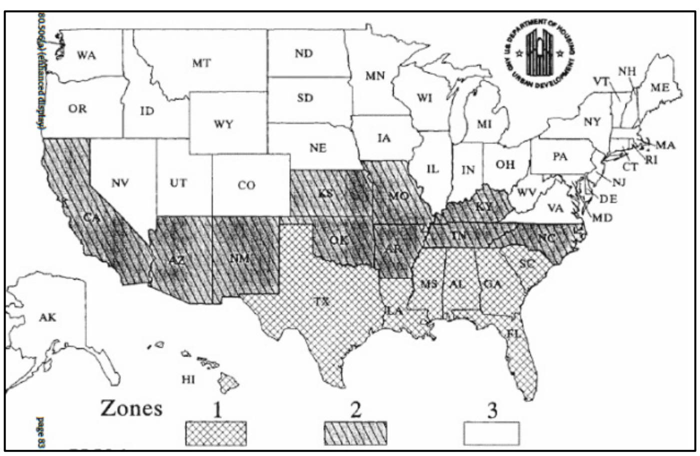
Introduction

This document provides guidance on integrating three heating and air-conditioning (H&AC) systems specifically designed to be installed entirely within the manufactured home production facility. Reimagining and reengineering the design and fabrication of the heating and cooling system, with all components installed in the plant under the existing HUD quality control regime, could potentially make homes more affordable by lowering energy costs and improving quality. This guide provides actionable guidance for engineering and production staff based on three prototype homes. The recommendations cover the design, construction, and commissioning of each system. These general guidelines should be combined with engineering judgment and input from H&AC product manufacturers to develop final designs for specific homes.

Applicability of This Guideline

This guideline and the underlying research apply to manufactured homes built to the Manufactured Home Construction and Safety Standards. This guide was developed on the basis of research that focused on HUD climate zones 1 and 2 (exhibit E1). Homes outside these zones may require alternative design measures. For example, for climate zone 3, a heat pump with enhanced cold climate capacity and efficiency may be required.

Exhibit E1. HUD Climate Zone Map



Source: Manufactured Home Construction and Safety Standards (MHCSS), 24 CFR Part 3280

Factory-Complete Heating and Cooling Solutions

The following describes three factory-complete H&AC systems.

- **Packaged System (Interior) with Ducted Distribution** is a fully self-contained unitary heat pump system installed inside the home's thermal envelope. These systems are popular in modular construction and hospitality buildings. Many years ago, manufactured homes used a version of this concept (the “Insider” heat pump). However, due to low demand and the amount of development needed to meet higher seasonal energy efficiency ratio and heating seasonal performance factor ratings, that concept was abandoned. Product options are limited to a few manufacturers.

- **Ducted Mini-Split Heat Pump, Frame-Mounted Outdoor Unit** is a ducted mini-split system that has the outdoor unit mounted on a frame extension of the chassis. A central air handler conditions the indoor air for distribution throughout the home using ductwork. Ducted mini-split systems use inverter-driven compressors and variable-speed fans to optimize performance. The outdoor units are slimmer than conventional systems, improving aesthetics. Mini-split systems are energy efficient, and certain market segments in the industry already use ductless varieties. Their high efficiency and similarity to traditional split systems made them a good candidate to investigate. Multiple brand options exist for ducted mini-splits because they are a mature technology.
- **Nonducted Packaged Heat Pump** is a packaged system that eliminates the need for ductwork, which can be a point of failure. These systems are similar to packaged terminal heat pumps but are new to the market and are energy efficient due to their variable-speed, inverter-driven technology. The product used is a single-zone unit, so one is installed in each thermal zone. The occupants can fully control each unit independently. Product options are limited to a few manufacturers.

Benefits

These factory-complete H&AC solutions include the following benefits:

1. In-plant quality control over the complete H&AC system, including ensuring proper sizing.
2. Eliminating the possibility of mismatched outdoor and indoor components.
3. Ensuring the correct thermostat for the equipment type.
4. Avoiding bottom liner tears due to field installation work.
5. Offering superior energy performance and comfort with variable-speed equipment.

