Factory Complete Heating and Cooling Solutions for Manufactured Homes

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Abstract

The manufactured housing industry could benefit from plant-installed, commercially competitive, and fully integrated heating and cooling solutions. This study explores two hardware integration and product configuration options that improve home performance and quality. It also explores changes to commercial arrangements, including the equipment distribution, inventory, and servicing necessary to align commercial interests. A production facility in southern Georgia integrated two system options into newly constructed manufactured homes: a packaged unitary system and a ducted mini-split heat pump. The findings demonstrate that both systems can be successfully implemented in the home production facility and operated as intended after transport. The packaged unitary system can be installed without additional work and skills. The ducted mini-split system requires more training and labor to install, but it costs less and has other benefits. By piloting these alternative heating and cooling systems, this study is a stepping stone for manufacturers looking for options to improve energy performance while reducing upfront cost.

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. One explanation for the lack of change is that the Manufactured Home Construction and Safety Standards (MHCSS), commonly referred to as the U.S. Department of Housing and Urban Development "HUD Code," has changed little for many years and mandates energy standards less stringent than the state codes (Talbot, 2012). In some cases, these 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 components of the heating and cooling system in two stages, with the home

manufacturer installing some parts, such as heating and some distribution components, in the factory and a technician installing other parts, such as cooling and parts of the distribution system, in the field (Dentz and Zhu, 2021). According to interviews with multiple industry experts, this bifurcation can result in reduced system operating efficiency, service issues, poor comfort, and increased homeownership costs. This article reports on a project that reimagines and reengineers the design and fabrication of the heating and cooling system, with all components installed in the plant under the existing regulated quality control regime.

The project concept evolved from discussions among industry experts asked to identify meaningful research that addresses the complex challenge of improving performance and affordability at the same time. The solutions and innovations are built on existing industry practices and promising technologies not currently used in the industry. The authors conducted a vetting process that required collaboration and partnerships with stakeholders, resulting in a list of "best" solutions. The project also builds on recent advances in heat pump technology that were not available previously.

The project aims to accomplish two core industry goals—making homes more affordable on a sustainable basis by lowering energy costs and improving quality. The work will drive down the cost of installing heat pumps, an important energy-efficient technology. Key aspects of the current heating and cooling selection, design, and installation process will likely change as project results are deployed. In the future, the manufacturer will take on most of the equipment installation responsibilities, such as installing the outdoor unit (whether air conditioning or heat pump) and refrigerant line connections, thereby revamping and replacing steps currently under the purview of the HVAC distributor and site technician.[1] Heating and cooling systems pre-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 operation instructions, helping to educate occupants on operations and maintenance needs and recognize the value of heat pumps.

Given the range of options, it is anticipated that regulators will accommodate technology changes in the short term through Alternate Construction letters. If the MHCSS, or HUD Code, restricts the use of a proposed heating and cooling system change, a process will be initiated to propose changes in the regulations through the normal Standards update process. To identify and address such issues preemptively, staff in the HUD Office of Manufactured Housing Standards will be kept abreast of project advances.

These research efforts, led by a team of engineers and marketing professionals and guided by a group of manufactured housing stakeholders, was based on applying an integrated and multidisciplinary approach to heating and cooling system design. The team sought to change deeply ingrained practices in the methods of home production, delivery, and installation. The recommendation included technical changes and new marketing, sales, and service approaches. HUD was the catalyst for bringing together otherwise competing industry members to cooperate to accomplish a common set of goals and to provide publicly available, independently verified results and data. The results provide the basis for improving home quality and energy efficiency.

[1] HVAC = heating, ventilation, and air conditioning.

Problem Statement

It is not uncommon in any industry for best practices to be set as a standard without evolution over time, even when those practices are, in the current environment, ineffective, inefficient, or even counterproductive. Homebuilding is no exception. A glaring example of a practice that has outlived its utility is the installation of the heating and cooling system in manufactured homes. By far, the most common scenario for heating and cooling design (about 90 percent of the roughly 105,000 manufactured homes produced each year) begins with the home manufacturers selecting inventory and installing components of the heating, distribution (typically air ducts), and ventilation systems 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. Experience has shown that fragmenting heating and cooling system decisions and outsourcing installation of important components 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 impacts on affordability (that is, energy costs) and equipment service life.

Performance degradation that results from a fragmented heating and cooling system is neither modest nor uncommon. The following is a partial list of flaws and faults in heating and cooling system performance stemming from a split design and installation process that this article addresses.

- **Oversized Cooling Equipment.** Typically, the HVAC distributor working for the retailer selects cooling capacity, with no input from the manufacturer. The negative consequences of this disconnect are legion—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 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.

- **Mismatched Outdoor and Indoor Components.** Almost all manufactured homes are provided with cooling 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). Mismatched products can lower operating efficiency (often significantly), create comfort issues, exacerbate indoor air quality-related moisture management issues from mismatched cooling products that cannot manage indoor humidity, especially in shoulder seasons,[2] or render the system unable to function, resulting in callbacks and costly equipment

[2] *Shoulder season* is a term referring to non-peak heating and cooling seasons. Spring and autumn are shoulder seasons.

replacements. Data collected from a utility-sponsored rebate program by Systems Building Research Alliance determined that about 10 percent of cooling system components are mismatched (Levy, 2022).

