

Comboflair®

Space Conditioning, Water Heating and Air Distribution System for HUD-Code Manufactured Housing Project Report



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Other Sponsors: Propane Education & Research Council, Alabama Gas Company

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Product development was coordinated by Henry DeLima of DeLima Associates, McLean, Virginia who assembled a competent and dedicated team of experts.

The conceptual design was based on earlier work by our engineering consultant, Joseph Pietsch of Dallas, TX and Joe Akin, our product development consultant who suggested several system configuration options and provided valuable assistance in the design of the hydronic heating subsystems.

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We are grateful for the financial assistance and guidance received from the Propane Education & Research Foundation (PERC), the U.S. Department of Energy (DOE) and Alagasco.

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Disclaimer

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Contents

Executive Summary	
1.0 Introduction	1
Manufactured Housing Market Characteristics	1
The Team & Sponsors	3
The Product	3
Field Testing	4
Report Format	4
2.0 Scope of Work	5
Statement of Problem	5
Project Objectives	5
Specific Objectives	5
3.0 Methodology	6
Needs Analysis	6
System Selection	7
Conceptual Design of System	9
Design First Comboflair® Prototype	11
Fabricate First Prototype	11
Fabricate Second Prototype	11
Fabricate Third Prototype	12
Fabricate Field Test Units	12
Design and Lab Test Other Configurations	13
Manufactured Home Production	14
Field Testing	19
4.0 Commercialization of Comboflair®	26
Design of Production Model	26
HUD-Code Issues to be Resolved	26
Manufacturer of Comboflair®	27
Product Launch	27
5.0 Additional Research Needs	29
Comfort Improvements	29
Energy Efficiency Improvements	29
Water Heater Sizing Methodology	30
Cost Reduction Improvements	31
Comparative Performance Testing	31
Glossary	32

Executive Summary

There are over 8 million manufactured homes¹ in the United States or 7.5 percent of the total housing stock occupied by over 7 percent of the U.S. population.

Only 10 States contain 50 percent of all manufactured housing units. These states include 8 Southern States, Michigan and California.

In 2006, the manufactured housing industry shipped approximately 117,300 units nationwide of which over 58 percent were shipped to Southern States.

Manufactured homes provide affordable housing. In the Year 2005, the average price of a 1,725 sq. ft. home was \$68,600 or \$39.77 per square feet compared to \$90.63 per square feet (excluding land costs) for a site-built home².

While the quality of the structural components of manufactured homes continues to improve, there have been no improvements to comfort conditions or the efficiency of HVAC systems in these homes. The need for improved space conditioning systems was identified by the manufactured housing industry and by the U.S. Department of Energy under its Building America Program.

Recognizing the need for new space conditioning and water heating systems for manufactured housing, DeLima Associates assembled a team to develop a space conditioning system that would enhance comfort conditions while also reducing energy usage at the systems level.

The product, Comboflair[®] was defined as a result of a needs analysis of project sponsors and industry stakeholders. An integrated system would be developed that would combine a packaged airconditioning system with a small-duct, high-velocity air distribution system. In its basic configura-

tion, the source for space heating would be a gas water heater. The complete system would be installed at the manufactured home factory and would require no site installation work at the homesite as is now required with conventional split-system air conditioners.

Several prototypes were fabricated and tested before a field test unit was completed in October 2005. The Comboflair[®] system, complete with ductwork, was installed in a 1,984 square feet, double-wide manufactured home built by Palm Harbor Homes in Austin, TX.

After the home was transported and installed at a Palm Harbor dealer lot in Austin, TX, a data acquisition system was installed for remote data collection. Over 60 parameters were continuously monitored and measurements were transmitted to a remote site every 15 minutes for performance analysis.

The Comboflair[®] system was field tested from February 2006 until April 2007. The cooling system performed in accordance with the design specifications. The heating system initially could not provide the needed capacity at peak heating conditions until the water heater was replaced with a higher capacity standard water heater. All system comfort goals were then met.

As a result of field testing, we have identified improvements to be made to specific components for incorporation into production models.

The Comboflair[®] system will be manufactured by Unico, Inc. at their new production facility in St. Louis, MO. The product will be initially launched in the hot-humid climates of the southern U.S.



Comboflair[®]-Three-ton cooling model

1. The term "Manufactured Home" was adopted in 1974 by the U.S. Congress to describe a type of house that is constructed in a factory to comply with a building code developed by HUD. In the past, manufactured homes were called "mobile homes," a term that is still used frequently.

2. Manufactured Housing Institute. Understanding Today's Manufactured Housing. New manufactured homes and new single family site-built homes (2005) www.manufactured-housing.org/understanding_today2006/cost_size.htm

1.0 Introduction

Manufactured Housing Market Characteristics

Manufactured housing is an important segment of the U.S. residential housing market since approximately 18 million people, over 7% of the U.S. population, live full-time in 7.3 million manufactured homes. The U.S. Bureau of Census reports that in 1999 about

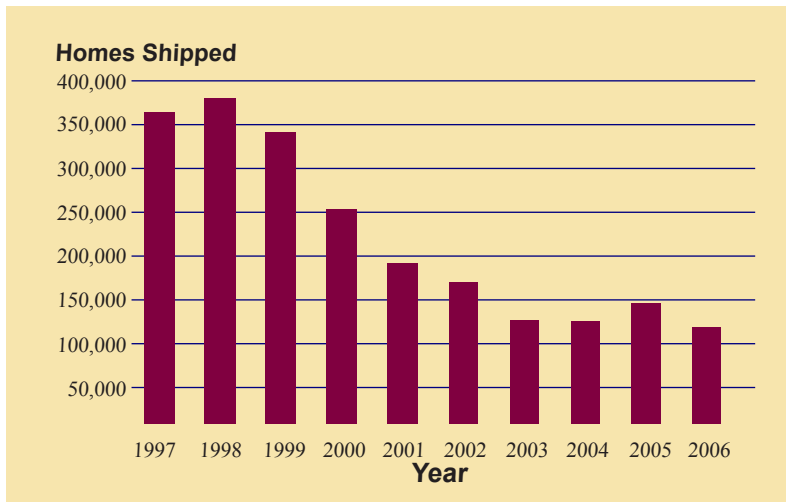


Exhibit 1.1: Manufactured Home shipments

one out of every four single-family housing starts and one out of three new single-family homes sold was a manufactured home. In 2006, the manufactured housing industry shipped nationwide approximately 117,300 units¹. There has been a rapid decline in homes shipped from a peak of 373,100 units in 1998 to only 130,800 units in 2003 after which, shipments appear to have stabilized at 130,000 to 150,000 units per year as shown in Exhibit 1.1.

Manufactured homes constitute the majority of housing that is affordable to low-to-moderate income American families. The Year 2005 average price for a single-wide unit (average size 1,080 sq. ft.) was \$33,800 or \$31.30 per square feet and for a multi-section structure (average size 1,725

sq. ft.) was \$ 68,600 or \$39.77 per square feet². Prices do not include air conditioning, which is generally installed in the field after the home is placed at the final homesite. This compares very favorably to “site-built” homes (average size 2,414 sq. ft.) which sold for an average price of \$218,781 (excluding land costs) in 2005 or \$90.63 per square feet.

Substantial cost saving (20% to 50% of a comparable site-built structure) is not the only reason that manufactured homes are in high demand. Other contributing factors are faster construction time, and improved construction quality due to required compliance with the U.S. Department of Housing & Urban Development (HUD) construction standards³. For these reasons it is anticipated that a large percentage of replacement homes in the hurricane devastated areas of the Gulf Coast will be manufactured homes.

An industry survey published in Manufactured Home Merchandiser Magazine indicates that the top 25 manufactured home producers account for roughly 95% of total industry shipments; the top 6 companies (Exhibit 1.2), account for over 70% of all homes shipped.

Six Largest Manufacturers in 2007
Clayton Homes
Champion Enterprises
Fleetwood Enterprises
Skyline Corporation
Cavalier Homes
Palm Harbor Homes

Exhibit 1.2: Six largest manufacturers of HUD-Code manufactured homes

In total, about 69 firms operating over 200 plants across the US produce manufactured homes under the HUD standards. Major manufactured home builders typically have multiple factories that serve regional or

1. U.S. Census Bureau. Manufactured Housing Shipments, Historic, March 2007. www.census.gov/const/www/mhsindex.html

2. Manufactured Housing Institute. Understanding Today's Manufactured Housing. New manufactured homes and new single family site-built homes (2005) www.manufacturedhousing.org/understanding_today2006/cost_size.htm

3. The Federal Manufactured Home Construction and Safety Standards (HUD-Code) went into effect in 1976. The standards, embodied in 24CFR3280, regulate manufactured housing design and construction, strength and durability, transportability, fire resistance, energy efficiency, and quality.

Number of Homes Shipped to States in 2006					
> 6,000	3,500 - 5,999	2,000 - 3,499	1,000 - 1,999	500 - 999	< 500
Florida	Mississippi	Pennsylvania	West Virginia	Nevada	South Dakota
Texas	Arizona	South Carolina	Illinois	Maine	Kansas
California	North Carolina	Arkansas	New Mexico	Delaware	Colorado
Louisiana	Alabama	Oklahoma	Michigan	Utah	Iowa
	Georgia	Washington	Indiana	Idaho	New Jersey
	Tennessee	New York	Minnesota	Maryland	Vermont
	Kentucky	Virginia	Wisconsin	Wyoming	North Dakota
		Oregon		Montana	Connecticut
		Missouri		New Hampshire	Massachusetts
		Ohio			Nebraska
					Alaska
					Rhode Island

Exhibit 1.3: Home shipments to states in 2006

local markets, usually within a shipping radius of only a few hundred miles from the plant. The greatest concentration of new shipments is in an 11-state belt from North Carolina to Florida and west through Kentucky to Texas as shown in Exhibit 1.3. This belt consistently receives from 50-60% of all new manufactured homes produced in the country. Historically, the southern census region accounts for about 63% of all recorded shipments.

Whereas “stick-built” homes are purchased from the same companies that build them, manufactured homes are sold to consumers through a network of company-owned or independent retailers or dealers. Buyers choose their homes by viewing finished models at a sales lot. They may take the home as-is or order a home from hundreds of available floor plans. They may custom-order interior finishes and appliances from a list of options. While surveys indicate that homeowners in general prefer propane or natural gas-fired appliances for cooking and space and water heating, home dealers generally do not actively promote gas-fired

space heating. Currently, the majority of homes shipped to southern states have electric resistance heating and electric water heaters despite the high operating costs associated with these appliances.

A market study by Foremost Insurance Company noted several drawbacks of owning a manufactured home; high on the list was energy-related comfort. Manufactured homes with heat pumps were characterized by many homeowners as being difficult to heat and those with resistance heat as having high energy costs. Many manufactured home buyers are shocked to discover that their monthly energy costs may exceed their mortgage payments. The low first-cost of a manufactured home attracts many buyers who are financially vulnerable if monthly costs rise or are unexpectedly high. Getting behind on mortgage payments due to the need to also pay high utility bills could result in loss of their home.

Unfortunately electric resistance heat is the most common electric heating system offered with manufactured homes due to its low first cost.

The Team & Sponsors

Recognizing the need for new space conditioning and water heating systems for manufactured housing, DeLima Associates assembled an expert team to develop the system. The members of the team were:

- ⊙ Unico, Inc. - an HVAC manufacturer of small-duct, high-velocity equipment with a well-equipped laboratory and testing facilities
- ⊙ Joseph Pietsch - an engineering consultant with experience in development of HVAC systems for manufactured housing
- ⊙ Joe Akin - a product development and engineering consultant with decades of experience with the natural gas industry in the area of combination space and water heating systems.
- ⊙ Palm Harbor Homes - the first manufactured home builder to build EnergyStar™-compliant homes.
- ⊙ Florida Solar Energy Center - an energy research institute that provided data acquisition services for the field testing phase. (Work was supported by DOE's Building America program.)