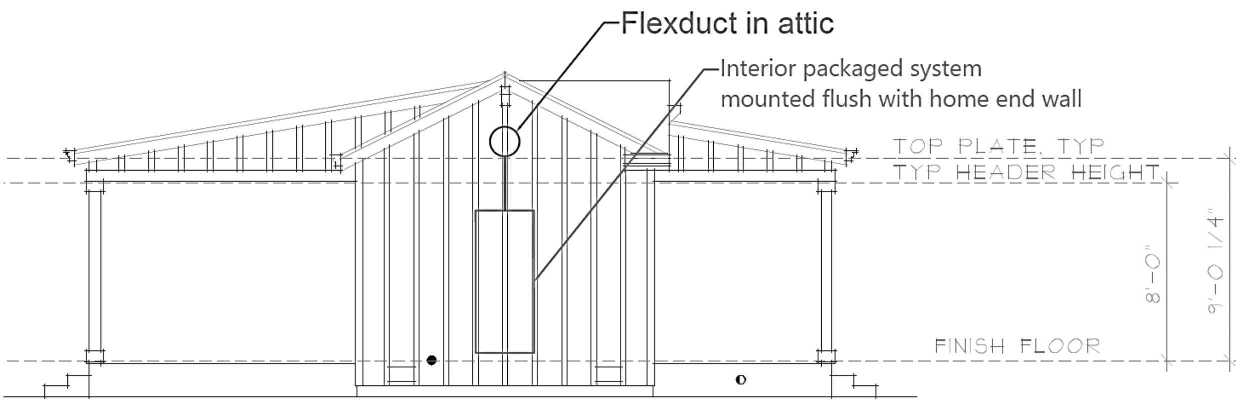
Packaged System (Interior) With Ducted Distribution

Design

Design and Floor Plan Selection. Most of the packaged unitary systems must be on an exterior wall to exchange air and heat with the outdoors. Many years ago, a unitary product was developed that was designed to provide intake air from under the home and exhaust it from the roof (the “Insider” heat pump). However, the concept was abandoned due to technical issues, and a product that can be placed in the center of the home is not currently available. Some packaged unitary systems can condition fresh air from outdoors without the need for additional ductwork and inlet ports for air. This feature can be an advantage for the home to comply with American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 62.1 and 62.2 standards. The fresh air supplies up to 130 cubic feet per minute of outdoor air.

Currently available versions of this system type are preferably installed at the end wall of the home rather than a side wall to provide adequate clearance in the attic to connect to the attic trunk duct. Presently, no similar product has downflow capabilities, but an end-wall location would also be preferable for such a product to connect to an underfloor trunk duct between the I-beams. Exhibit E2 shows an example of adequate attic clearance connecting to an overhead duct.

Exhibit E2. Example of Adequate Attic Clearance for Packaged System Duct Connection

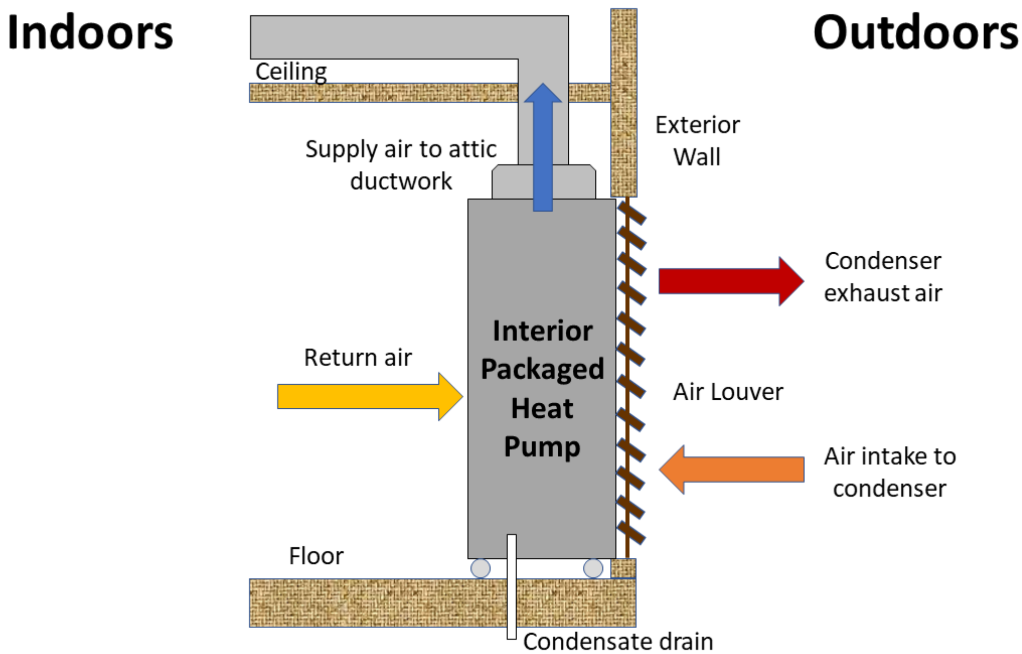


Note: If system is installed on the side wall, ducts may need to be bent to form an “S-shape” duct.

Source: Systems Building Research Alliance

An opening will need to be provided in the wall and a plenum sleeve and louver installed to trim out the opening. Depending on the size of the louvered area, the overall coefficient of heat transmission (U_o value) may slightly increase. Exhibit E3 shows a side view of this system.

Exhibit E3. Schematic of Interior Packaged Heat Pump Installation Adjacent to Exterior Wall



Source: Electric Power Research Institute

Design Approval Primary Inspection Agency Approval

HUD requires heating, ventilation, and air-conditioning (HVAC) equipment to be listed under Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Standard 210/240. Packaged systems may not be listed, which will then trigger the need for an Alternative Construction letter.