- **Incorrect Refrigerant Line Charge.** Achieving the listed efficiencies requires the technician to install and charge the refrigerant lines properly and the lines to be free of leaks. Lacking formal oversight, site installations may be under- or overcharged. Line charge issues will 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 will dictate the type of thermostat to be installed in the home. It is not uncommon for the manufacturer to install one type of thermostat and for the field technician to install one for a different product type (for example, the manufacturer expects an air conditioning system, but the technician installs a heat pump). The result is extra work, material cost, and, often, reduced functionality and energy waste.
- **Bottom Liner Tears.** 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. 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. 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 manufacturer to address. In the case of the heating and cooling system, the HVAC installer is not directly accountable. This lack of accountability is insidious in two respects. When failures occur, the feedback to the plant is, at best, indirect; as a result, systemic issues are difficult to pinpoint and resolve. Lacking commercial ties to the installer, manufacturers have few options for enforcing quality installation procedures. Fragmenting the installation process also creates consumer confusion when a repair is needed, as determining the responsible party whose warranty covers the repair work is often difficult.
- **Improper Configuration of Fresh Air Intake.** The fresh air intake duct is the ventilation system for many manufactured homes. Typically, the HVAC installer sets the intake position when the cooling coil is added in the field. Improper configuration compromises ventilation. Like other previous examples, the ventilation system is more prone to improper setup when performed outside the plant's quality control process.

Factory-Complete Heating and Cooling Solutions

To explore the potential heating and cooling systems not currently used in the manufactured home industry, the authors surveyed industry stakeholders to identify options for factory-complete heating and cooling solutions, including associated advantages and barriers to their adoption (see appendix). In this first stage of the process, the focus was on identifying options and assessing

technical merits. The project's Technical Advisory Group, consisting mainly of senior engineering staff with leading home manufacturers, provided input for this phase. The authors assessed related market acceptance considerations in interviews with the Marketing and Commercialization Panel, emphasizing costs, servicing, and other business-related criteria.

Key technical considerations from the input of the project Technical Advisory Group follow.

- **Design Flexibility.** Most manufactured homes are either single-wides or double-wides (two sections joined together), and the heating and cooling system 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 downflow ducts, whereas in the South, upflow ducts are sometimes used. Some heating and cooling equipment can accommodate both directions with a conversion kit. Restrictions on the placement of heating and cooling indoor and outdoor components, such as the need to be adjacent to an exterior wall, may limit floor plans for such solutions.

- **Sizing.** Manufactured homes range from less than 800 square feet to more than 2,500 square feet. The heating and cooling capacity range of a heating and cooling system will have to cover these different home sizes in a wide range of climate locations.

- **Efficiency.** Inefficient system operation is a major factor in high energy bills. Improving system efficiency can help homeowners save money.

- **Ease of Installation.** Speed of installation is critical to maintaining the factory production rate. A simpler installation process requires less time and labor. New skills might require additional investment in staff training and tools. The complexity and difficulty of the installation procedure may also increase the risk of system failure due to improper installation. The necessity of any onsite work will add expense.

- **Balanced Air Distribution.** The system must distribute conditioned air evenly across all bedrooms and main living areas.

- **Transportability.** The completed home might have to be shipped hundreds of miles without damage.

- **Testing and Commissioning Procedures for the System.** System testing and commissioning will fall under the plant's purview. The complexity and difficulty of the procedure may require training of new skills and added labor during production and, thus, can increase the cost to customers; however, the in-plant quality control process may reduce service calls. Savings from improved quality and operational efficiency may partially offset the added cost.

- **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 the indoor or outdoor unit should be tolerable for occupants.

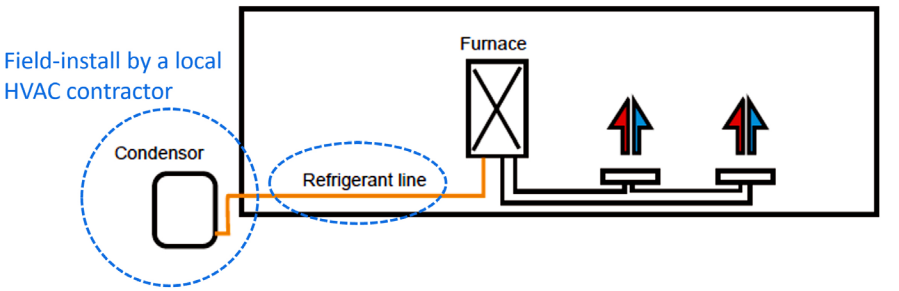
- **Changes to the HUD Standards.** Given the range of technical options under current consideration, technology changes will likely be accommodated in the short term through the application for Alternative Construction letters. If the standards restrict the use of a proposed heating and cooling system 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 Packaged Terminal Heat Pump unit required an Alternative Construction letter because of abridged Air Conditioning, Heating, and Refrigeration Institute (AHRI) certifications.[3]

- **Aesthetics.** The appearance and location of the heating and cooling system must be acceptable to homeowners. The market prefers aesthetics comparable with site-built homes.

Current industry heating and cooling practices consist of installing a gas or electric furnace in manufactured home by the plant, with site-installed cooling components. Air distribution is typically accomplished by placing ducts 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. Cooling components are 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 (exhibit 1). A local contractor performs field installation. As noted previously, this configuration is susceptible to a rash of potential quality and performance failures.

Exhibit 1

Current Typical Heating and Air Conditioning Setup in Manufactured Homes



HVAC = heating, ventilation, and air conditioning.
Source: SBRA, Milestone Report: Identification and Selection of Factory Complete HVAC Solutions

In response, the industry has experimented with other approaches that put the installation of the key heating and cooling system components under the factory's auspices. As a first step in this project, to learn from previous efforts, the authors conducted a survey with industry experts and stakeholders to identify opportunities to advance the most promising practices and select the most promising ideas for further development. The survey and literature search identified the following options for in-plant completion of the heating and cooling system.

[3] Ephoca is certified to AHRI 390 instead of HUD's requirement of AHRI Standard 210/240.

- **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 duct distribution.
- **Type 4.** Packaged unitary system (exterior) with duct distribution.
- **Type 5.** Ductless mini-split heat pump.[4]
- **Type 6.** Ducted mini-split heat pump.
- **Type 7.** Nonducted packaged heat pump.