Financial and in-kind assistance was provided by:

- ⊙ U.S. Department of Energy (DOE)
- ⊙ Propane Education & Research Council (PERC)
- ⊙ Alagasco unit of Energen
- ⊙ Unico, Inc.
- ⊙ Palm Harbor Homes

The Product

During the first task of the project, DeLima Associates conducted a requirements analysis to identify the needs of the sponsors and the industry stakeholders including owners of manufactured homes. As a result of the

requirements analysis, the development team decided to design a complete system that combined proven HVAC components to address space heating/cooling, air supply/return, sensible/latent temperature control with a leak-tight air distribution system. A gas-fired domestic storage water heater is used as the heating source. An instantaneous water heater could also be used as the heating source but we were concerned about the cost impact of incorporating an instantaneous water heater. For ease of installation, we decided to package the refrigerant section consisting of the air handler, evaporator and condenser coils, compressor and hydronic (heating) coils and pump into a single unit that could be shipped from the HVAC manufacturer directly to the manufactured home factory and installed in the home like any other appliance. Due to space constraints in manufactured homes, our goal for the unit's footprint was 36 inches wide by 40 inches deep. Our final footprint for the 3-ton unit is 30 inches wide by 34 inches deep. The air distribution system is a small-duct, high-velocity system using fiberglass ductboard trunk ducts with 2-inch spunbond-nylon air-tight branch ducts routed to multiple ceiling outlets in each conditioned space. The principal components of the Comboflair® system are shown in Exhibit 1.4.

Comboflair® has been developed in 2-, 3-, and 4-ton cooling sizes in two space heating configurations:

- ⊙ 100% gas hydronic heating
- ⊙ Electric heat pump with gas hydronic auxiliary heating

In the 100% gas hydronic configuration, a natural gas or propane water heater supplies all the space heating needs of the home. In the electric heat pump configuration the gas or propane water heater will be used only to provide auxiliary heating at a set outdoor temperature or when the supply air temperature drops below 100°F.

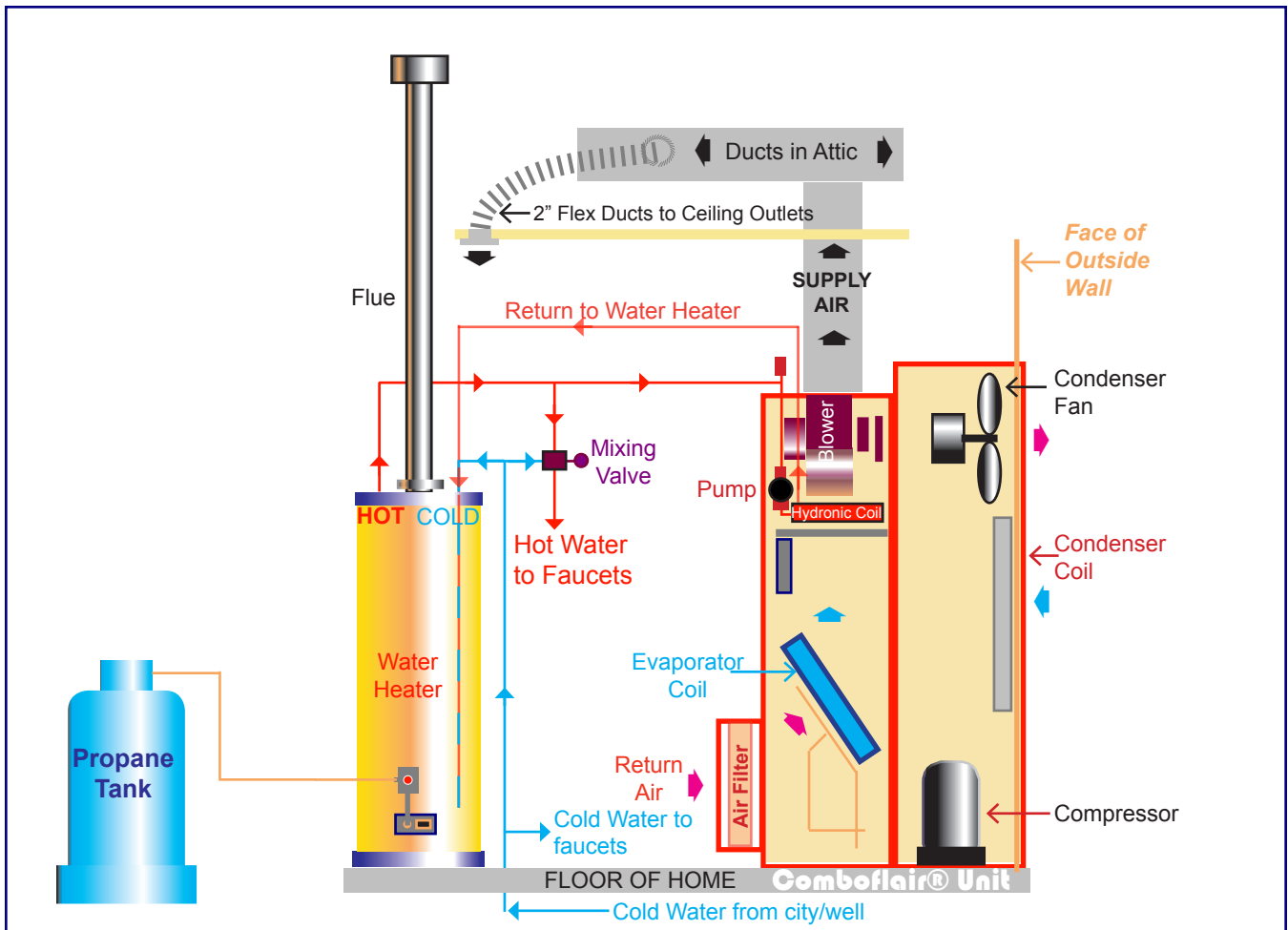


Exhibit 1.4: Principal Components of Comboflair® System

Field Testing

The Comboflair® system was installed in a 1,984 square foot Palm Harbor double-wide manufactured home and field-tested for 15 months in Austin, TX. As a result of the testing we have identified improvements to be made to specific components for incorporation into production models.

Report Format

The details of this project are described in the following chapters:

The Scope of Work and the objectives of the project are described in Chapter 2.

The methodology used in developing the Comboflair® system from the requirements analysis through the prototype development, test home production and the field testing process are described in Chapter 3. Results of field tests are also provided in this chapter.

The Product Launch phase including the description of the production model, code issues, development of marketing materials and description of target markets are described in Chapter 4, Commercialization of Comboflair®. Chapter 5 identifies further research necessary for product improvement.

Unico, Inc. laboratory test results and Field Test data are provided in an Appendix.

2.0 Scope of Work

Statement of Problem

Currently most new manufactured homes shipped are all-electric homes with electric resistance furnaces and electric water heaters. The HUD-Code, which prescribes minimum envelope requirements for manufactured homes, reduces the space heating and sensible cooling loads of the homes, but has no impact on the latent cooling loads which tend to be high, especially in hot humid climates due to leaky under-floor ducts which are typical for this type of housing.

Since the HUD-Code does not require space cooling to be installed at the factory, most manufactured homes are shipped without air conditioning. If the purchaser of the home desires air conditioning, a local contractor upgrades the motor-blower system to provide air conditioning levels of air-flows by discarding the inadequate blower system installed at the factory with a larger system. However, the duct sizes cannot be increased to handle the larger air volume causing inefficient cooling and increased noise levels. The manufactured home buyer who opts for air conditioning is forced to pay for an additional motor-blower system. Since virtually all air conditioning is installed at the placement site, manufactured home builders have to rely on local subcontracted HVAC dealers to properly size and install split-system air conditioners for their homes. However, the manufactured home builder, and not the HVAC dealer, remains responsible to the home buyer for comfort conditions in the home. As the enforcement authority over manufactured home construction, HUD will often require the home manufacturer to repair or replace improperly sized or installed HVAC systems. The proposed Comboflair® system can be tested

at the home factory, prior to shipping and eliminates the need for site installation of HVAC systems and their associated problems.

Project Objectives

The overall objective of this project was to design, fabricate, test and commercialize an efficient, integrated appliance for space heating, space cooling, water heating and air distribution in HUD-Code manufactured homes.

Specific Objectives

The Team addressed the specific requirements of the manufactured housing industry and of the sponsors, U.S. Department of Energy, Propane Education & Research Council and Alagasco.

The manufactured housing industry requirements:

- ⊙ Packaged heating/cooling unit for complete installation at the manufactured home factory
- ⊙ Low interior noise
- ⊙ Low duct leakage
- ⊙ Moisture removal capability

The U.S. Department of Energy requirements:

- ⊙ Designed to meet minimum efficiency standards for equipment class⁴.

The gas industry requirements:

- ⊙ Propane or Natural Gas as heating energy source
- ⊙ Sufficient capacity to maintain 70°F indoor temperature with 2 sequential 10-minute showers.
- ⊙ Minimum water temperature at showers no less than 105 °F.

4. DOE requires a minimum cooling efficiency SEER of 11.0 for small-duct, high-velocity systems.

3.0 Methodology

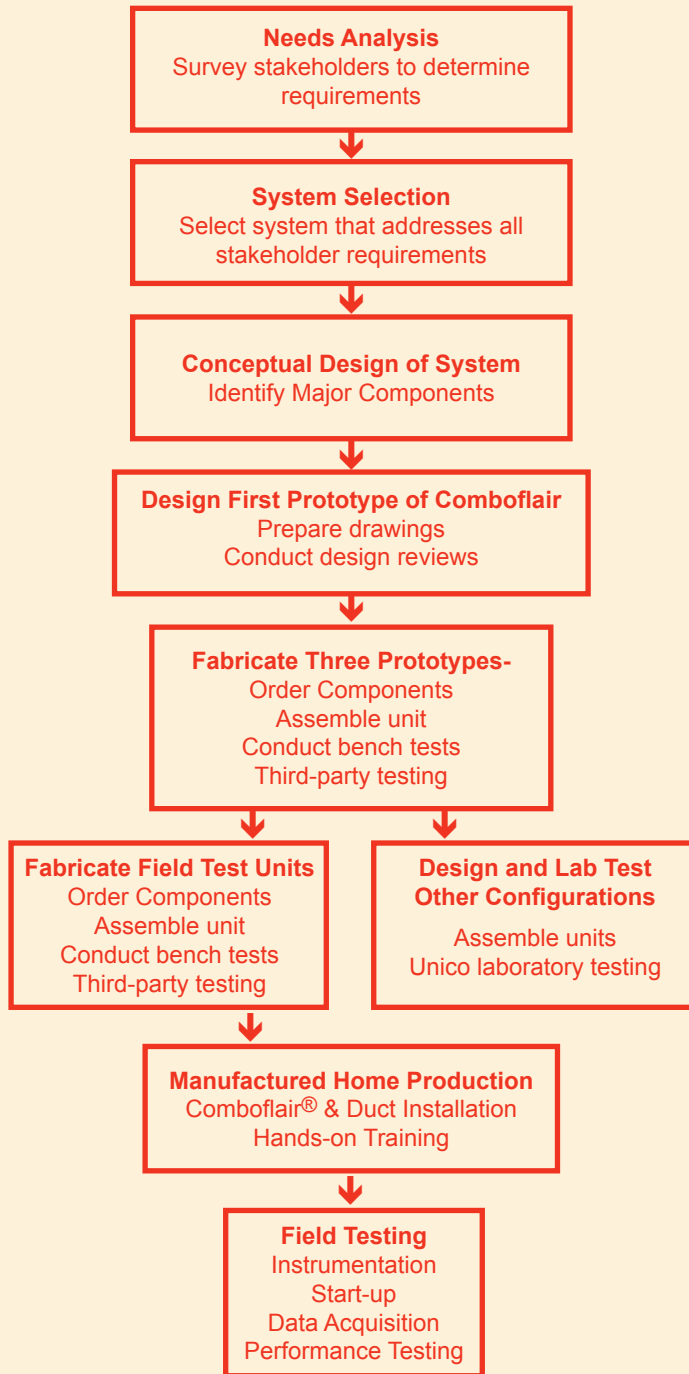


Exhibit 3.1: Major tasks

The work plan consisted of the tasks shown in Exhibit 3.1. The most important task was to determine the needs of stakeholders, as described below:

Needs Analysis
Survey stakeholders to determine requirements

Prior to equipment development, the project team met with representatives of the manufactured housing industry including producers, homeowners and state regulatory agencies. The results of these interviews are summarized below with energy-related issues identified with *:

Issues identified by homeowner associations

- ⊙ High energy bills due to all-electric heating and water heating*
- ⊙ Very noisy heating and air conditioning systems due to central location of furnace
- ⊙ Great variation of temperature from room to room*
- ⊙ Indoor humidity reduction in summer requires too cold thermostat settings*
- ⊙ Noisy outdoor unit near windows
- ⊙ Initial startup problems

Issues identified by producers (home manufacturers)

- ⊙ Limited choice of HVAC products-only one manufacturer
- ⊙ Noise is the Number 1 problem due to hallway location of furnace/blower.
- ⊙ Compromises in duct sizing due to limited attic space for ductwork*
- ⊙ Underfloor ductwork often damaged during shipment causing duct leakage*
- ⊙ Limited control over local HVAC dealer for A/C installation at site. Call backs due to improper sizing*, improper rout-

ing of refrigerant piping and damage to ductwork* and ductwrap during site installation of A/C. Uneven heating and cooling between rooms*.