Equipment Sizing and Air Distribution. Equipment capacity options may be limited for this type of system. The most common size is 24 one-thousand British thermal units (kBtu) per hour nominal, with some available up to 36 kBtu per hour, which may be insufficient for large homes in some climates. Enhanced insulation can reduce cooling and heating loads. Supplemental electric heat can also be used to increase heating capacity, but it will increase operational costs. To ensure thermal comfort and energy efficiency, Air Conditioning Contractors of America (ACCA) Manuals J and S, or other equivalent methodologies, should be used to size the H&AC system. The equipment should be sized to operate in heat pump mode down to design heating temperatures and use only electric resistance to supplement compressor heating during the coldest hours or during defrosting.

Packaged unitary systems currently on the market are only compatible with overhead ductwork (upflow air). Future models may be available with side discharge, which may be suitable for in-floor duct systems.

Design Tips

- Design the HVAC closet to be adjacent to an end wall, roughly underneath the attic main duct trunk location.
- Select product certified under AHRI Standard 210/240 to avoid needing an Alternative Construction letter.
- Use ACCA Manuals J and S, or other equivalent methodologies, to ensure that the heating and cooling loads can be met and to avoid oversizing the HVAC system.

Available Manufacturers (Representative List)

- Friedrich VERT-I-PAK VHA Series.
- Friedrich VRP® Series.
- Islandaire EZ Series VP.
- General Electric AZ95 Series.
- Ice Air Single Packaged Heat Pump Series.
- Amana AVH Series.
- First Co. SPXB-HP Series.

Construction

Production

Follow manufacturer instructions carefully, and heed the following important quality-check items during home constructions:

- Double-check that the exterior wall opening size is correct and that it is the proper height above the floor.
- Tightly seal joints in the air handler closet (except the free area designated for the return air) to avoid pulling air from building cracks and assemblies.
- Ensure that the free area for air movement (for air return) meets the requirements in the manufacturer's manual.
- Make sure doors are wide enough to move the unit in and out if future replacement is required.
- Provide sufficient clearance above the unit for the duct connection.
- Install a pest screen at the louver to block rodents and insects.
- Check manufacturer's required drain size before installing plumbing.
- Check that the thermostat is compatible with the equipment.

Transportation Protection

The completed homes must be able to be shipped hundreds of miles without damage. The packaged unitary system may have a built-in mechanism to secure it to the floor or walls before shipping. The entire system is inside the thermal envelope, so it is less prone to vandalism and damage during transport. The louvered opening should be securely covered at the exterior to prevent water entry during transport and storage.