Short List of Solutions

The Technical Advisory Group finalized the selection of the system options in a meeting that delved into the short-listed options, with the expectation that two to three of the options would be promoted for subsequent development. The discussion helped get every member on common ground and move toward consensus.

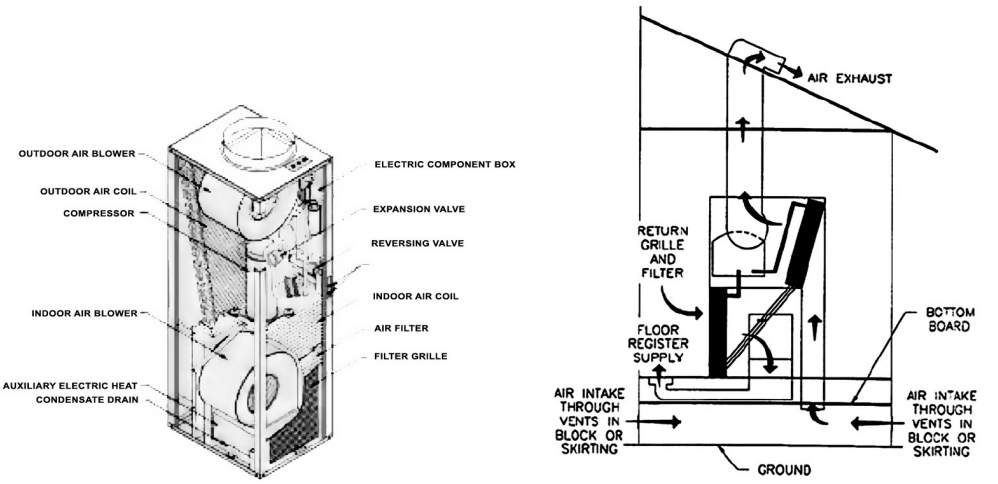
On the basis of the evaluation of the advantages and challenges of each of the seven options identified and with input from the project's Technical Advisory Group, the authors selected three options for continued consideration.

1. **Packaged Unitary System (Interior) with Duct Distribution (Type 3).** Type 3 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, a version of this concept was used in manufactured homes (the "insider" heat pump in 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, that concept was abandoned (Lubliner, Hadley, and Parker, 2007). The Technical Advisory Group was interested in revisiting this approach with today's technology (exhibit 3).

[4] *Mini-split system* here refers to a compact, high-efficiency heat pump with one or multiple indoor heads and one or more outdoor compressors.

Exhibit 2

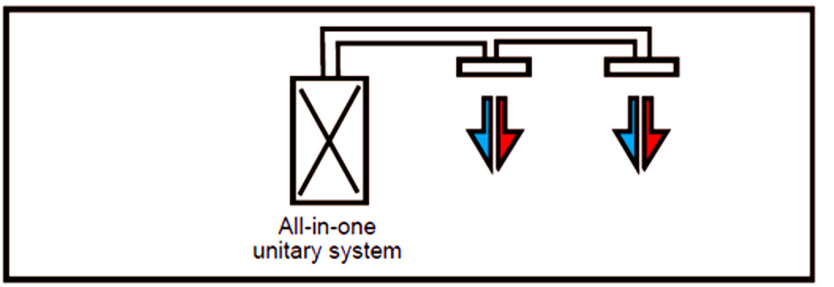
The Insider Heat Pump



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

Exhibit 3

Packaged Unitary System (Interior) with Duct Distribution

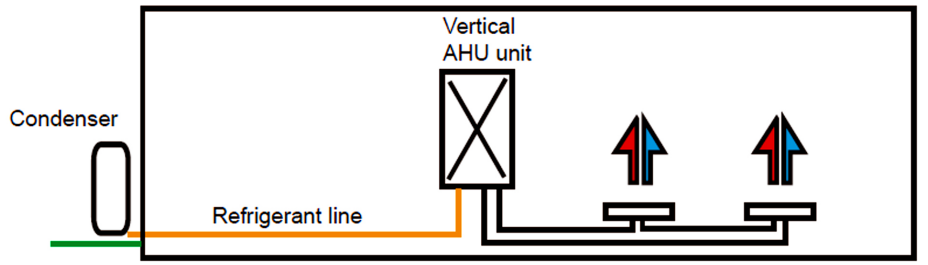


Source: SBRA, Milestone Report: Identification and Selection of Factory Complete HVAC Solutions

2. **Ducted Mini-Split Heat Pump; Compressor Mounted on Frame (Type 1 + 6).** This type is a combination of systems 1 and 6. The decision was made to use a ducted mini-split system instead of the conventional air conditioner or heat pump paired with an indoor electric or gas furnace. Mini-split systems are more energy efficient, and certain market segments in the industry already use them. Efficiency and industry usage made it more valuable to investigate. Ducted mini-split systems use inverter-driven compressors and variable-speed fans to optimize performance. The outdoor units are slimmer than conventional systems, which improves aesthetics (exhibit 4).

Exhibit 4

Ducted Mini-Split Heat Pump with Compressor Mounted on Frame

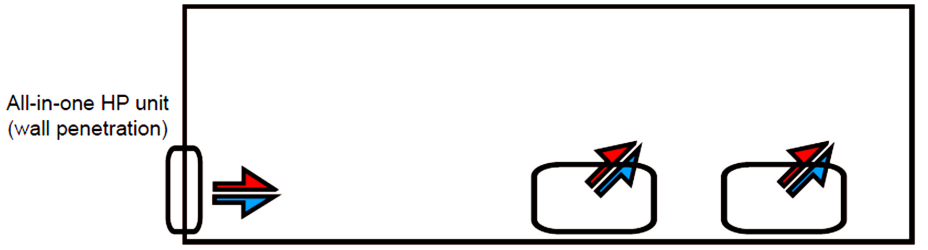


Source: SBRA, Milestone Report: Identification and Selection of Factory Complete HVAC Solutions

3. **Nonducted Packaged Heat Pump (Type 7).** Type 7 is a nonducted system that eliminates the design and installation of ductwork, which can be points of failure in current practice (exhibit 5). The unit to be demonstrated 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



Source: SBRA, Milestone Report: Identification and Selection of Factory Complete HVAC Solutions

Each proposed system was incorporated into at least one home for testing purposes with industry partners.