Issues identified by state regulatory agency representatives

- ⊙ Homeowner complaints due to inadequate heating or cooling*
- ⊙ Damage to underfloor ductwork causing air leakage* and intake of humid air and rodents/pests
- ⊙ Slow resolution of HVAC problems due to subcontracted work with minimum manufactured home builder oversight.

System Selection

Select system that addresses all stakeholder requirements

The Needs Assessment identified air distribution and duct leakage as being the critical factors to be addressed in development of space conditioning systems for manufactured housing. Studies have shown that 20-40 percent of conditioned air in manufactured homes is lost through duct leakage. We therefore focused on adopting the most efficient air distribution system for this application, the Unico, Small-Duct, High-Velocity (SDHV) system.

Manufactured homes ship to their final site without air conditioning equipment because the HUD-Code does not require air conditioning in homes. Since manufactured home builders are not equipped to install air conditioning, they arrange for a second-tier HVAC subcontractor to install a split-system air conditioner at the final placement site. Since it is difficult to control, site installation has been problematic for manufactured home builders who are required by law to guarantee proper installation of all appliances including the air conditioning system which is the only appliance that is not installed at the manufactured home plant.

A major objective of this project was to develop a self-contained packaged unit that would be installed in the manufactured home factory and that would require no refrigerant work at the factory. Since the SDHV system was not available as a packaged unit, the goal of this project was to design, fabricate and test a packaged SDHV unit. The heating energy source for space heating would be a gas-fired water heater.

The SDHV system addresses each of the issues identified by stakeholders, as described below:

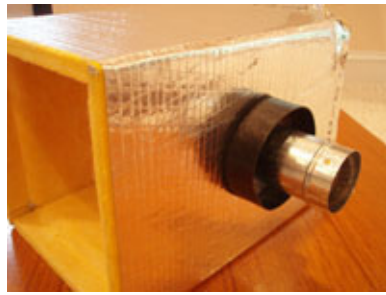
1. Lower energy costs for space heating, space cooling and water heating.

We looked at both conventional and SDHV duct systems and determined that SDHV systems offer a potential energy savings of 38% over a conventional system because the measured typical losses are less than 5% compared to conventional duct losses of 20 to 35%. In manufactured homes, duct losses have been measured at up to 40% due to installation and transportation damage. This is a significant problem. While it is possible to improve upon these values, conventional ducts are inherently more difficult to seal and to properly insulate due to their size. As further evidence of this, Carrier Corporation has create a separate division devoted exclusively to sealing duct systems using a aerosol adhesive system developed at LBL. This is costly and unlikely to used in manufactured homes.

The reason SDHV ductwork does not have these problems is threefold: one, the ducts are smaller, as much as 70% less in cross-sectional area and 50% less in surface area; two, there are fewer joints to seal in the field; and three, the ductwork and connections are engineered and factory built for low leakage and easy assembly, which make for fewer field installation problems. There are no conventional duct systems that have these advantages.



2-inch hole for duct adapter



Duct adapter with gasketed air-tight connection



2-inch insulated flex duct clamped to adapter



Flex duct connected to ceiling outlet

Exhibit 3.2: Air-Tight Duct Connections

DOE is in the process of formulating a rule to establish a separate product class for SDHV systems that will address ductwork in addition to equipment energy use. In the interim, DOE has specified a minimum cooling mode efficiency of 11 SEER for the SDHV equipment. The project goal for the base unit is 11 SEER.

Water heating standby losses are reduced in the winter by using a properly sized natural gas or propane water heater for space heating thereby increasing the water heater's load factor and reducing standby losses. An additional advantage of gas heated water is the availability of hot water for showers during electric power outages.

2. Lower noise levels for HVAC system

Conventional ducts in attics of manufactured homes are typically undersized because of severe space constraints caused by roof trusses. This is often the cause for

noisy systems. Any duct can be attenuated for a cost. Obviously, the larger the duct, the more it costs. This fix is typically field applied by the contractor unless you use SDHV ductwork which is factory assembled. We believe that SDHV systems present a more cost effective solution.

3. Great variation of temperature from room to room

The usual cause for uneven temperatures in rooms is inadequate duct size due to space constraints in attic spaces of manufactured homes. SDHV systems require air flow rates that are about 50% less than for conventional HVAC systems and therefore require smaller ducts. Space constraints are not a problem for SDHV ducts which are 70% less in cross-sectional area than conventional ducts, yet provide precise cooling in all conditioned spaces. In addition, the high velocity outlets and aspiration effect ensure complete mixing of room air with minimal stratification from floor to ceiling.

4. Better humidity control

Humidity removal in areas of humid climates is both a comfort and a health concern. This is a particular issue for manufacturing housing because it is difficult to size the cooling capacity of the HVAC unit if location of final placement of the house is unknown. Using high latent removal equipment can alleviate the problem of oversizing to some degree. In other words, if the equipment can remove more moisture, it is more tolerant to slight oversizing and has a greater range of applicability. Since the majority of manufactured homes are located in high humidity regions of the South, SDHV systems provide the opportunity to reduce energy use by eliminating the need to lower the thermostat simply to remove humidity. SDHV systems are shown to remove 30% more moisture under standard ARI condi-

tions than conventional systems because they operate under different conditions (i.e. lower air quantities with thicker heat exchangers).

5. Protection of ductwork from damage

Ductwork in manufactured homes tends to be routed through the attic space in southern climates and below the home chassis in northern climates. The underfloor trunk ducts in double-wide homes are connected using a flexible crossover duct. Underfloor ducts are highly vulnerable to damage and the crossover duct often gets ruptured allowing water and rodents to enter ductwork and the living space. Attic ducts are protected from damage but are often undersized because of space constraints in the attic cavity. SDHV main ducts are small enough to fit in the attic space and are seamless because they are fabricated at the factory and use engineered leak-tight gasket-equipped fittings at connections to the flexible branch ducts.

The single-package air-handler, compressor, evaporator, condenser and hydronic coil system (Comboflair®) addresses the need for complete installation at the factory with no “site-completion” work.

Manufactured homes ship to their final site without air conditioning equipment because the HUD-Code does not require air conditioning in homes. Since manufactured home builders are not equipped to install air conditioning, they arrange for a second-tier HVAC subcontractor to install a split-system air conditioner at the final placement site. Since the installer is not an employee of the manufactured home company, oversight is often lacking and call-backs from homeowners for service is costly for the manufactured home company who must guarantee the workmanship of the installer.

A major objective of this project therefore, was to develop a self-contained packaged unit that would be installed in the manufactured home factory and that would require no refrigerant work at the factory. Since the SDHV system was not available as a packaged unit, the project team decided to design, fabricate and test a packaged SDHV unit that would be ready for installation at the manufactured home plant, similar to the installation of a refrigerator.

A piping “tree” would be designed for simple connection of the water heater to the Comboflair® unit.

To ensure proper placement of valves to control the supply of heated water to the Comboflair® unit and tempered water to faucets, a fully integrated piping tree would be designed that would require no additional work or installation at the manufactured home plant.



The system selected was a high-velocity air-handler integrated with a condenser/compressor, evaporator, hydronic coil contained in a single package with small-duct air distribution. Hot water for space heating was to be provided by a natural gas or propane water heater.

Conceptual Design of System

Identify major components

The system consists of 3 major subsystems:

- Comboflair® Unit
- Water Heater Interconnection
- Air Distribution

The Comboflair® Unit

During the needs analysis it was determined that the Comboflair unit would need to be fully contained within the home. The unit could be located in a hallway closet which

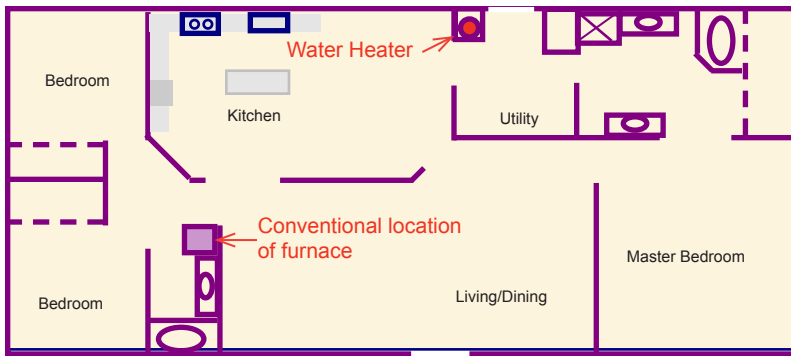


Exhibit 3.3: Typical Location of Furnace

is the conventional location for furnaces in manufactured homes as shown in Exhibit 3.3. An interior location could not be used because it would require that air from the crawl space be used for the condensing section. The HUD-Code does not permit the use of the crawl space as an air intake. This would require the use of a duct extension through the crawl space with an intake through the house skirting at an exterior wall as shown as Comboflair® Location Option 1 in Exhibit 3.4.



Exhibit 3.4: Alternate Locations of Comboflair®

We decided to design the unit to be located in the home at an exterior wall. The location selected for this project was Comboflair® Location Option 2 shown in Exhibit 3.4. While any exterior location is suitable, we selected a space in the utility room. The unit penetrates the exterior wall for condenser air intake/exhaust.

Once the location of the unit was finalized, design criteria were developed which

included the overall dimensions of the unit and its major components and location of components for easy serviceability. At this point it was decided that the unit would consist of two distinct sections, an “outdoor section” consisting of the compressor, and condensing section and an “indoor section” consisting of the air-handler, evaporator coil and hydronic heating coil and controls.

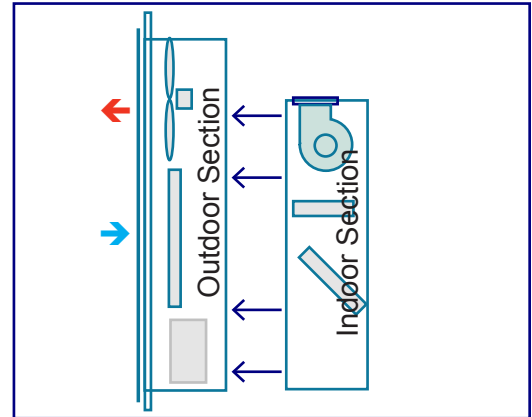


Exhibit 3.5: Two Sections of Comboflair®

The two sections would be bolted together to provide extra rigidity and allow for a physical/thermal/acoustic barrier from the outdoors as shown in Exhibit 3.5. This design allows for the unit to be used as a split-system in other HVAC applications.

Water Heater Interconnection

The Comboflair® system is a combination space and water heating (combo) system that uses heated water from a conventional water heater for space heating. While combo systems have been proven to be very efficient and reliable when correctly installed, they often fail when valves and piping are incorrectly installed. To ensure fail-safe installation, we decided to design a valve piping tree containing all necessary valves, air vents and mixing devices to prevent improper installation at the manufactured home factory. The piping tree would be pre-assembled and ready for installation on any water heater without the need for special tools.

Air Distribution

The SDHV air distribution system selected for this project was the standard Unico, Inc. glass fiberboard main ducts with standard 2-inch insulated spun-bond nylon flexible ducts with 2-inch round ceiling registers. All duct accessories would be standard Unico stock items.

**Design First Comboflair®
Prototype**
Prepare drawings
Conduct design reviews

The first prototype was a 3-ton SDHV cooling unit. The Oak Ridge National Laboratory's refrigerant cycle computer model was used to simulate the performance of condenser coils, evaporator coils, compressor, condenser fan, indoor blower and fan motors. Coil types and sizes were input into this model to determine the energy efficiency impact of each selection.

After component selections were made, a complete set of drawings was prepared showing the location of all components. Design reviews were conducted with the project consultants and the changes were incorporated into the final design of the first prototype.