Ducted Mini-Split Heat Pump, Frame-Mounted Outdoor Unit

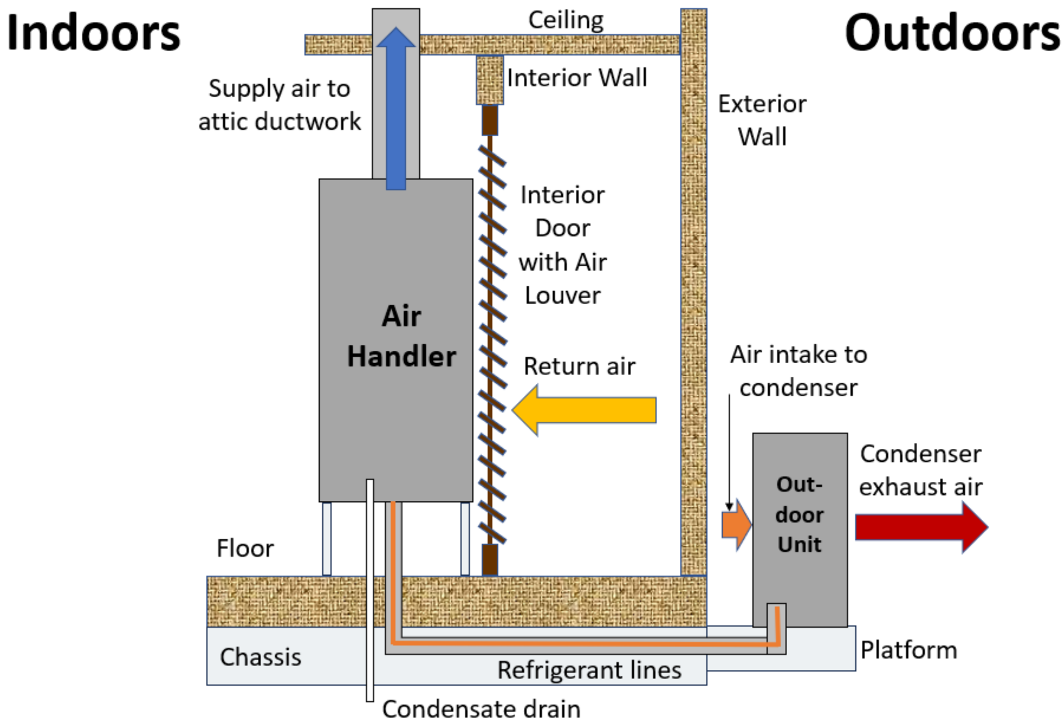
Design

Design and Floor Plan Selection. A key element of this system is the factory-fabricated exterior platform to mount the heat pump's outdoor unit. It requires precision in fabrication so that the outdoor unit can be securely anchored to the platform. Because the platform will have to withstand the weight of the unit and vibration during transportation, the bracket material, the structure, and the location to attach the platform to the home chassis frame must be carefully designed. One of two methods can generally be used to connect the brackets to the chassis frame—bolting or welding. The bolted option is preferable for a temporary setup for which, after home installation, the platform is removed and placed on the ground or other lower pad or platform. This configuration may be advantageous where the site is uneven and an outdoor unit mounted high on the end of the home is aesthetically unappealing. If this method is chosen, however, the refrigerant tubing and the wiring that connects the heat pump's indoor and outdoor sections must be provided with additional length so that the outdoor section can be lowered to ground level after home installation. This additional length must be secured during home shipment, and it is especially important to minimize tubing vibration during transport to diminish the risk of a refrigerant leak.

The ducted interior air handler can be installed almost anywhere in the home within the limitation of the maximum refrigerant line run from the outdoor unit to the interior unit, which is generally 25 to 50 feet. The lines should avoid sharp bends and crossing over the main rails, which are the lowest point of the chassis and could make the lines more susceptible to road damage.

The outdoor unit must generally be installed on the end wall of the home due to transportation width limitations. Exhibit E4 shows a side view of this system.

Exhibit E4. Schematic of Exterior Extension Frame-Mounted Ducted Mini-Split Heat Pump



Source: Systems Building Research Alliance

Design Approval Primary Inspection Agency Approval

HUD requires HVAC equipment to be listed under AHRI Standard 210/240. Most mini-split heat pump systems will be listed under this standard. Therefore, an Alternative Construction letter may not be needed.

Equipment Sizing and Air Distribution. Central air handler mini-split systems come in multiple sizes from which to choose. System capacity ranges from 24 to 48 kBtu per hour, which can sufficiently cover most manufactured home sizes and climates. To ensure thermal comfort and energy efficiency, ACCA Manuals J and S, or other equivalent methodologies, should be used to size the HVAC system. Ducted mini-splits typically do not need electric resistance backup elements.

Many ducted mini-split systems on the market can be converted into the downflow configuration for underfloor ductwork. The default configuration will be upflow, but a conversion kit can convert the vertical indoor air handler to downflow.

Design Tips

- Design the floor plan to maximize the distance between bedrooms and the outdoor unit to reduce sound and vibration transmission to these rooms.

- The outdoor unit should be mounted on an end wall to facilitate transportation.
- Consider the maximum refrigerant line run between outdoor and interior units for the selected product, considering vertical and horizontal bends. These heat pumps often come precharged with refrigerant that is sufficient up to a maximum refrigerant line length (e.g., 25 feet). If the refrigerant line length exceeds the maximum allowed, additional refrigerant must be added to the system during factory installation.
- Locate the outdoor unit where the refrigerant lines can run smoothly without sharp bends and to avoid the need to cross over the main rail.
- Locate the outdoor unit away from windows to minimize the aesthetic effect on the final site.
- Select a product certified under AHRI Standard 210/240 to avoid the need for an Alternative Construction letter.
- Use ACCA Manuals J and S, or other equivalent methodologies, to ensure that the design heating and cooling loads can be met and to avoid oversizing the HVAC system.

Available Manufacturers (Representative List)

Dozens of companies manufacture ducted mini-split heat pumps. Some of the more popular brands are—

- LG Electronics.
- Mitsubishi.
- Fujitsu.
- Daikin.

Construction

Production

Follow manufacturer instructions carefully, and consider the following design tips during home construction:

- Check that the exterior platform is level and provides sufficient clearance between the home and the outdoor unit per the manufacturer's requirements.
- Ensure that the platform is relatively stiff. This reinforcement may require additional mounting brackets.
- Rubber pads can be placed on the extension platform to reduce vibration transmission to the frame and home.
- Sufficiently sized PVC pipes can protect the refrigerant lines under the home, especially during home transport, and sealing the ends of the pipe (e.g., with spray foam) is recommended to prevent water or vermin infiltration.

- Tightly seal joints in the air handler closet, except the free area designated for the return air, to avoid pulling air from building cracks and assemblies.
- Ensure that the free area for air movement (for air return) meets the requirements in the manufacturer's manual.
- Provide sufficient clearance above the indoor air handler for the duct connection.
- Check manufacturer-required condensate drain size before installing plumbing.
- Check that the thermostat is compatible with the equipment.
- Securely fasten the indoor unit to the floor and walls before shipping, using the manufacturer-provided mechanism if present or by other means if not.