Prototype Process and Findings

Integrating the full heating and cooling system installation in the manufactured home plant provides an opportunity to rethink current practice and potentially open new revenue opportunities for the factory.

The packaged unitary and ducted mini-split systems were prototyped in March 2022 in partnership with the Clayton Homes plant in Waycross, Georgia. The nonducted packaged system is scheduled to be prototyped in late 2022 at the Karsten-Clayton Homes plant in Sacramento, California; therefore, production processes and findings were not available at the time of this publication.

The heating and cooling systems used are listed as follows.

- Packaged unitary ducted system: Friedrich, model VRP36K10.
- Ducted mini-split heat pump: LG, model LUU249HV (outdoor) and LVN241HV4 (indoor).
- Nonducted packaged heat pump: Ephoca, model DP91HDSO.

The following section discusses, for each system, the added work to home production, ease of system installation, short-term performance evaluation, transport to a site, servicing arrangements, and cost.

Packaged Unitary System

A high-efficiency packaged unitary heat pump was installed in a double-section home with an air grille on an exterior wall (Friedrich VRP36K10) at the Clayton Homes plant in Waycross, Georgia.

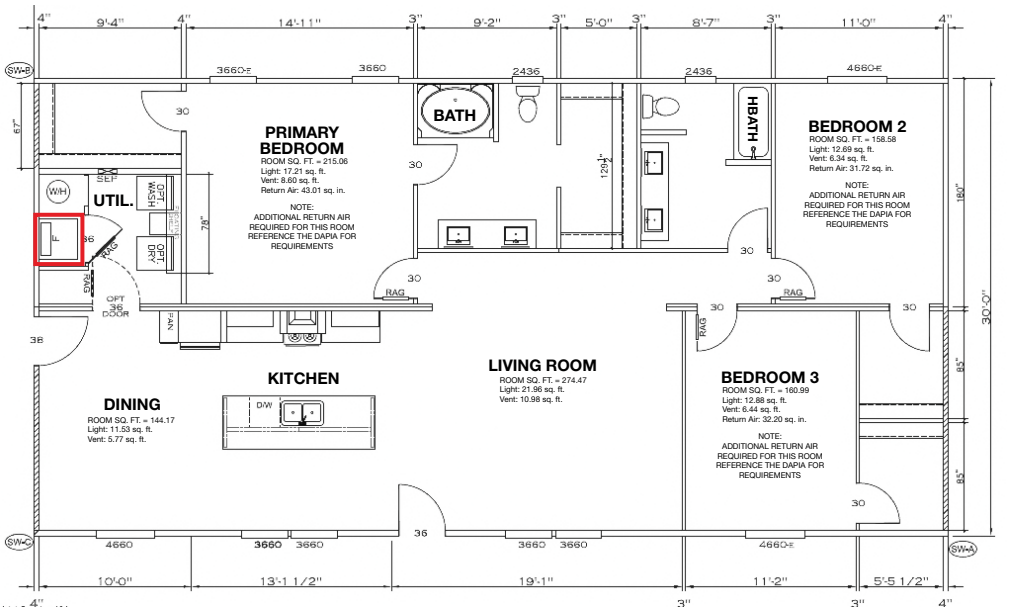
Implementation Process

The packaged heat pump must be located at an exterior wall to exchange air and heat with the outdoors. The end wall of the home is preferable to a side wall to provide adequate clearance in the attic for connection to the attic trunk duct. A rough opening must be provided in the wall and a plenum sleeve and louver installed to trim out the opening (exhibit 6). The Uo value will slightly increase (0.3 percent) due to the home's louvered area (about 12 square feet).[5]

[5] Per the Restoration Dictionary, "The 'Uo value' is the overall coefficient of heat transmission of the manufactured home based on the respective thermal zone location and an indoor design temperature of 70° F, and is defined in units of BTU/(hour)(square foot)(°F)."

Exhibit 6

Floor Plan of the Double-Section Home with Friedrich VRP Heat Pump



Source: Clayton Homes

The packaged unit is then connected to the overhead ductwork and wired to the electrical panel, the condensate line connected to the heat pump, and the unit connected to a wall-mounted thermostat (exhibit 7).[6] No transport protection measures are needed because the unit is fully secured in place and inside the thermal envelope. The entire system is within the thermal envelope; thus, it is less prone to vandalism and floods (exhibit 8).

[6] Currently, only upflow air configuration is available so this packaged unit can be used for homes with attic ducts but not under-floor ducts.

Exhibit 7

Construction of the Exterior Wall Opening

Source: SBRA, Milestone Report: Factory Construction Process and Results

Exhibit 8

Final Setup of the Friedrich Unit

Source: SBRA, Milestone Report: Factory Construction Process and Results

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, through which it exchanges air and heat with the outdoors. Thus, the only additional work required is to provide an exterior wall rough opening and install a sleeve and louver to cover the opening. A drain pan and drip ledge are equipped in the unit to plumb any excess water driven from wind, rain, and ice through the louver.

2. **Does Not Require an Alternative Construction Letter.** An Alternative Construction letter is not required. Per HUD Code 3280.703, the AHRI 210/240 listing (for the single-packaged air-source heat pump) held by this product is compliant. This system is mandated to use low-global warming potential refrigerants starting in 2025.