Fabricate First Prototype
Order components
Assemble unit
Conduct bench tests

Specifications were developed for each of the components and orders were placed with vendors. Upon receipt of components they were examined and tested against the requirements in the specifications. The prototype was assembled and bench tests were performed on Unico, Inc.'s testing apparatus that was designed specifically for



Exhibit 3.6: Laboratory Testing of Comboflair®

testing the Comboflair® unit. Since noise is of major concern, three different propeller fan configurations were tested to determine impact on noise and efficiency. Test results indicated a cooling capacity of 38,000 Btu at ARI test conditions, exceeding the design goals for cooling capacity.

**Fabricate Second
Prototype**
Order components
Assemble unit
Conduct bench tests
Third-party testing

Several changes were made to the original design to reduce the size of the unit. A more compact condenser coil was designed to reduce the overall size of the unit. The most significant change was to change the coil configuration. The compressor mounts were reinforced to prevent damage during shipment of the unit to the manufactured home plant and during transportation of the home

to the final homesite. The unit was tested at Unico’s facility before being shipped for third-party performance testing to the ETL test facility in Philadelphia for environmental chamber tests in accordance with ARI standards. The measured cooling capacity of 30,774 Btu/Hr. was below our capacity goal of 36,000 Btu/Hr.

Fabricate Third Prototype
Redesign components
Assemble unit
Conduct laboratory tests

Prototype 3 was fabricated. This was the final prototype before the Field Test units were designed and fabricated. This prototype featured the following improvements over previous prototypes:

- Intertwined Evaporator Circuits – improved capacity and more stable TXV operation
- Reduced-height three row condenser – better access to compressor compartment
- Dedicated heat pump and air conditioning expansion valves – improved system control
- Relocated distributors immediately downstream of expansion valves – more uniform refrigerant distribution, more stable control.

The objectives of design/fabrication/testing of Prototype 3 were to determine optimal system charge, to adjust indoor expansion valve superheat, to measure performance at ARI rating conditions A and B and to compare actual performance to predicted (simulated performance) results.

This prototype was tested at the Underwriters Laboratories facility in Dallas, TX. The purpose of this test was to verify Unico’s in-house testing procedures. Performance tests were then conducted at Unico, Inc. on a specially designed test apparatus in accordance with ARI Standard 210/240-94,

“Standard for Unitary Air-Conditioning and Air-Source Heat Pump Equipment” and ANSI/ASHRAE Standard 37-88, “Methods of Testing for Rating Unitary Air-Conditioning and Heat Pump Equipment”, published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

During testing it was noted that initially, sub cooling and EER increased with additional charge. With continued charging, however, the increase in EER diminished. Optimal charge was 7 lb 12 oz, with 14.8°F subcooling. All test objectives were met. Prototype 3 produced 39,700 btu/hr cooling at the ARI “A” test condition (exceeding the 36,000 btu/hr cooling capacity goal) and produced 11.0 SEER at the ARI “B” test condition.

The measured data and computer simulated model predictions were in agreement.

Fabricate Field Test Units
Order components
Assemble unit
Conduct laboratory tests

Since the third prototype exceeded the design goals, we fabricated 2 field test units using the identical design and components from the third prototype. After testing the units, one was shipped to the Palm Harbor Homes factory in Austin, TX for installation in a manufactured home model. The only design change in the Field Test units is the addition of a baffle/stiffener plate between the condenser section and the compressor to allow for easier access to the compressor and its accessories. We designed a special one-piece hydronic interface between the water heater and the Comboflair® air handler consisting of check-valves, a water tempering valve, expansion valve, manual and automatic air vents and shut-off valves. All free ends of the interface are equipped with unions for quick installation at the factory.

Design and Lab Test Other Configurations

Assemble units
Conduct laboratory tests

While the field tests were in progress at the Austin, TX test house, Unico, Inc. designed several configurations of 3-Ton, 4-Ton and 2-Ton Comboflair® models.

3-Ton Model Redesign & Testing

The 3-Ton Comboflair® unit was redesigned to improve efficiency. Tests were run in Unico's test facility using two different fan motors ($\frac{1}{2}$ horsepower and $\frac{1}{3}$ horsepower) and two different refrigerant compressors (single-stage and 2-stage). Test data for performance at 82°F and 95°F outdoor conditions were used to calculate SEER. An SEER of 12.93 was calculated



4-Ton Comboflair® unit

for the $\frac{1}{3}$ horsepower motor with a styrofoam inlet ring (on condenser fan). Without the inlet ring the SEER dropped to 11.67. In addition, the $\frac{1}{3}$ horsepower motor was much quieter than the $\frac{1}{2}$ horsepower motor. Other configurations were also tested (such as one with a bowed condenser coil) and abandoned because efficiency improvements were not sufficient to justify the increase in first cost.

4-Ton Model Design, Fabrication & Testing

The 4-Ton Comboflair® unit was designed and fabricated at Unico, Inc. Except for the 42-inch width of this unit all other dimensions are identical to the 3-Ton models. The greater width was necessary to accommodate the larger condenser coil and dual propeller fans. Tests were run in Unico's test facility using two different fan motors ($\frac{1}{2}$ horsepower and $\frac{1}{3}$ horsepower) and two different refrigerant compressors (single-stage and 2-stage). Test data for performance at 82°F and 95°F outdoor conditions were used to calculate SEER. An SEER of 11.56 was calculated for the $\frac{1}{3}$ horsepower motor with styrofoam inlet rings (on condenser fans).

2-Ton Model Design & Testing

The 2-Ton Comboflair® unit was designed using the same cabinet as that for the 3-Ton model. This allowed the use of the 3-Ton size condenser coil which was needed to obtain higher efficiencies since 2-speed compressors are not available in a 2-Ton cooling capacity. The desired efficiency could not be obtained for this size unit even with the oversized condenser coil. Unico will therefore not be able to offer this size unit until the efficiency level can be improved. However, since Unico's target market is double-wide and larger manufactured homes which require 3-Ton and larger cooling capacity units, there may not be any demand for 2-Ton Comboflair® units.

**Manufactured Home
Production**
Comboflair & duct installation
Hands-on training

Austin, TX was selected as the location for testing Comboflair® for several reasons:

- Texas leads the country in manufactured home production and is second only to Florida in home placements.
- Our manufactured home team member, Palm Harbor Homes is headquartered in Texas.
- Palm Harbor’s Austin manufacturing plant is a high-volume facility and the main producer of homes shipped to a large area of the South including the Gulf Coast states.
- The Texas Railroad Commission, headquartered in Austin, TX had expressed interest in supporting the introduction of propane-fueled manufactured homes.

The construction drawings for the field test home (Austin, TX) were received from Palm Harbor Homes and were used to calculate heating and cooling loads. The heating and cooling loads at Austin, TX design conditions were 19,062 Btu/hr and 2.6 tons. The 3-ton Comboflair® field test unit as designed would exceed the design heating and cooling requirements of the test home. The total house loads were used to size the trunk ducts and the room-specific loads were used to calculate the number of Unico outlets per room. After the ducts were sized, the duct layout was designed for this specific home model. The planned duct layout with location of Comboflair® unit and water heater is shown in Exhibit 3.7.

Prior to the home production date, the comboflair unit with precut ducts and the valve piping tree were shipped from Unico to the Palm Harbor plant in Austin, TX. The water heater was not shipped because we decided to use a standard manufactured home convertible gas water heater stocked by the Palm Harbor plant.

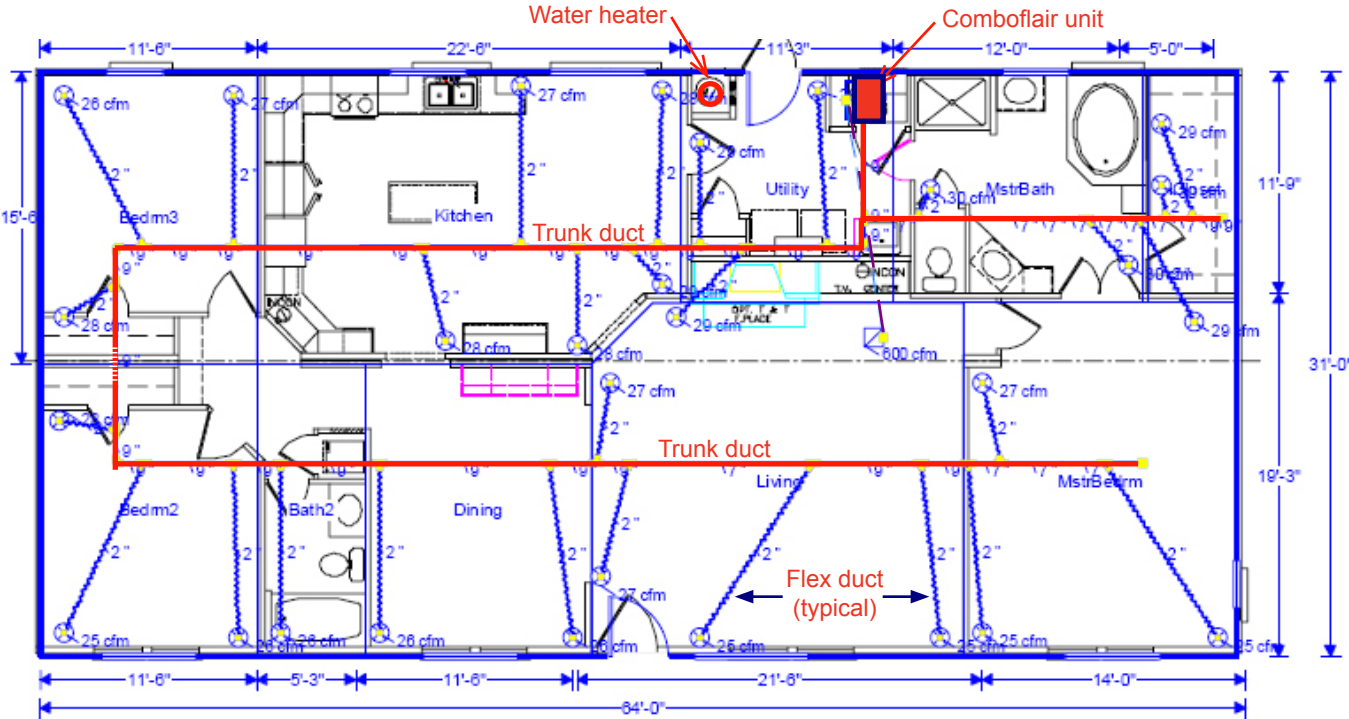


Exhibit 3.7: Comboflair® System Duct Layout

Home production and installation of Comboflair system with duct-work.

The first step in home production was the fabrication of the steel chassis complete with axles and hitches for transportation to the final homesite or dealer lot. Since the test home is a double-wide model, two identical chassis were fabricated. Upon completion of the chassis, the wood floor joists and floor deck were attached to the

assembly area. Wall framing was assembled on a large table where it was then attached to drywall. Openings for doors and windows were then cut out and wall insulation was placed between wood framing of exterior walls. Exhibit 3.9 shows the walls stacked to the side, ready to be nailed to the floor.

The comboflair unit was then placed and bolted to the floor deck as shown in Exhibit 3.10.



Exhibit 3.8: View of Floor Deck of Home

assembly area. Wall framing was assembled on a large table where it was then attached to drywall. Openings for doors and windows were then cut out and wall insulation was placed between wood framing of exterior walls. Exhibit 3.9 shows the walls stacked to the side, ready to be nailed to the floor.



Exhibit 3.10: Comboflair® Unit Bolted to Floor

After all interior walls and appliances were placed on the floor deck, the pre-assembled and insulated exterior walls were hoisted and then lowered and nailed to the floor



Exhibit 3.9: Wall Assemblies



Exhibit 3.11: Lowering of Exterior Wall



Exhibit 3.12: Final Placement of Exterior Wall with Comboflair® Unit

deck as shown in Exhibit 3.11. The combo-flair unit fits within the framed opening as shown in Exhibit 3.12.

The roof assembly consisted of a drywall ceiling, wood roof trusses, blown-in insulation, plywood roof sheathing and asphalt shingles. The ceiling drywall was first laid on a flat table and then the pre-built roof trusses were positioned using a fixture.



Exhibit 3.13: Trunk Duct Inserted through Roof Trusses.

The roof trusses were glued to the drywall ceiling with polyurethane foam and cross supports were nailed to the tops of the trusses to keep them from collapsing like dominoes. The fiberglass trunk duct was assembled and installed through the truss openings as shown in Exhibit 3.13.