Transportation

The completed homes must be able to be shipped hundreds of miles without damage. The outdoor heat pump unit must be fully secured to the extension platform and be covered by a protective material, such as sturdy cardboard or carpet scrap, during transportation. If the refrigerant lines are underneath the home, fully protect them from road debris by enclosing them in PVC pipe secured to chassis cross-members with steel straps.

Nonducted Packaged Heat Pump

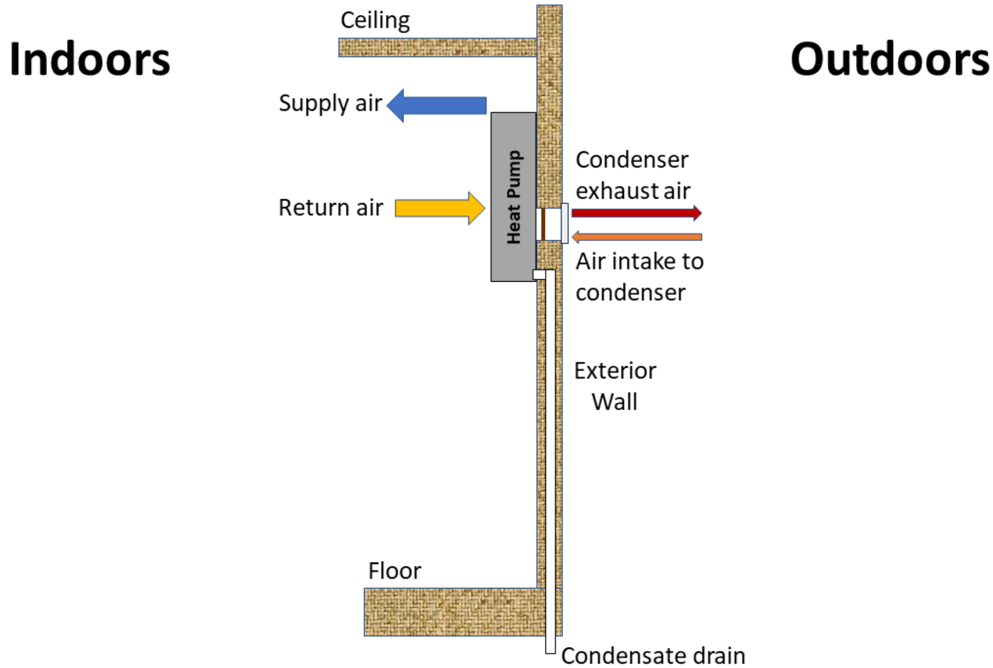
Design

Design and Floor Plan Selection. The nonducted packaged heat pump (also known as a single package vertical heat pump, or SPVHP) is a completely self-contained system that does not require distribution ductwork or refrigerant lines. Changing the home floor plan to accommodate this system is not necessary because one unit is installed in each zone as long as an exterior wall is available.

Some SPVHPs have multiple mounting options and can be installed high or low on the wall or even perpendicular to the exterior wall with the addition of a side wall conversion kit. Mounting high on the wall provides flexibility for furniture placement. However, the touchscreen controller will become inaccessible, requiring the use of a remote control or smartphone application. If mounted low on the wall, placing furniture becomes more restricted because the supply air blows from the front of the unit and should not be blocked.

Each heat pump unit will require a pair of round openings (6 to 10 inches in diameter) in the exterior wall to exchange air with the outside, a condensate drain, and a power connection. Exhibit E5 shows a side view of this system.

Exhibit E5. Schematic of Interior Nonducted Packaged Heat Pump Installation Adjacent to Exterior Wall



Source: Systems Building Research Alliance

Design Approval Primary Inspection Agency Approval

An Alternative Construction letter may be required to install the nonducted packaged unit because of abridged AHRI certifications. For example, the Ephoca All-in-One (AIO) is certified to AHRI 390 instead of HUD's requirement of AHRI Standard 210/240. The Alternative Construction letter for the demonstration home took 3 months to obtain from HUD. Future Alternative Construction letters may take less time now that HUD and the industry have experience with the product type.

Equipment Sizing and Air Distribution

Equipment capacity options are limited for this type of system. The single-zone system has sufficient capacity for most climate zones; however, it will likely be oversized for bedrooms. For example, the Ephoca AIO-rated capacity is 8.1 kBtu per hour for heating and cooling; with the addition of a resistance heating element, it increases to 14 kBtu per hour for heating.

Design Tips

- Design floor plans so that the unit will be on the exterior walls (for air exchange) in each zone.
- Determine if the heat pump should be mounted high or low on the wall.

- Select an exterior louver from the list of louvers approved by the heat pump manufacturer.

Available Manufacturers (Representative List)

- Ephoca.
- Wythe Air.
- Ice Air.
- Olympia Splendid.

Construction

Production

Follow manufacturer instructions carefully, and heed the following important quality-check items during home construction:

- When moving the unit, make sure it is kept in an upright position at all times.
- Ensure that the unit is installed level on both horizontal and vertical axes.
- Seal around exterior louvers and interior sleeves to limit infiltration.