3. **Aesthetics.** This system will have a flat grilled louver on the end wall. It does not have an outdoor unit that is high up on the wall, which the customer disliked.

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, of their 10 floor plan designs, only 1 design could accommodate the packaged unit installation without significant modification.

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

3. **Narrow Capacity Range.** The maximum capacity is approximately 3 tons for the packaged system, which can be too small for homes larger than the prototyped double-wide home (1,800 square feet) or homes in cold climates. The average multisection home built in 2021 was 1,794 square feet. Assuming that 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 is a worse-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, it is not an ideal solution from an efficiency standpoint. Improving the thermal envelope Uo value might be a better way of mitigating the heating load.

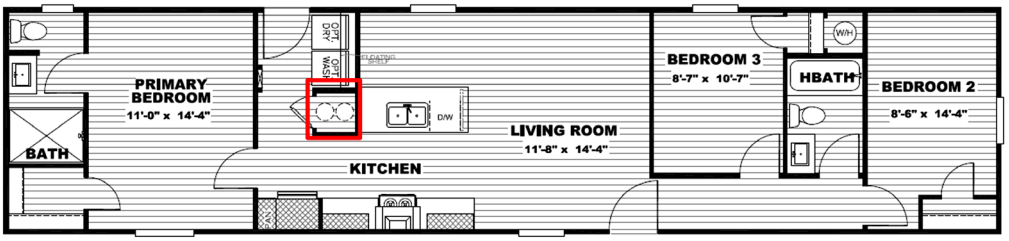
4. **Higher Price.** Although easier installation means less labor, the equipment is more expensive than a standard split system (a roughly 40- to 50-percent increase in equipment cost).

Attic-Ducted Mini-Split Heat Pump

A high-efficiency split heat pump was installed in a single-section home with outdoor portion mounted on a home chassis extension and the air handler located in an interior closet (LG LV241HV4) at the Clayton Homes plant in Waycross, Georgia (exhibit 9).

Exhibit 9

Floor Plan of the Single-Wide Home with LG Ducted Mini-Split Heat Pump



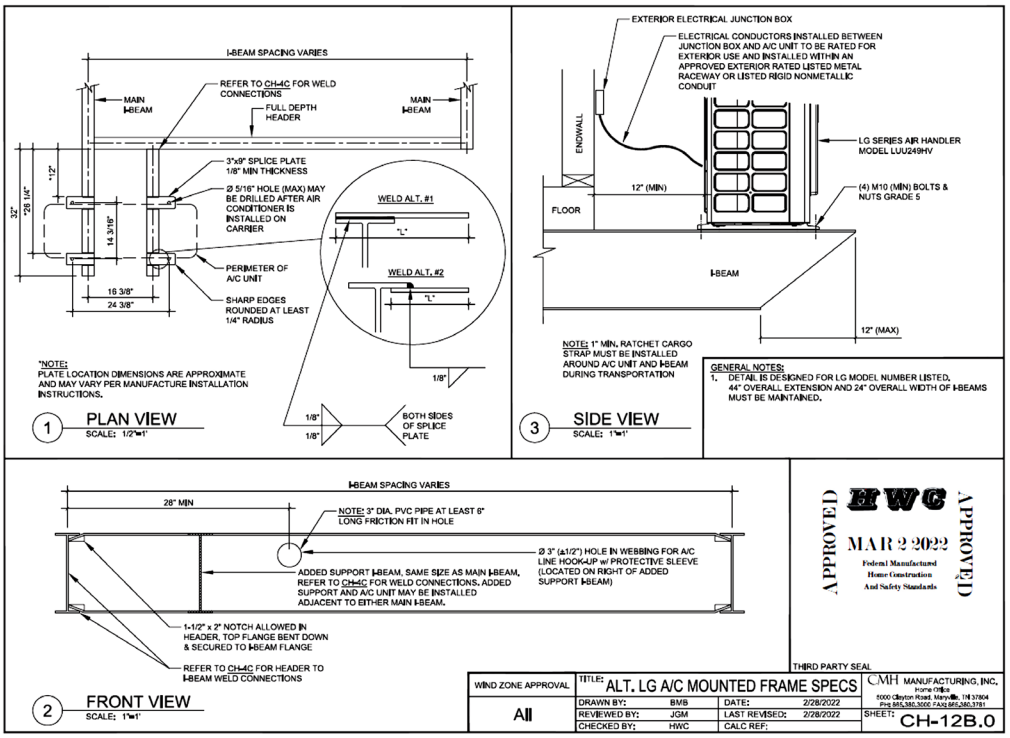
Source: Clayton Homes

Implementation Process

To securely mount the outdoor unit to the exterior of the home, a metal frame was welded to the home chassis. The design was based on Clayton's other mount-on-frame projects (mostly for mini-split systems) and adjusted to the dimensions of the LG system. This redesign had to be submitted to the Design Approval Primary Inspection Agency—Hilborn, Werner, Carter & Associates, Inc. (HWC)—for approval (exhibit 10).