The flexible branch ducts were connected to the trunk duct in 3 steps for an airtight connection as illustrated in Exhibit 3.14. In Step 1, a 2-inch hole is punched in the trunk duct. In Step 2, a gasketed duct



Step 1



Step 2



Step 3

Exhibit 3.14: Connections for Flexible Ducts

adapter is inserted and screwed into the 2-inch hole. In Step 3, the flexible duct is clamped onto the adapter and the insulation jacket is taped to the adapter collar.



Exhibit 3.15: Supply and Return Ducts in Attic

After the trunk duct and branch ducts were installed, the return air duct was installed as shown in Exhibit 3.15.

After installation of ducts, the ceiling/truss assembly was hoisted as shown in Exhibit 3.16 and placed on the home as shown in Exhibit 3.17.



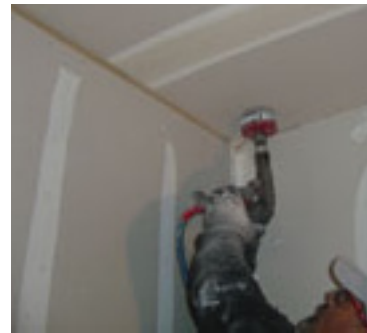
Exhibit 3.16: Roof Assembly Lifted from Assembly Table

Supply outlet connections are shown in Exhibit 3.18. In Step 1, holes were cut in the ceiling for the supply outlets. In Step 2,



Exhibit 3.17: Roof Assembly Placed on Walls

the flexible ducts were pulled down from the attic space into each room through these holes and connected to the supply outlets (Step 3) after the rooms were painted.



Step 1



Step 2



Step 3

Exhibit 3.18: Supply Outlet Connections

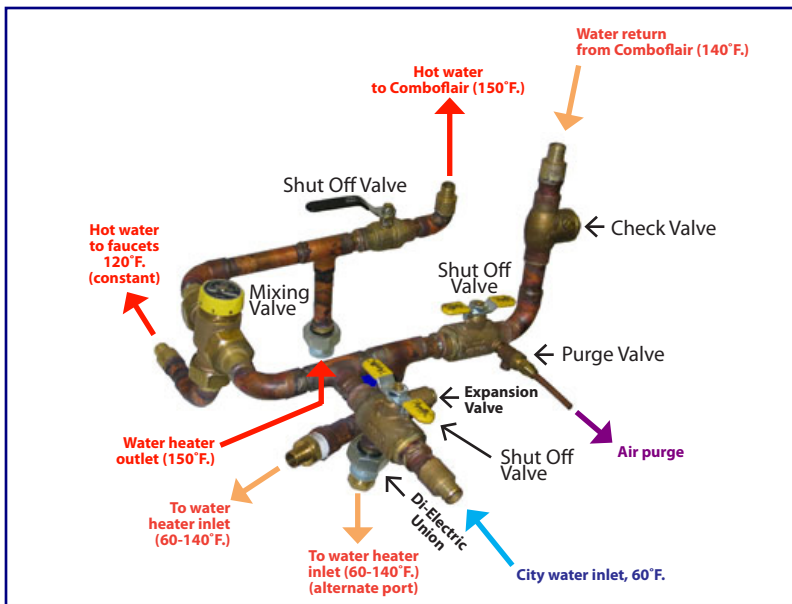


Exhibit 3.19: Components of Piping Tree

After the trunk duct was connected to the Comboflair® unit, the piping tree as shown in Exhibit 3.19, was installed, and PEX piping was connected between the water heater and Comboflair®.

Insulation was blown into the attic space before the roof sheathing and shingles were installed. The final production activities included installation of windows and siding and interior trim and fixtures.



Exhibit 3.20: Home set on Piers

As mentioned earlier, the home is a double-wide model which required each of the two sections to be separately towed to the Palm Harbor dealer’s lot near the Austin, TX airport. The sections were installed on piers (Exhibit 3.20) and mated together before the plumbing and electrical connections were made between the sections. A portion of the roof was then removed to connect the two ends of the trunk ducts in the attic with a flexible duct section. A 320 gallon propane tank was installed and gas service to the home was initiated. A conversion kit was used to convert the home’s natural gas water heater to use propane. City water and electrical power connections were completed before the water heater and Comboflair® unit were energized.



Exhibit 3.21: Front View of Test Home

Field Testing

Instrumentation
Start-up
Data Acquisition
Performance Testing

The field testing was scheduled for the period of October 2005 through September 2006. However, production of the home was delayed to December 2005 due to diversion of resources to emergency production of manufactured homes for Hurricane Katrina evacuees. Since the home was not shipped to the site until February 2006, it was decided to extend the testing to April 2007 to capture one complete heating and one complete cooling season.

OBJECTIVE OF FIELD TESTING

The objective of field testing is to evaluate the performance of Comboflair® in controlled but realistic indoor settings under a variety of outdoor conditions. Lighting was operated and humid air was introduced into the home to simulate occupancy. Performance would be evaluated based on the degree of indoor comfort provided by the system, the responsiveness of the system to changing outdoor conditions and different indoor conditions (e.g., presence/ absence of internal loads such as domestic water demand), and the energy efficiency of the system. It should be noted that the objectives of this testing are different from, and perhaps broader than, engineering testing of heating or cooling systems. The levels of comfort, both thermal and noise, and system responsiveness are priority parameters in this testing as compared to just efficiency testing.

As inputs to the assessment, a variety of parameters describing outdoor weather conditions, system response, indoor comfort, availability of domestic hot water and energy consumption would be monitored. The monitoring results would be used initially

for the assessment of system performance and would provide a basis for extrapolation of results to other manufactured home models or weather conditions through energy simulation.

PARAMETERS FOR TESTING

Parameters that were monitored and their respective monitoring locations are discussed below:

Outdoor Parameters

Outdoor air temperature is the principal determinant of heating or cooling demand. Wind speed, wind direction and solar



Exhibit 3.22: Weather Station

radiation can also play important roles. While relative humidity has a much smaller impact in Austin than in a more humid climate, it is usually required as an input to energy models. For the above reasons, it was essential that the following outdoor parameters be measured:

- Air temperature
- Relative humidity
- Solar radiation

A self-contained weather station was installed on the roof of the home as shown in Exhibit 3.22. to obtain ambient tempera-



Exhibit 3.23: Temp./ Humidity Sensor at Thermostat

ture, relative humidity and solar insolation measurements.

Indoor Parameters

Indoor air temperatures and relative humidity were measured in the vicinity of the house thermostat as shown in Exhibit 3.23 and in each of the three bedrooms. Exhibit 3.24 shows the location of the temperature/relative humidity sensor in the master bedroom which is typical of sensors in all bedrooms. Temperature and relative humidity were measured continuously and averaged over 15-minute periods to determine heating and cooling performance of equipment and the ability of the system to provide uniform space temperatures throughout the house. Additional measurements such as the temperature and air flow rates at each supply outlet were performed manually during each site visit by team members.



Exhibit 3.24: Temp./ Humidity Sensor in Master Bedroom

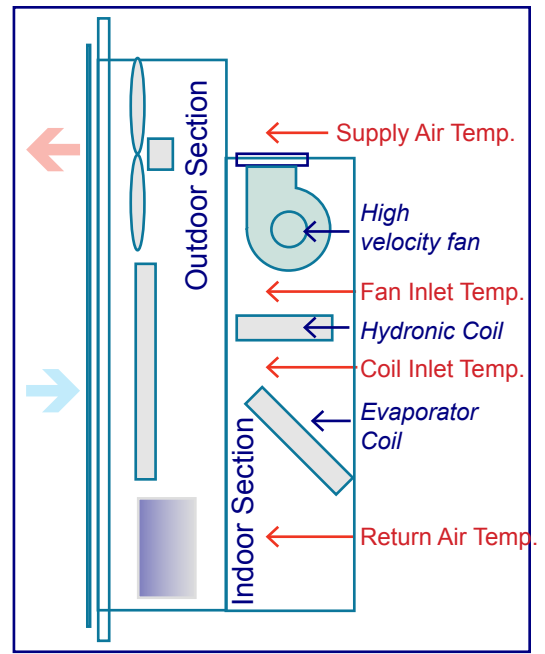


Exhibit 3.25: Comboflair® Air Side Measurements

Comboflair® Airside Parameters

Air temperatures in the delivery system during HVAC operation were continuously measured in the trunk duct (supply air) to the attic space. In addition, air temperatures were measured in the return air plenum, at the inlet to the hydronic coil, and at the inlet to the high-velocity blower of the Comboflair® unit as indicated in Exhibit 3.25. which allowed performance of each component of the indoor section to be observed. Power usage by the high-velocity blower was also monitored.

Comboflair® Refrigeration Cycle Parameters

Every aspect of the refrigeration cycle performance was continuously monitored. Temperature and pressure levels were obtained at the compressor, condenser, evaporator and at the liquid and suction lines. Condenser fan and compressor energy usage was also monitored.

Hydronic Space and Water Heating Parameters.

The space heating system consists of a propane-fueled water heater, a hydronic coil,

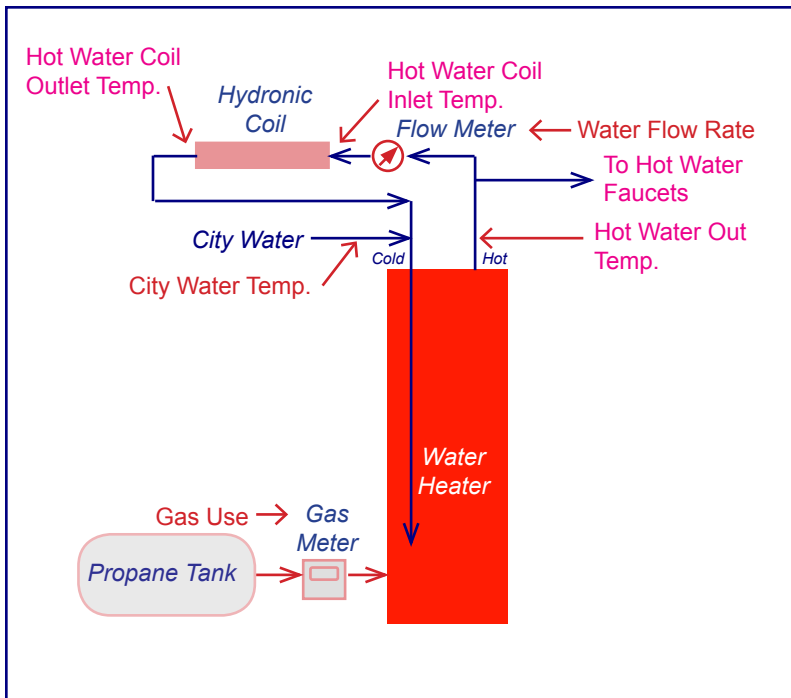


Exhibit 3.26: Comboflair® Water Side Measurements

water circulating pump and an assortment of valves. In order to test the performance of the heating system it was necessary to measure gas usage, water flow rate and several water temperatures as shown in Exhibit 3.26:

- The city water temperature
- Tank outlet water temperature
- Hydronic coil entering and leaving water temperatures

In addition to measuring water temperatures, air temperatures were also measured at the inlet to the hydronic coil and at the supply air plenum. Water and gas flow meters are shown in Exhibits 3.27 and 3.28 respectively. Power usage by the high-velocity blower was also monitored during the heating operating mode.