Transportation

The nonducted packaged system should be completely secured and installed before shipment. Therefore, no additional transportation protection is needed. The entire system is inside the thermal envelope, so it is less prone to vandalism and damage during transport. Securely cover the louvered opening at the exterior to prevent water entry during transport and storage.

Commissioning

Testing and Tuning Performance

Commission the heat pump to ensure that it is running as intended. If power can be connected to the unit, complete the following checks before shipment:

- Power it on and off.
- Test all controls.
- Make sure that fans and compressor operate and do not produce strange or excessive noise.
- Ensure that airflow is as expected in all settings at both supply and returns and through louvers.
- Check that the equipment's automated self-check does not produce errors.
- Confirm cooling and heating operation (ambient conditions allowing).
- Confirm that supply air temperature measures are as expected.

Homeowner Information

Consider providing the following information to homeowners.

Making the Most of the Heating and Cooling System

Adjustments to controls and settings can improve comfort and energy performance.

- Adjusting fan flow rates can help optimize comfort and may be done once seasonally or whenever needed.
- Heat pump fan speed can influence comfort by affecting the dehumidification capacity of the heat pump. Lower speeds generally will dehumidify more thoroughly.
- Fan speed also affects air mixing within the room. Increasing fan speed will improve mixing air in the main space and reduce temperature stratification.
- Higher heat pump fan speeds can also increase heat pump efficiency by decreasing temperature differences across the heat exchanger.
- Heat pump fan speed and vane direction can reduce local comfort if air blows directly on a sitting area, for example.

Heating and Cooling System Maintenance

Regular maintenance is important to the success of high-performance heating and cooling equipment. Follow these guidelines for ongoing maintenance.

- Clean (if appropriate) or replace the heat pump air handler filters.
- Dust from the home may build up on the supply and return grilles. It can be vacuumed or wiped off periodically.
- Keep the area around the exterior louver clear of foliage and debris to ensure good airflow.
- See equipment manufacturers' manuals for additional equipment-specific maintenance needs.

Appendix F. Commercial Guideline for Manufactured Homes

Introduction

This document provides guidance on commercializing heating and air-conditioning (H&AC) systems specifically designed to be installed entirely within the manufactured home production facility. The document provides actionable guidance for business managers, retail staff, and manufacturers based on three prototyped homes with plant-installed H&AC systems. The recommendations cover business relationship setup, strategies for minimizing cost, and equipment servicing of these H&AC systems. Homes built using these systems may also qualify for the ENERGY STAR Certified Manufactured Home and the Zero Energy Ready Home programs. This commercial guide seeks to help home manufacturers successfully transition to plant-installed H&AC systems.

Factory-Complete Heating and Air-Conditioning Solutions

This guideline identifies barriers to plant-installed H&AC equipment approaches ingrained in common practice in the manufactured housing industry and suggests ways to overcome them. These barriers were identified through discussions with home manufacturers and retailers.