Exhibit 10

Frame Extension Design Approval

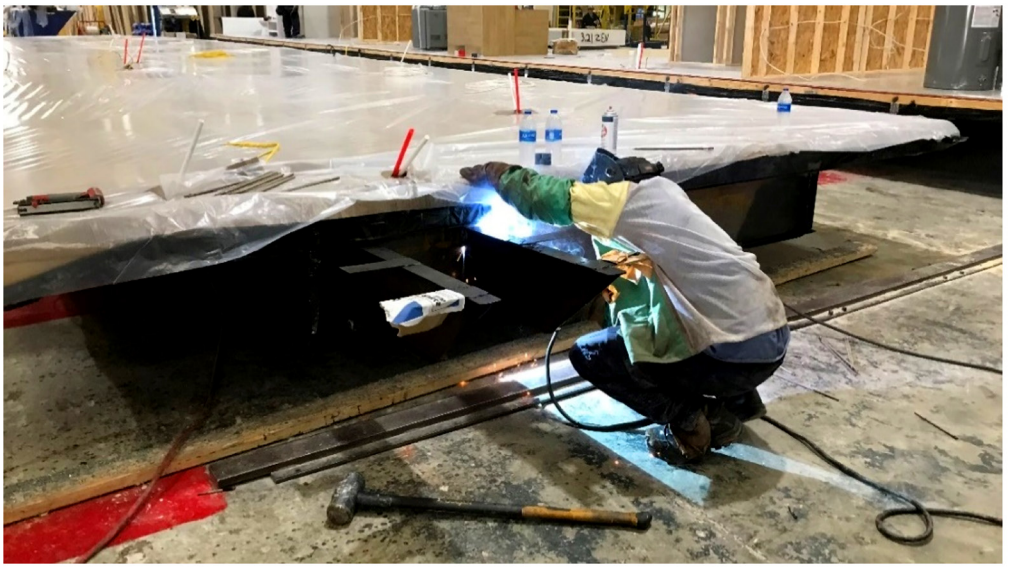


Source: Clayton Homes

An I-beam header was installed on the rear of the home spanning between the main I-beams, and two metal plates were welded to the header (exhibits 11 and 12). A 4-inch hole was punched through the rear header to run a polyvinyl chloride, or PVC, pipe to protect the refrigerant line. The pipe is 4 inches in diameter and runs from the floor under the indoor unit to the outdoor unit.

Exhibit 11

Welding Frame Extension to Rear Header for the LG Outdoor Unit



Source: SBRA, Milestone Report: Factory Construction Process and Results

Exhibit 12

Four-Inch PVC Pipe Protection for the Refrigerant Line Set for the LG System

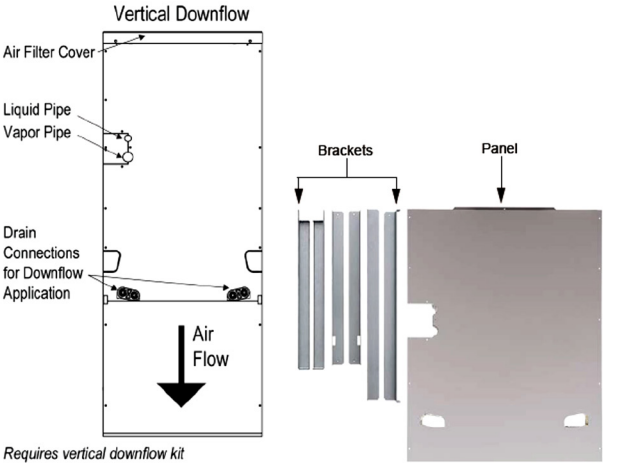
Source: SBRA, Milestone Report: Factory Construction Process and Results

The indoor air-handling unit (AHU) was then connected to the overhead ductwork. The prototype home has upflow air ductwork, but the vertical AHU can also be converted to serve ducts under the floor (exhibit 13). The outdoor unit was then wired to the electrical panel. The indoor unit gets power from the outdoor unit. Finally, the condensate line was connected, and the AHU was wired to a wall-mounted thermostat. After securing the outdoor unit to the platform and connecting the refrigerant line set to the ports, a leakage and evacuation test was performed (exhibit 14). Because the line length exceeded the precharged refrigerant length maximum, a small amount of additional refrigerant was added.[7]

[7] For the prototyped LG unit, the outdoor unit holds a precharged refrigerant volume enough to run up to 24.6 feet.

Exhibit 13

LG Heat Pump Air Handler Downflow Configuration and Conversion Kit



Source: LG Vertical Air Handling Unit Downflow Conversion Kit Installation Manual

Exhibit 14

Refrigerant Line Leakage Test of LG Heat Pump

Source: SBRA, Milestone Report: Factory Construction Process and Results

Benefits

1. **Great Energy Performance.** The efficiency of the ducted mini-split system is superior to the standard split system heat pump that the plant typically uses (SEER 14, HSPF 8.2). The variable-speed LG unit has a SEER of 18 and HSPF of 10 for a 3-ton unit, and a SEER of 19.5 and HSPF of 11 for a 2-ton unit. Ducted distribution, however, reduces efficiency and capacity somewhat compared with ductless units.

2. **Does Not Require an Alternative Construction Letter.** An Alternative Construction letter was not required for the LG unit. Per HUD Code 3280.703, the AHRI 210/240 listing is acceptable for the air-source heat pump. This system is mandated to use low-global warming potential refrigerants starting in 2025.

3. **Quiet.** The indoor AHU unit provides a very quiet operation of about 50 A-weighted decibels (dBA) compared with a traditional furnace air handler (61 to 68 dBA). The U.S. Environmental Protection Agency (EPA) identified an average 24-hour exposure limit of 45 dBA for indoor residential areas to provide comfort and protect the health of occupants (EPA, 1974).

4. **Floor Plan Design Flexibility.** The ducted mini-split unit offers more flexibility on floorplan designs. The 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.[8] However, if additional refrigerant is not added to the system, the lines can only run a limited distance (about 25 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 ($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 parts and materials that are required. Additional tools are necessary to complete those tasks (for example, a pressure gauge and a 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, higher outdoor units are typically less prone to floods, winds, and vandalism.

[8] The LG outdoor unit that was installed can reach a maximum length of 164 feet.

Design and Commercial Practice Changes

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

Current Commercial Setup

The current commercial setup associated with heating and cooling 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 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 coil and outdoor unit. These affiliated contractors are also responsible for future servicing if the outdoor unit fails. Use of the alternative heating and cooling systems that are fully installed in the plant will require commercial arrangement and business relationship changes, as the following section describes.