A list of parameters that were measured are provided in Exhibit 3.29

COMMISSIONING OF SYSTEMS

Prior to starting the field test we simulated the performance of the standard HUD-Code compliant water heater that was shipped



Exhibit 3.27: Water Flow Meter



Exhibit 3.28: Gas Flow Meter

REFERENCE	PARAMETER MEASURED	REFERENCE	PARAMETER MEASURED
CTYTEM	City Water Temp In °F	EVPDMX	Max. Evaporator Distributor Temp. °F
DHWOUT	Hot Water Out °F	CSATMX	Max. Condenser Sat. Temp. °F
AMBTMP	Ambient Temp. °F	LIQLMX	Max. Compressor Liquid Line Temp. °F
BOXTMP	CR10 Box Temp. °F	EVSTMX	Max. Evaporator Sat. Temp. °F
TSTTRH	Thermostat Rel. Hum.	CMDPMX	Max. Compressor Disch. Pressure PSI
MSTRRH	Master Bedrm. Rel. Hum.	CMSPMX	Max. Compressor Suction Pressure PSI
SECDRH	Second Bedrm. Rel. Hum.	EVPPMX	Max. Evaporator Suction Pressure PSI
THRDRH	Third Bedrm. Rel. Hum.	CMDSMN	Min. Compressor Disch. Temp. °F
AMBTRH	Ambient Rel. Hum.	CMDCMN	Min. Compressor Suction Temp. °F
VOLTAG	Voltage	EVPDMN	Min. Evaporator Distributor Temp. °F
AMPCNT	Counter for Amps>10	CSATMN	Min. Condenser Sat. Temp. °F
PWRUSE	Power Use Watts	LIQLMN	Min. Compressor Liquid Line Temp. °F
TSTTMP	Thermostat Temp. °F	EVSTMN	Min. Evaporator Sat. Temp. °F
MSTRTM	Master Bedrm. Temp. °F	CMDPMN	Min. Compressor Disch. Pressure PSI
SECDTM	Second Bedrm. Temp. °F	CMSPMN	Min. Compressor Suction Pressure PSI
THRDTM	Third Bedrm. Temp. °F	EVPPMN	Min. Evaporator Suction Pressure PSI
AMBRTD	Ambient Temp. RTD °F	RETAIR	Return Air Temp. °F
PYRANO	Solar Insolation W/M ²	SUPAIR	Supply Air Temp. °F
HTRFLO	Avg. Heat Coil Loop Flow Gal.	HCOLIN	Hot Water Coil Incoming Air Temp. °F
CMPDIS	Compressor Disch. Temp. °F	FANAIN	Fan Incoming Air Temp. °F
CMPSUC	Compressor Suction Temp. °F	AMPUSE	Amperage
EVPDIS	Evaporator Distributor Temp. °F	H2OOUT	Hot Water Coil Outlet Temp. °F
CSATMP	Condenser Sat. Temp. °F	H2OINL	Hot Water Coil Inlet Temp. °F
LIQLIN	Compressor Liquid Line Temp. °F	RUNTLO	Run Time Amps-each minute (0-4.9)
EVSTMP	Evaporator Sat. Temp. °F	RUNTMD	Run Time Amps-each minute (5-6.9)
CMPDSP	Compressor Disch. Pressure PSI	RUNTHI	Run Time Amps-each minute (7-20)
CMPSCP	Compressor Suction Pressure PSI	GASUSE	Gas Use Cu. Ft.
EVPRES	Evaporator Suction Pressure PSI	FLOTOT	Total Flow Gallons
CMPDMX	Max. Compressor Disch. Temp. °F	TIPBKT	Tipping Bucket
CMPSMX	Max. Compressor Suction Temp. °F	TOTPWR	Total Power Use Watt Hours

Exhibit 3.29: Parameters that were Measured by the Data Acquisition System and averaged in 15-minute intervals

with the home to determine the adequacy of its capacity for space heating and water heating at the Austin location. A spreadsheet was developed to simulate the space and water heating performance of Comboflair in Austin, TX. We were able to predict the space and water heating output using the conventional 40-gallon gas water heater that is normally shipped with this size home. From our calculations it was deter-

mined that the water heater shipped with the home would be able to provide 70°F indoor room temperature and no less than 105 °F. water temperature for 2 consecutive showers at peak heating load conditions at this site.

The Comboflair system was commissioned in the heating mode during the second week of February 2006. The Comboflair®

unit was started and air temperature and air flow were measured at each outlet. The system was designed to provide 30 CFM at each outlet. We noticed that the air flow was excessive at 2 outlets and below design value at one outlet. Temperature variation between outlets did not exceed 4°F.

Instrumentation of the home was completed in February 2006 by the Florida Solar Energy Center (FSEC) under contract to U.S. Department of Energy. The data acquisition system was calibrated and tested, and software was developed and installed to allow for remote real-time measurements to be viewed on-line at a web site maintained by FSEC.

The system operated in the heating mode from February 16, 2006 through April 6, 2006. Unfortunately we discovered that the water heater capacity was inadequate to meet the peak heating loads during a cold spell at the site from February 16 through February 23, 2006. We suspected that the natural gas to propane conversion kit used on this water heater was incorrect due to an incorrect burner orifice which was restricting the gas flow to the burner but by the time we were able to change the orifice, the cold spell was over and the heating capacity was sufficient to meet the heating load until the end of February. Comboflair® operation was minimal during the month of March when the weather was mild.

The system operated in the cooling mode from March 28, 2006 through December 5, 2006. During the summer months, the Comboflair® was able to maintain the thermostat set point except when the outside temperature was greater than design (96°F) and when the unit needed maintenance for dirty filters.

Significant field test events are summarized in Exhibit 3.30

SIGNIFICANT FIELD TEST EVENTS	
2005	
Dec. 6-8	Trained workers and installed Comboflair system at Palm Harbor Factory.
Dec. 13-14	System testing prior to shipping
2006	
Jan. 30	Home installed at dealer lot
Feb. 3-4	DOE HQ Peer Review
Feb. 6-10	Data Acquisition system installed
Feb. 16-22	Manual data collection initiated
Feb. 26	Incorrect burner orifice on water heater-insufficient capacity
Feb. 27	Instrumentation diagnostic check
Mar. 10	New burner orifice for water htr.
Mar. 1-30	No heating load
Apr. 1	Cooling Mode-Thermostat : 77°F
Apr. 13	No power to site-utility problem
Apr. 19-20	Instrumentation diagnostic check
May 9	Power restored to site
May 9-13	Intermittent power at site
May 24	Site visit to check systems; power to home upgraded
May 26	Unit shutdown due to unrelated water leak in house plumbing
Jun. 27	Power lost: cable stolen
Jul. 7	Power restored
Aug. 1	System failure due to dirty condenser caused by dust from highway construction.
Aug. 28	Condenser coil cleaned, fan replaced, system restarted
Dec. 12	Heating Mode- Thermostat: 70°F. Upgraded water heater; performed shower load tests
2007	
Jan. 2	Propane tank empty
Jan. 13	Propane tank refilled
Jan. 26	Water leak reported. Unit shutdown.
Feb. 28	Thermostat set to Auto (heat/cool). Transfer grilles blocked.
Apr. 19	Data collection completed
May 16	DOE Site Review
May 16	End of Field Test

Exhibit 3.30: List of Significant Field Test Events

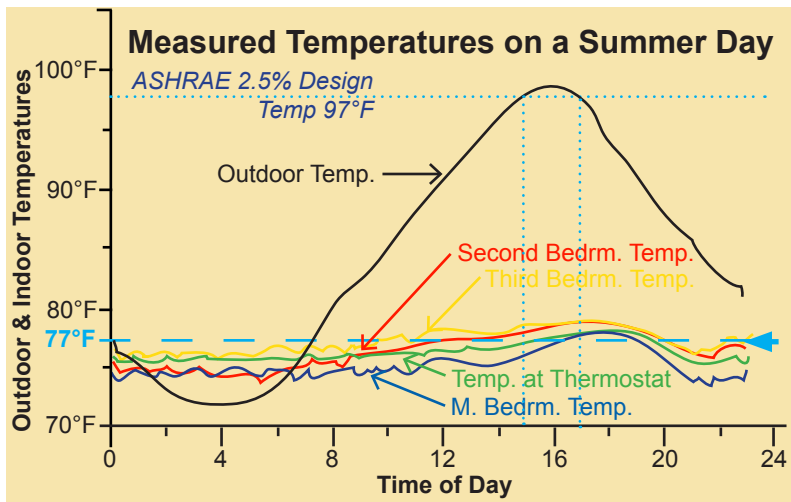


Exhibit 3.31: Performance on a Typical Summer Day

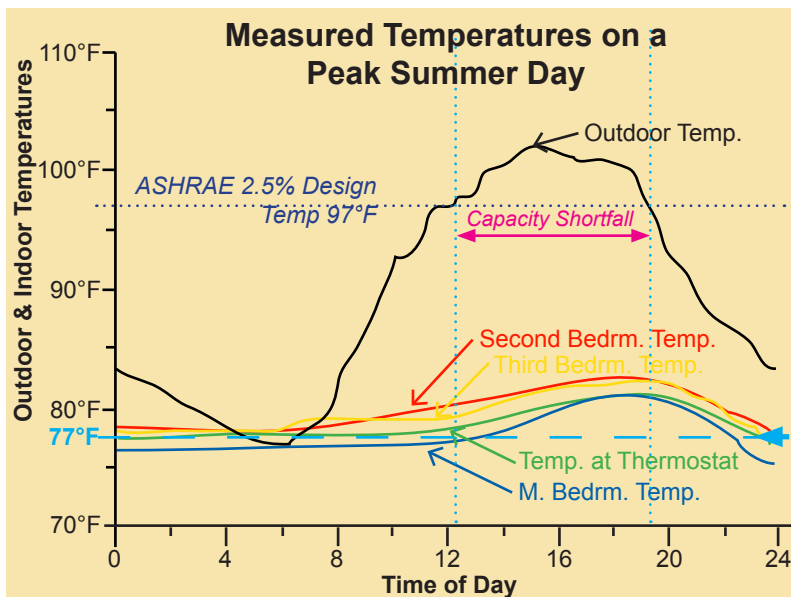


Exhibit 3.32: Performance on a Peak Cooling Day

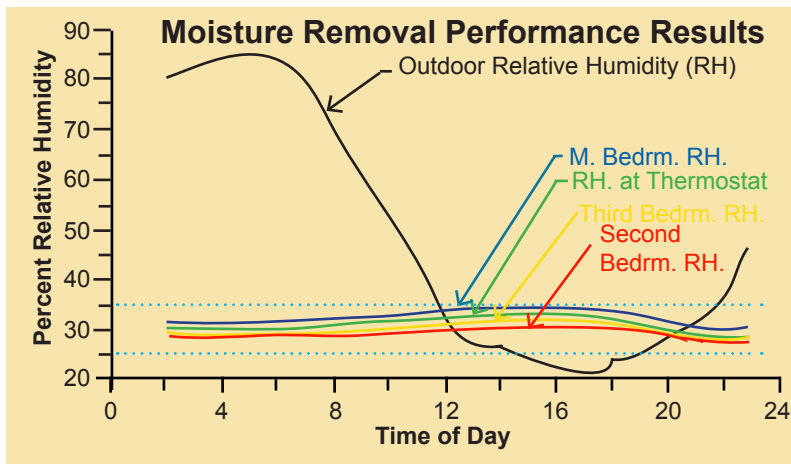


Exhibit 3.33: Moisture Removal Performance

TEST RESULTS

The Comboflair® unit was selected to meet the cooling design load of the home using the ASHRAE 2.5% design temperature of 97°F. for Austin, TX. From examination of data collected from the field test it appears that the unit was able to maintain the indoor temperature at the 77°F. thermostat setpoint. Temperature profiles for a typical summer day (June 6, 2006), are shown in Exhibit 3.31. The outdoor temperature profile for a 24-hour period is indicated by the black line which shows that the design temperature is exceeded for approximately 2 hours on this day. It is important to note that the Comboflair® unit is able to maintain the indoor temperature in all monitored rooms to within ± 2 F. of the thermostat setpoint which was one of the goals of this project.

The Comboflair® unit did not have enough capacity to maintain the thermostat setpoint temperature for an 8-hour period on July 18, 2006 when the outdoor temperature exceeded the design temperature as shown in Exhibit 3.32. Despite this capacity shortfall, this unit is correctly sized for this home and the local weather conditions as per ASHRAE guidelines.

One of the attributes of the Comboflair® unit is its superior moisture removal attribute. All monitored spaces were maintained in a narrow relative humidity range of between 25 and 35 percent as shown in Exhibit 3.33 despite huge diurnal variations in outdoor relative humidity and forced introduction of moist air into the home by means of a humidifier that was operational throughout the year.

As stated earlier, the space heating performance could not be adequately tested during the first heating season due to defective burner orifice and lack of heating days. A new water heater was installed and testing of the heating system was initiated in December 2006.