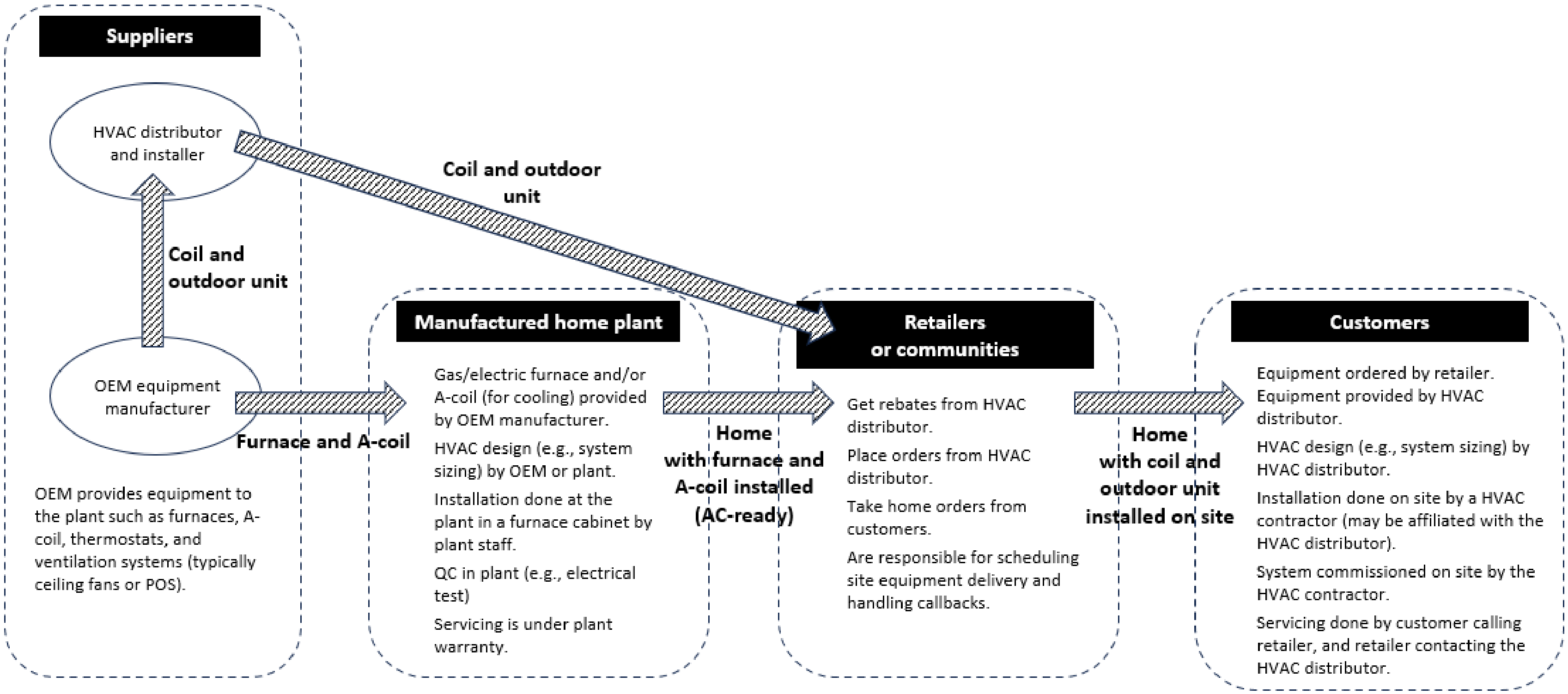
Business Relationships

- **Issues.** Responsibilities for H&AC selection, design, and installation currently are split—home manufacturers install heating (e.g., electric resistance or natural gas furnaces), air distribution, and ventilation systems in the plant, and a heating, ventilation, and air-conditioning (HVAC) distributor or local HVAC contractor selects cooling (or heat pump) equipment and installs it at the home site. Having multiple entities responsible for different processes can increase costs to customers, increase the risk of quality problems, and complicate program compliance procedures, such as collecting information to verify that compliant equipment is installed.
- **Suggested Improvements.** With a plant-installed H&AC system, full responsibility for the equipment shifts to the home manufacturer, and the process is simplified. Key parts of the current business relationship and installation process are likely to change (exhibit F1). Exhibits F2 and F3 diagram the current and future states of business relationships.

Exhibit F1. Key Process Changes Associated With Plant Completion of Heating and Air-Conditioning Systems

Process	Responsible Party		Associated Process Changes
	Now	Future	
Sell home, including heating, ventilation, and air-conditioning (HVAC) equipment	Retailer	Retailer	• Retailer buys HVAC equipment from and coordinates sale only with home manufacturer. • Home manufacturer needs to set up to take orders for cooling equipment and heat pumps, including the entire system in the stocking, ordering, and design process.
HVAC system design	Split: home manufacturer and HVAC distributor	Home manufacturer	• Home manufacturer will take responsibility for designing the cooling and heat pump system, integrating the entire HVAC design process and coordinating all components.
Cooling and heat pump equipment stocking	HVAC distributor	Home manufacturer and HVAC distributor	• All HVAC parts will be ordered and stocked by the home manufacturing plant. The HVAC distributor will no longer supply cooling and heat pump equipment to the site but may provide it to the plant.
HVAC system installation in home	Split: home manufacturer and HVAC installer	Home manufacturer, with HVAC installer support in some cases	• Various home production process changes will have to be made, as described in the final project report. • Home production staff will need to bring in trained and licensed outside technicians to perform specialized tasks, such as installation, charging, and testing of refrigerant lines.
Complete home installation at site	HVAC installer	None (possible limited role of technician)	• Elimination of most or all the HVAC site installation steps.

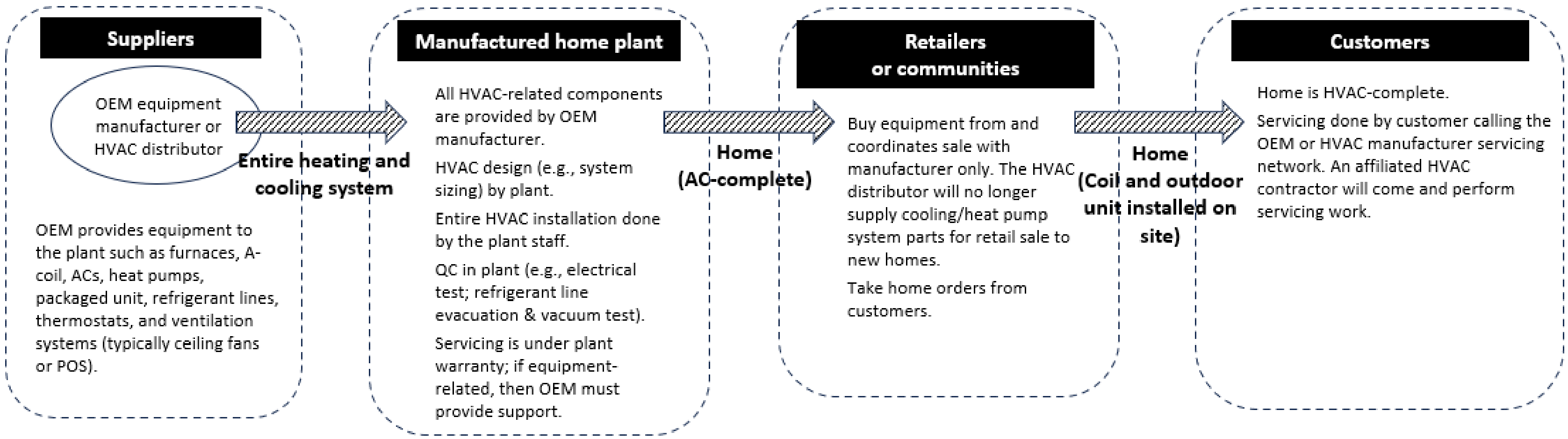
Exhibit F2. Current-State Business Relationship