Current State

Two major paths to selling a manufactured home exist: via retailers or via manufactured housing communities. In both scenarios, the HVAC distributor, retailer, or contractor plays a critical role in providing, installing, and servicing the outdoor equipment (and coil). For servicing, the homeowner or resident calls the retailer, and, depending on the type of system failure, the retailer finds the right party to service the system.[9] The following is a list of parties responsible for different activities of the heating and cooling processes.

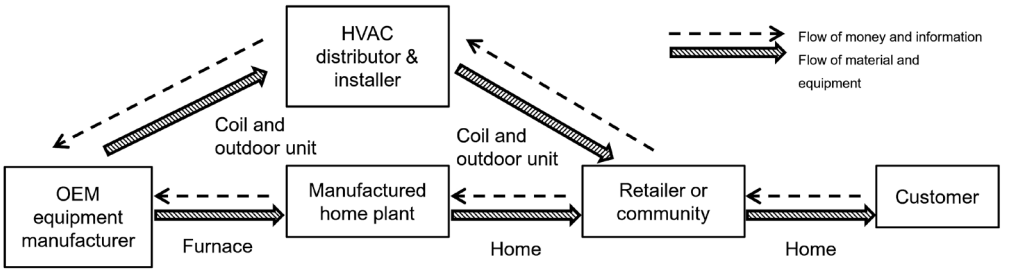
- Distribution of equipment: Original equipment manufacturer (OEM) (both indoor and outdoor); HVAC distributor (outdoor).
- Equipment stocking: Plant (indoor); HVAC distributor (outdoor).
- Installation: Plant (indoor); local HVAC contractor (outdoor).
- Service, warranty, and repair: Local HVAC contractor.

The diagram in exhibit 15 captures the current state of financial relationships in the heating and cooling processes for homes in scattered lots and communities. The OEM sells some equipment to the manufactured home plant and the balance to an HVAC distributor. These parallel streams recombine at the site when the retailer or community purchases them and they are delivered to the customer.

[9] An indoor unit is the plant's responsibility, and an outdoor unit and coil are the HVAC distributor's responsibility.

Exhibit 15

Current State Model (Scattered Lot and Communities)



HVAC = heating, ventilation, and air conditioning. OEM = original equipment manufacturer.
Source: SBRA, Milestone Report: Cost Assessment Report

Future State—Full Heating and Air Conditioning System Installed by the Plant

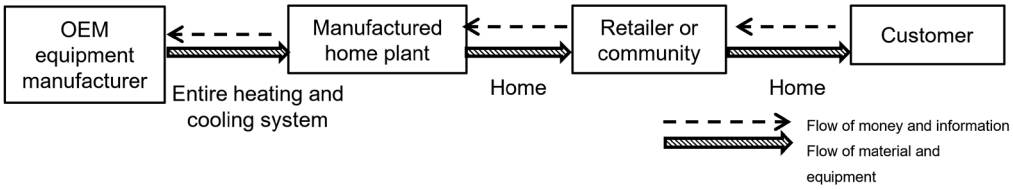
In the future, most of the responsibilities will be moved to the plant. All heating and cooling components would be provided directly to the plant. The in-plant quality control process may reduce service calls, and savings from improved quality and operational efficiency may partially offset the added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

- Distribution of equipment: OEM or HVAC distributor (indoor and outdoor).
- Equipment stocking: Plant or HVAC distributor.
- Installation: Plant.
- Service, warranty, and repair: Local HVAC contractor, plant, or HVAC distributor.

Exhibit 16 captures the financial 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 16

Future State Model



HVAC = heating, ventilation, and air conditioning. OEM = original equipment manufacturer.
Source: SBRA, Milestone Report: Cost Assessment Report

To further understand the commercial benefits and liabilities of each system, a list of evaluation criteria was divided into the categories **More Critical** (exhibit 17) and **Less Critical** (exhibit 18) to the Industry on the basis of input from the Marketing and Commercialization Panel, which comprises manufactured home sales and marketing directors, home installation specialists, and HVAC sales representatives.

Exhibit 17

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 retailer).	Approximately $1,200–$1,500 increase from current practice (cost to the retailer).	Approximately $8,000–$9,500 increase from current practice (cost to the retailer).
Service costs	Warranty is 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 is included for up to 10 years (parts only). Labor included only for the first year.
New inventory procedure	Equipment stored in the plant.	Equipment stored in the plant.	Equipment stored in the plant.
Region marketability	Not flexible. Currently, available only in homes with upflow air ducts (mostly produced for HUD climate zone 1).	Flexible. The air handler can serve both up- and downflow air.	Flexible. Zonal system.
Impact on existing business relationships	Large impact—will need to change supplier and possibly cut out heating, ventilation, and air conditioning distributors from the value chain currently in close relationship with the retailers. See the previous section on business relationship change.	Current supplier (HVAC distributors or OEMs) might be able to provide a similar product. See the previous section on business relationship changes.	Large impact—will need to change supplier and possibly cut out HVAC distributors from the value chain, currently in close relationship with the retailers. See the previous section on business relationship changes.
Process for system maintenance and service at the site	National footprint might be limited because the system type is less common. Need skills and expertise to do maintenance.	Might not be an issue. However, if local HVAC contractors were to perform the servicing, they might be reluctant because of making less money: installation would be removed from their contract.	National footprint will be limited because the system type is very new, and currently, only a handful of manufacturers produce this type of system. Skills and expertise are needed to perform maintenance.

Source: SBRA, Milestone Report: Cost Assessment Report

Exhibit 18

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 component parts from multiple suppliers	Component parts from multiple suppliers might be limited because the system type is less common.	Not an issue.	Component parts from multiple suppliers might be limited because the system type is less common.