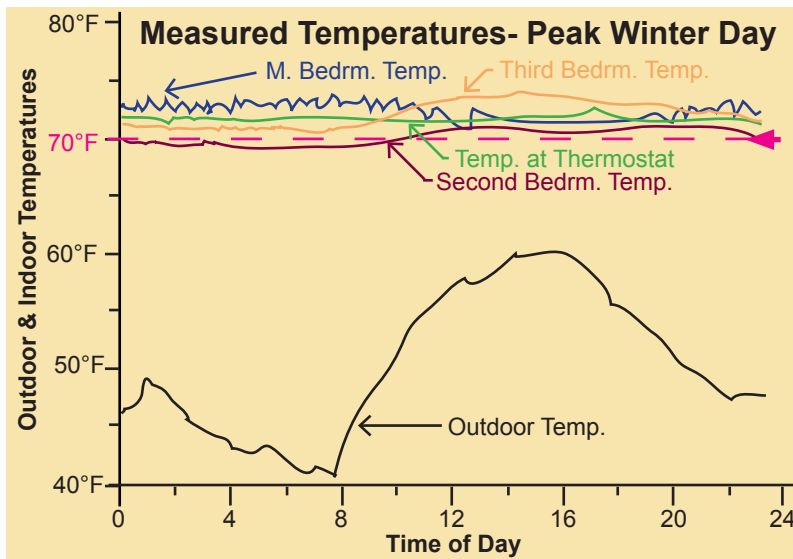


Exhibit 3.34: Performance on a Peak Winter Day

From examination of data collected from the field test it appears that the unit was able to maintain the indoor temperature at the 70°F. thermostat setpoint. Temperature profiles for a peak winter day (December 31, 2006), are shown in Exhibit 3.34. The outdoor temperature profile for a 24-hour period is indicated by the black line. It is important to note that the Comboflair® unit is able to maintain the indoor temperature in all monitored rooms to within ± 2 F.

Since the Comboflair® system relies on hot water from the gas-fired storage water heater for space heating, tests were conducted to determine if the burner capacity and storage capacity of the water heater were adequate to provide sufficient hot water for both space heating and for showers during the coldest hours in winter. Results of space and water heating performance of the Comboflair® system are shown in Exhibit 3.35.

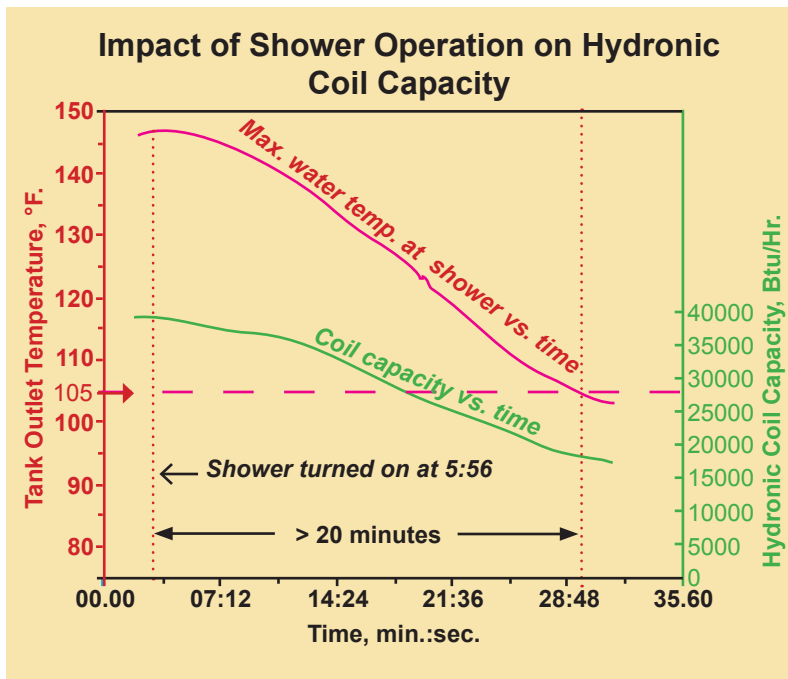


Exhibit 3.35: Impact of Shower Operation on Hydronic Coil Capacity

In this sample test, one shower was turned on at its highest temperature setting during a cold winter day. The shower temperature did not decrease below 105 °F. for over 20 minutes while the unit maintained the indoor space temperature at 70°F. thereby exceeding our goal of providing 2 sequential 10-minute showers with ≥ 105 °F water.

Field testing was successfully completed on May 15, 2007 and the model home was released to Palm Harbor Homes for sale.

4.0 Commercialization of Comboflair®

Design of Production Model

This activity not funded by sponsors

As a result of the field test we have identified a number of component modifications for incorporation into the production models. Component modifications include the following:

- ⊙ Replace single-speed compressor with two-speed compressor for the 3-ton and 4-ton models to improve SEER from 11 to 13.
- ⊙ Replace indoor fan motor with variable-speed, high-efficiency motor for improved SEER.
- ⊙ Install a baffle plate to separate the compressor section from the condenser coil to improve acoustics and serviceability.
- ⊙ Relocate air filter to within the unit enclosure to reduce installation costs.
- ⊙ Recess the unit supports so that exterior wall can be installed without modifying the sole plate.
- ⊙ Provide flange (flashing) on unit for better seal to exterior wall.
- ⊙ Design and fabricate duct transition fittings between unit and trunk duct in attic.
- ⊙ Use a closed loop configuration for the trunk duct in the attic space to ensure automatic balancing of air distribution.

Design of the production model has been completed. This design incorporates the modifications described above and a number of cost reduction measures. Orders have been placed for the new components and fabrication will commence upon receipt of components from vendors.

HUD-Code Issues to be Resolved

This activity not funded by sponsors

The heat source for Comboflair® is a gas water heater which is used for space heating the home and for all water heating applications. Efficient operation of Comboflair® requires the selection of a properly sized water heater in terms of thermal output and water storage capacity. Unfortunately, all water heater manufacturers currently produce only one model of water heater for the manufactured housing market, which has the lowest efficiency and capacity of all their residential products available for sale. The capacity of this model is not sufficient for most Comboflair® applications.

All manufacturers contacted claim that the HUD-Code mandates gas fuel conversion capability for water heaters sold for manufactured housing applications. The HUD Code references UL Standard 307B which requires that “*gas appliance shall be designed to use natural gas and LP-Gas interchangeably or LP-Gas only.*”

Due to this constraint, manufacturers are not willing to produce a range of capacities and efficiencies of conversion-capable water heaters for manufactured housing since this market is relatively small (<40,000 units/year) compared to the conventional residential market (>4.5 million units/year).

HUD officials claim that the reason for the gas convertibility requirement is to allow a homeowner with a piped natural gas supplied home to use propane if the home were to be relocated to a site that does not have piped natural gas. Apparently this is rarely

the case today, because less than 5 percent of manufactured homes are ever relocated.

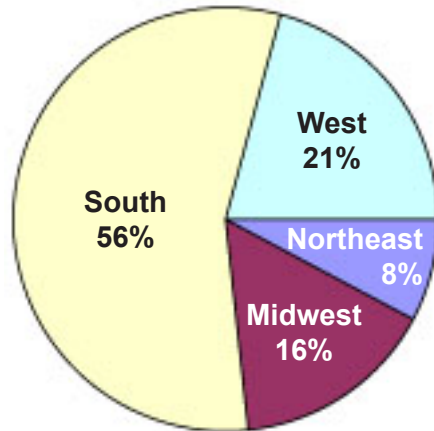


Exhibit 4.1: Shares of Shipments by Census Regions

The project team has initiated a petition to delete the “interchangeability” requirement for water heaters so that any water heater may be used in manufactured homes. Until this requirement is changed, HUD has agreed to provide a waiver to allow any wa-

ter heater to be used with the Comboflair® system under the “alternative construction (AC)” rules.

Manufacturer of Comboflair®

The Comboflair® system will be manufactured, and supported by Unico, Inc. at its new manufacturing facility in St. Louis, MO. where it has the capability to build 3,000 units in the first year. Production of the first units will commence as soon as orders are received. The production of Comboflair® will not conflict with Unico’s production of its existing line of SDHV systems and will not cannibalize sales of its existing products since manufactured housing is a new market for the company.

Product Launch Selecting Target Markets *This activity not funded by sponsors*

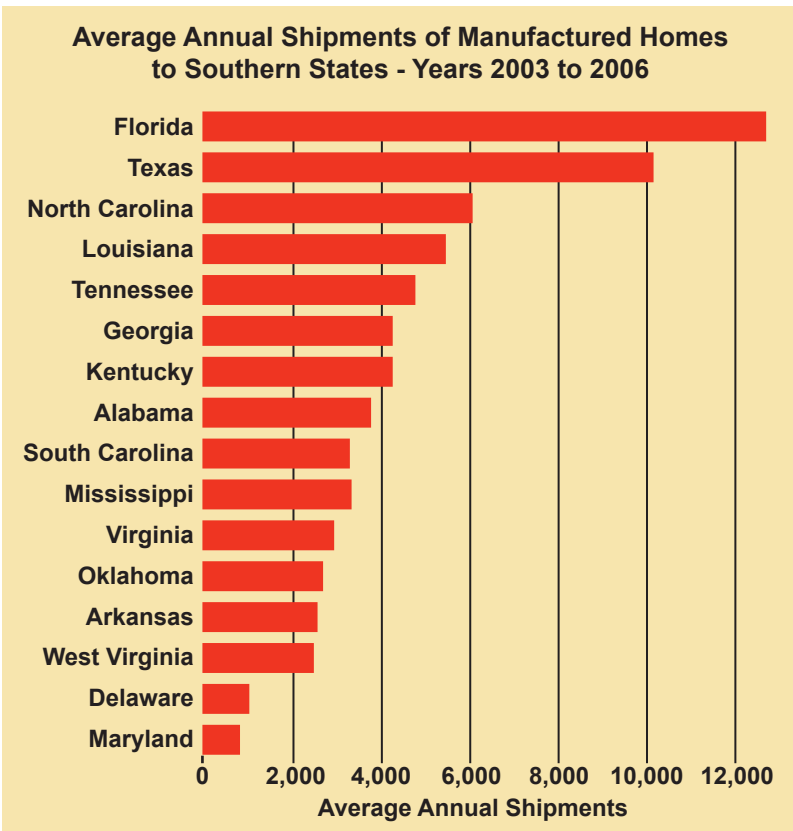


Exhibit 4.2: Average Annual Shipments of Manufactured Homes to Southern States

Comboflair® will be initially launched in the South since more than half of all manufactured home shipments are to the southern states. The chart in Exhibit 4.1 indicates a 56 percent average market share for new shipments to the South during the period of 2003-2006. Within the South Census Region, the state with the highest recent (last 4 years) shipments is Florida with 12,675 homes followed by Texas with 10,075 homes as shown in Exhibit 4.2.

With the assistance of industry stakeholders we have developed a plan to market the Comboflair® which will be launched as soon as orders are received. Comboflair® will be launched in Texas for the following reasons:

- ⦿ Manufactured homes have traditionally been very popular in Texas with over 10,000 installed per year.

- ⊙ A member of the project team, Palm Harbor Homes is headquartered in Texas and the company's plant in Austin, TX has received training and has installed the Comboflair® system in one of their homes. Palm Harbor will offer the Comboflair® as an HVAC option to homebuyers.
- ⊙ The Texas Railroad Commission has offered to support the introduction of the propane-fueled Comboflair® system by providing information about its attributes and with cash rebates to homebuyers and retailers.
- ⊙ The wide range of climatic conditions in Texas from hot/dry conditions to hot/humid coastal conditions will be a good test of the attributes of the Comboflair® system.

Product Launch

Developing Marketing Materials

This activity not funded by sponsors

We have initiated pre-launch activities including the following:

- ⊙ Design of informational brochures targeted to specific audiences: manufactured home builders, home retailers and potential homebuyers
- ⊙ Development of a web site describing the attributes of Comboflair® and products available with specifications
- ⊙ Development of training seminars for manufactured home retailers
- ⊙ Development of incentive programs with state agencies and fuel suppliers for the benefit of home retailers and homebuyers.

Since the field test was conducted on a high-volume dealer's lot we were able to observe the home sales process and the participation of the key players in the sale of manufactured homes. It was very clear that the sales staff at the dealership play the most important role in motivating potential

homebuyers in selecting specific options. Obviously, the salesperson only offers options that he/she is familiar with and that does not require additional work on the part of the salesperson. This is one reason why the majority of homes sold in the South are all-electric despite the high-energy operating costs associated with these homes that use an electric resistance furnace for space heating and an electric water heater for water heating. Promoting all-electric homes is easy because the salesperson does not need to arrange for natural gas or propane connections at the homesite. While most salespersons are familiar with the process to get electric utility connections, they often do not know who to contact for gas service.