AC = air conditioning. HVAC = heating, ventilation, and air-conditioning. OEM = original equipment manufacturer. POS =positive pressure system. QC = quality check.

Source: Systems Building Research Alliance

Exhibit F3. Future-State Business Relationship



AC = air conditioning. HVAC = heating, ventilation, and air-conditioning. OEM = original equipment manufacturer. POS = positive pressure ventilation system. QC = quality check.

Source: Systems Building Research Alliance

For the home manufacturer, the inventory will change. Manufacturers will have to order and stock additional H&AC components in the plant. Changes to HVAC system design will require that manufacturers properly size the cooling capacity and design placement of the outdoor unit (if any). Changes to production will require that manufacturers install the entire system in the plant and, preferably, properly quality check the system in the plant to ensure system installation integrity.

The retailer will no longer have to coordinate with the HVAC distributor or contractor to schedule equipment deliveries. Service calls will be directed to the plant or HVAC equipment provider (original equipment manufacturer or HVAC distributor), depending on the relationship the manufacturer sets up. The factory home price will include the entire H&AC system.

- **Results.** The revised arrangements ideally simplify business relationships and improve the overall efficacy of the processes from inventory through service.

Affordability

- **Issue.** Plant-installed H&AC systems can cost more than traditional split systems.
- **Suggested Improvements.** Depending on the H&AC equipment brand and system chosen, the cost may vary. Plant-installed H&AC systems can be marketed as air-conditioning-complete homes. Heat pumps may cost more upfront, but energy savings from the higher efficiency can offset some of the upfront fees. With outdoor components, the plant purchases in bulk; plants may be able to reduce costs from suppliers. With retailers no longer needing to coordinate with the HVAC distributors, they may be able to lower costs as well. Moreover, labor costs in the factory should be less than contractor costs in the field once plants refine and optimize the process.
- **Results.** The plant-installed H&AC solution has the potential to lower costs and provide better performance if well planned.

Equipment Service

- **Issues.** Lacking commercial ties to the H&AC installer, home manufacturers currently have few options for enforcing quality installation procedures. The fragmented installation process creates consumer confusion when repairs are needed because determining the responsible party whose warranty covers the repair work can be difficult.
- **Suggested Improvements.** HVAC contractors are less inclined to provide service for systems they did not install. One way to overcome this challenge is to leverage the HVAC

equipment manufacturer's national service network. National coverage is crucial because manufactured homes are shipped throughout the United States. To ensure that service is available, plants should partner with H&AC manufacturers with a robust service network.

Homeowner education can also help reduce the need for service calls. Home manufacturers, who will be in charge of system design and selection, can provide detailed guidance to homeowners, including operational tips and simple troubleshooting guides.

- **Results.** Shifting to plant-installed H&AC systems can lead to reduced need for service because of the quality control in the plant. An established service network can facilitate tracking issues better, which changes to design or installation procedures can then address.

Energy Program Compliance

- **Issues.** Documenting heat pump information (model number and brand) and providing evidence that a heat pump has been purchased can be a painful process. The current ENERGY STAR Version 2.0 and the U.S. Department of Energy (DOE) Zero Energy Ready Home (ZERH) for Manufactured Home V1 programs offer credits for heat pumps. However, most heat pumps are installed in the field, and verifying the purchase and installation of compliant equipment is not straightforward. If home manufacturing plants cannot properly document heat pumps, they risk losing eligibility for valuable tax credits on those homes.
- **Suggested Improvements.** If the entire heat pump is installed in the plant, it will be easy to verify that it is installed and to report details to the Environmental Protection Agency, DOE program managers, and quality assurance providers.
- **Results.** Installing H&AC systems in the home manufacturing plant is expected to result in a simple and more reliable process for ensuring and documenting compliant heat pump installation on ENERGY STAR and ZERH homes for tax credit purposes.

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