Source: SBRA, Milestone Report: Cost Assessment Report

The cost to the plant and to the retailer of the prototyped systems were compared with a baseline system, a traditional split heat pump unit, to highlight the system upgrade cost (exhibits 19 and 20).

Exhibit 19

Estimated Costs to the Plant of the Prototyped Heating and Air Conditioning Systems

System Description	Cost to Plant	
	Materials	Labor
Baseline—Traditional split 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)
Friedrich home that includes packaged heat pump, connection to ductwork, and thermostat.	$5,952	$135
LG home that includes indoor air-handling unit, outdoor unit, connection to ductwork, and thermostat.	$4,109	$210

Source: SBRA, Milestone Report: Cost Assessment Report

Exhibit 20

Estimated Costs to the Retailer 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
Friedrich home that includes packaged heat pump, connection to ductwork, and thermostat.	$9,345
LG home that includes indoor air-handling unit, outdoor unit, connection to ductwork, and thermostat.	$6,452

Source: SBRA, Milestone Report: Cost Assessment Report

Technical Advisory Group members and the Marketing and Commercialization Panel believed that the first cost to the homeowner was an important consideration. The heating and cooling equipment cost, if included, can add $2,000 to $6,000 to the home's retail price, which is challenging for an affordable housing product.

Feedback from the Industry

On the basis of the findings, the Technical Advisory Group discussed improvements that could be made in the system designs and integration into the home. Exhibits 21 and 22 describe the design and commercial hurdles encountered and their corresponding solutions.

Exhibit 21

Design Hurdles and Solutions

Hurdles	Solutions
1. Floor plan design inflexibility	For the packaged unitary system, overcoming the hurdle of floor plan design flexibility will be difficult because it must be on an exterior wall. The best solution is to design the mechanical room at the end wall housing the packaged unit. To avoid adding refrigerant to the ducted mini-split unit, limit line length to 25 feet.
2. Limited airflow options	A side-discharge supply air configuration must be developed for the packaged unitary system to direct air down to ducts under the floor.
3. System capacity limitation	For the packaged unitary system, the heating and air conditioning manufacturer will need to increase the capacity range of the unit, especially for homes larger than 1,800 square feet (about 30 percent of the homes shipped in 2021) or homes in HUD climate zone 3 (about 20 percent of the homes shipped in 2021) (MHI, 2022).
4. New skills and additional work needed	For the ducted mini-split unit, an installer with the U.S. Environmental Protection Agency Section 608 Technician Certification (Type II for residential air conditioning and heat pump) is required to do the connecting, evacuation and vacuuming, and charging of refrigerant. The plant will have to provide a training program for staff to develop the required skillset.
5. Mount-on-frame will add to the total length of the home	If the home is already designed to the maximum length allowable by factory constraints, the length added to the end of the house may exceed the limitation of the production line. One solution is to weld the extension frame at the final station so the added length will not block the line. If the home is already designed to the maximum length allowable by factory constraints, the length added to the end of the house may exceed the limitation of the production line. One solution is to weld the extension frame at the final station so the added length will not block the line.
6. Aesthetic issues	For the ducted mini-split unit, the outdoor unit is hard to conceal because it is mounted on the frame. One possible solution to this dilemma is to use a bolt-on option and relocate the unit to the ground on site; one can build a shroud around the unit or adopt shade landscaping to hide the equipment from sight.
7. Floods, other damage, and vandalism	The packaged unit is within the thermal envelope; thus, it is less prone to floods, fire, wind damage, and vandalism. The mount-on-frame system is high off the ground, reducing the risk of flooding. Specific protection can be provided to prevent wind damage and vandalism of the outdoor unit, such as covering it with a tarp during strong wind and locking the disconnect box to prevent theft.

Source: SBRA, Milestone Report: Factory Construction Process and Results

Exhibit 22

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 HVAC manufacturers would provide servicing for the new proposed approach. National coverage is crucial because manufactured homes are shipped throughout the United States. To expand the existing network, partnership with other servicing programs may also be a solution. For example, LG has a partnership with JB Warranties that provides certified servicing.
3. Impact on existing business relationships	If HVAC manufacturers or HVAC OEMs provide the equipment, the HVAC distributors may be removed from the business relationship because home manufacturers could assume those responsibilities. However, the HVAC distributors could still sell the equipment to the home manufacturers, and the plant could install it. The retailers have an established relationship with the HVAC distributors, which they might be reluctant to change.
4. Availability of component parts from multiple suppliers	For reliability, having multiple suppliers to provide the components is always better than relying on a single supplier.

Source: SBRA, Milestone Report: Factory Construction Process and Results

Conclusions

Of the two systems, plant management appreciated the ease of installation of the packaged unit but noted that equipment cost might be a hindrance. The ducted mini-split system has superior energy performance and is competitive on cost, but the additional work associated with the installation and commissioning is a major drawback. Both systems showed that they could be fully integrated into the homes' construction process, be soundly transported to the site, and meet the performance evaluation and operational expectations.

This study, however, has revealed some stumbling blocks—in the technical and commercial aspects—that require further effort to resolve. Those hurdles include higher equipment costs, limited airflow options, new skills and additional work needed, and changes to existing business relationships. 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 the plants to adopt the factory-installed heating and cooling components concept. Future discussions should also be held with the HVAC distributors to explore collaboration possibilities further. Resolving those problems can help make manufactured homes more affordable on a sustained basis and improve quality and resilience.

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Appendix

Exhibit A1

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
Director of Production	Production flow, home manufacturing efficiency
Vice President of Engineering and Design	Manufactured housing heating, ventilation, and air conditioning systems and production

Source: SBRA, Project Narrative

Exhibit A2

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

Source: SBRA, Project Narrative

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