The informational brochures will describe the technology and its attributes. For example, the product brochure for prospective homebuyers will emphasize the lower energy operating costs, low noise, improved moisture removal and better quality control since all the space conditioning equipment will be installed in the manufactured home factory. The product brochure for manufactured home producers will emphasize installation flexibility with smaller airtight ducts in the attic, correct sizing of cooling equipment, better quality control and elimination of site installation work. The product brochure and training seminars for sales staff at dealerships will emphasize the lower energy operating costs, low noise, better quality control and elimination of site completion work related to HVAC systems. Natural gas and propane fuel supplier contacts, and information on supplier incentives and propane rebates will be provided to sales staff.

Our sponsors, the natural gas industry and the Propane Education and Research Council have offered to promote Comboflair through multiple channels including newsletters, trade shows, fact sheets and advertising campaigns.

5.0 Additional Research Needs

The project team has successfully developed and tested an integrated space conditioning, water heating and air-distribution system for manufactured housing. All requirements of the sponsors have been fully met and the product is now in the hands of the manufacturer, Unico, Inc. who is committed to produce and commercialize the Comboflair® system.

During the 15-month field testing of the Comboflair® system the team identified research needs in the areas of comfort, efficiency and cost reduction improvements described below:

Comfort Improvements

Comfort improvements include condenser fan noise reduction and precise moisture control capability.

⊙ Condenser Fan Noise Reduction

Interior noise levels due to operation of the airhandler section are minimal and virtually nonexistent when the fan is on low speed. However, the condenser fan which is much quieter than a conventional split-system condenser section creates noise levels that can be considered to be unacceptable if it faces an outdoor living space such as a recreational deck. Additional research needs to be conducted to design a low noise, axial flow fan that also achieves high efficiency for the motor.

⊙ Precise Moisture Removal Control for Hot/Humid Climates

The entry of exterior humid air into homes is being recognized as the major source of most of the indoor air quality moisture related problems in the humid south contributing to toxic mold infestation. Moisture

problems may be exacerbated now that the HUD-Code requires continuous mechanical ventilation of the home using outside air for ventilation. One of the attributes of the Comboflair system is its superior moisture removal capability as compared to conventional air-conditioning systems. However, in order to obtain precise control of moisture levels we need to explore the feasibility of developing auxiliaries and control systems for the Comboflair® system so that occupants can control the indoor moisture levels in their homes regardless of room temperature thereby preventing mold infestation. All air entering the home should be dehumidified by cooling it below its dew point (55° F.) At this temperature, all the moisture in the air will condense and can be drained out of the home. Unfortunately, air at 55 degrees Fahrenheit is too cold for occupant comfort and therefore needs to be heated to the required thermostat temperature of about 75 degrees Fahrenheit in the cooling mode. Our current integrated system could be modified to either use the existing hydronic water-to-air heat exchanger to heat the 55 degree air to the thermostat set points or to add a hot gas reheat coil between the refrigerant compressor and condenser coil. Since our unit is in a single-package configuration, all piping and controls would be housed in the existing unit enclosure.

Energy Efficiency Improvements

Performance test results indicate that the Comboflair® unit meets DOE's minimum efficiency standard of 11SEER for the SDHV class of air-conditioning equipment. Performance testing of the 3-ton and 4-ton sizes of Comboflair production models has

resulted in SEERs of 13.0. This efficiency level was achieved by replacing the single-speed compressor with a 2-speed compressor. We are confident that greater improvements in unit efficiency can be achieved by re-engineering several of the sub-system components such as blower scrolls, motors, refrigerant management and systems controls.

Water Heater Sizing Methodology

The Comboflair® system must meet both the space heating and domestic hot water loads under “design” winter conditions with the lowest expected cold (city or well) water supply temperature, assuming various typical, nominal hot water draw scenarios. It is therefore important to select the appropriately sized water heater (in terms of burner and water storage capacity) and hydronic heating coil for every manufactured home leaving the factory. Since the space heating capacity of the Comboflair® system is fully dependent on the capacity of the water heater, it is essential that a water heater sizing guide be developed for Comboflair® systems.

The proposed guidelines would provide information on the following aspects of comb systems in manufactured and modular homes:

- ⊙ Sizing of water heaters and hydronic heating coils to meet the combined loads of space heating and domestic hot water under design conditions
- ⊙ Sizing of water heaters based on climate differences, especially allowing for cold water supply temperatures occurring in the winter
- ⊙ Sizing of water heaters based on the duration of showers, the number of bathrooms, and the use of washing machines

- ⊙ Sizing of hydronic heating coils based on regional winter design conditions with allowances for night-time setback, when desired.
- ⊙ Commissioning of systems that address the venting (air purging) of the system and calibration of water heater thermostat and tempering valve since temperatures are currently not shown on water heater thermostats and tempering valves.



Exhibit 5.1: Typical thermostat for water heaters does not have temperature markings.

The benefit of using the proposed guidelines is a Comboflair® system that reliably and effectively provides the required space heating and domestic hot water at the final building placement site.

Cost Reduction Improvements

Since manufactured housing is synonymous with low-cost housing, the key issue impacting market success of Comboflair® will be our ability to not only lower the first-cost of the system but also the cost of installing the complete system. We are hoping that the manufacturer of the home will pass on the savings gained from eliminating site completion work, to the homeowner.

⦿ **Reduction of Installation Costs**

We are confident that the Comboflair® system will cost less to install than a conventional system because the complete system will be installed at the manufactured home factory instead of at the homesite by a subcontractor. Upon receipt of each order Unico, Inc. will send pre-formed trunk ducts and pre-cut flex ducts specific to the home model thereby reducing time and labor costs for duct assembly. Unico will also fabricate and stock duct transitions and elbows to suit a variety of roof pitches and sloped ceilings to minimize duct fabrication labor at the manufactured home factory.

⦿ **Reduction of First Costs**

First costs of the Comboflair® system will be higher than conventional HVAC systems in manufactured homes because many of its components are specialized and made in smaller quantities. However, Unico has already started to re-evaluate each component based on cost/benefit analysis and the availability of automated production processes. Upon completion of its new manufacturing and warehouse facility, Unico will be able to value-engineer and fabricate virtually all of the sheet metal-related components of Comboflair® at this facility at lower cost than currently available from vendors because of the inability to obtain quantity discounts at this early stage of commercialization.

Comparative Performance Testing

While the goal of the field test was to evaluate the performance of Comboflair® in a realistic setting, for which we have obtained valuable data, we were not able to compare its performance to that of conventional HVAC and water heating systems in a manufactured home. We were not able to perform side-by-side performance tests with a conventional HVAC system because the Palm Harbor dealer would not site an identical model home (with a conventional HVAC system) on the lot due to space constraints.

We have identified the ideal test site for comparative testing- the manufactured home laboratory at the Florida Solar Energy Center (FSEC). This laboratory consists of a fully-instrumented double-wide manufactured home containing two parallel HVAC systems. One system is a single packaged air-conditioning system with electric heat and an underfloor air distribution system. The second system is an upflow split air-conditioning system with electric heat and a conventional air distribution system with ducts in the attic space.

We are proposing to add the Comboflair® system complete with its small ducts as the third HVAC system in this home. Each of the three systems could be scheduled to run for a week at a time throughout the year to allow us to compare whole building performance and operating costs. The results of this experiment could be used to develop minimum efficiency standards for small-duct, high-velocity systems that would address minimum moisture removal levels and maximum duct leakage quantities in addition to minimum levels of energy efficiency since all these measurements have a direct impact on the operating costs for heating and cooling the home.

Glossary

A/C	Air conditioning unit
Alagasco	Alagasco, headquartered in Birmingham, AL is the largest natural gas utility in Alabama and is one of the two operating units of Energen Corporation. Alagasco is one of the sponsors of this project.
All-Electric Home	Any home that uses electricity for space heating.
ARI	The Air-Conditioning and Refrigeration Institute (ARI) is the trade association representing manufacturers of more than 90 percent of the air conditioning and commercial refrigeration equipment installed in North America. ARI develops standards that establish rating criteria and procedures for measuring and certifying product performance. Performance tests of Comboflair® were conducted in accordance with ARI Standards 210/240-90.
ASHRAE	The American Society of Heating, Refrigerating, and Air-Conditioning Engineers is an international organization whose mission is to advance the science of heating, ventilation, air conditioning and refrigeration and to develop standards and test procedures. Performance tests of Comboflair® were conducted in accordance with ASHRAE Standard 37-88.
Census Regions	Groupings of states that subdivide the U.S. for presenting a variety of data. There are four Census Regions: Northeast, Midwest, South and West.
Comboflair®	Registered trade mark owned by DeLima Associates for an integrated space conditioning and water heating system where the refrigerant section consisting of the air handler, evaporator and condenser coils, compressor and hydronic heating coils and pump are packaged in a single unit.
Condenser Coil	Heat exchanger that rejects heat absorbed by the evaporator and the heat energy input to the refrigerant compressor (in the cooling mode).
Condensing Section	The section of an air conditioning system that consists of the refrigerant compressor, the condenser coil and the condenser fan
DeLima Associates	Management consulting firm located in McLean, VA and the principal investigator for this R&D project.
DOE	The U.S. Department of Energy (DOE), works closely with manufacturers to conduct research and development on technologies for energy efficiency. DOE is a co-sponsor of this R&D project.
Electric Resistance Heating	A space heating system where a resistance-type heating element heats the circulating air either directly or through a metal sheath enclosing the resistance element.
EnergyStar™	A joint program of the U.S. Environmental Protection Agency (EPA) and DOE. EnergyStar™ qualified homes must meet strict guidelines for energy efficiency set by EPA.

Evaporator Coil	Heat exchanger that absorbs heat from the conditioned space (in the cooling mode).
FSEC	Florida Solar Energy Center (FSEC), conducts energy research and is the manager for DOE's Building America Program. FSEC was responsible for instrumenting the Comboflair® test home in Austin, TX and in setting up a remote data acquisition system.
Electric Heat Pump	An electric device with both heating and cooling capabilities that extracts heat from one medium at a lower (the heat source) temperature and transfers it to another at a higher temperature (the heat sink), thereby cooling the first and warming the second.
HUD	The U.S. Department of Housing and Urban Development (HUD), manages the Manufactured Housing Program and monitors, and enforces Federal manufactured home construction and safety standards codified in 42 U.S.C. 5401 et seq.; 24 CFR Part 3280 and Part 3282.
HUD-Code	The Federal Manufactured Home Construction and Safety Standards described in 24 CFR Part 3280 and Part 3282.
HVAC	Heating, Ventilating and Air Conditioning
Hydronic Coil	Heat exchanger used to transfer heat from the water heater in a Comboflair® system to the air stream during the heating mode.
Manufactured Home	The term "Manufactured Home" was adopted in 1974 by the U.S. Congress to describe a type of house that is constructed in a factory to comply with a building code developed by HUD. In the past, manufactured homes were called "mobile homes," a term that is still used frequently.
Palm Harbor Homes	One of the most innovative manufactured home producers headquartered in Addison, TX is known for its highly efficient homes. Palm Harbor is the manufactured homes team member on this project. Palm Harbor provided the test home used on this project.
PERC	The Propane Education & Research Council (PERC), is the research arm of the propane industry and funds the research and development of new and efficient propane equipment. PERC co-funded this project.
SDHV	Small-Duct, High-Velocity (SDHV) system is a novel space conditioning system that uses lower air quantities at higher velocities to condition spaces. The advantages of lower airflow are greater moisture removal and smaller air distribution ducts. The higher flow velocities combined with 2-inch supply outlets facilitates optimal mixing of room air to minimize temperature stratification.
SEER	Seasonal Energy Efficiency Ratio (SEER) is the ratio of the cooling output (Btu.) during its normal seasonal usage to energy input (watt-hrs.) during the same period. DOE has set the minimum SEER for SDHV equipment such as the Comboflair® at 11.0.
Texas Railroad Commission	A regulatory agency that oversees the oil, gas and mining industries in Texas. A specific mission of the railroad commission is to promote the use and safety of propane. The propane marketing staff of the Commission have been involved in promoting the "Propane Manufactured Home"
UL Standard 307B	This standard requires all natural gas water heaters for manufactured homes be designed to use natural gas and propane interchangeably.
Unico, Inc.	Unico, Inc. located in St. Louis, MO is the premier manufacturer of SDHV systems in the U.S. and has been responsible for designing and fabricating the Comboflair® system. Unico, Inc. will manufacture and commercialize Comboflair®.

