Architectual Design and HVAC Assessment Prototyping and Testing Plan - DRAFT

Summary

Dates	
September 2017 through October 2018	
Location	
Test sites: To be determined Climate zones: IECC Zone TBD (Warm-Humid), IECC Zone TBD (Cold)	
Manufacturing Partner	
Hi-Tech Housing, Inc.	
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1 Background

FEMA has established the goal of creating manufactured housing units (MHU) that are capable of providing temporary shelter for survivors after disasters. Four MHU floor plans will be developed: an Express, 1-bedroom, 2-bedroom and 3-bedroom units. The MHUs must be capable of being deployed anywhere in the continental US, simplifying logistics and providing FEMA with consistent and predictable shelter solutions for victims of disasters.

The Test Plan describes the planned process of finalizing the design of all systems, constructing prototype units, transporting them to the test sites, inspection, testing, and long-term monitoring. The goal of this task is to evaluate and refine the MHU designs with respect to architectural layout, universal accessibility, materials and methods of construction, ventilation, space conditioning, fire suppression systems and transportation system design. Two prototype MHUs will be tested—an express and a 3-bedroom unit—in both extreme hot and cold climates. The prototypes will be evaluated through a combination of diagnostic and visual testing and inspection, including both short- and long-term tests that assess MHU system operation and performance. The test results will be used to refine the standard floorplan designs, inform the procurement process and help define a routine quality control process. In addition, the functioning and efficiency of key systems will be verified and quantified.

Research Questions

The key questions to be addressed by this research plan include but are not limited to the following:

- Are the spaces well laid out, spatial configuration rationalized and efficient?
- Do the designs and construction details facilitate the home building process?
- Are the floor plans compact and efficient, and are all spaces accessible? Do the designs conform to the Uniform Federal Accessibility Standards (UFAS), Architectural Barriers Act (ABA), and Emergency Transportable Housing (ETH) requirements? Are there design changes that would more efficienctly or effectively meet these standards?
- Are the building systems—in particular, the space conditioning hot water and sprinkler tank-and-pump systems (TPS)—optimally designed and located? In particular, is the TPS enclosure designed and located such that the TPS is easy to install and access? Are there any space and height constraints for the TPS? Do any other changes need to be made to the sprinkler components and its distribution system to comply with NFPA13D requirements or other system design considerations?
- What are the best HVAC solutions considing efficiency, cost, performance, installation and maintenance of the system? What are the comparative benefits of the alternatives, including system components and distribution? How does the space-conditioning system meet heating and cooling sensible and latent loads in all rooms of the house with respect to ASHRAE-55 and ACCA Manual RS?
- Are the MHUs resistant to long-haul transportation damage? What components and assemblies must be made more robust to avoid transportation damage?

- What ventilation methods best achieve HUD Code ventilation requirements, including consideration of cost, performance, installation, operation and integration with the HVAC system design?

2 Approach

Two types of MHUs—the Express Unit and the 3 Bedroom Unit—will be tested in extreme heating and cooling climates. There are five primary areas of testing and assessment:

1. Architectural design
2. Accessibility of spaces
3. HVAC design
4. Fire Sprinkler/ TPS design
5. Transportation damage assessment

In addition, this task will coordinate with other tasks associated with bulk water testing, foundation system and structural design evaluation and with a separate assessment of transportation system design being conducted for FEMA by Oak Ridge National Laborary.

The designs to be built and tested are described below:

The Express Unit is the smallest and the most compact MHU. This unit is intended to fill the need of quick disaster response. In order to transport homes rapidly without a permit, they must be 8’-6” or narrower in width and less than 53’ in length. The unit has living and dining spaces, one bedroom and one bathroom. All spaces are designed as accessible in compliance with Uniform Federal Accessibility Standards (UFAS) and Architectural Barriers Act (ABA). The floor plan is shown in Figure 1.

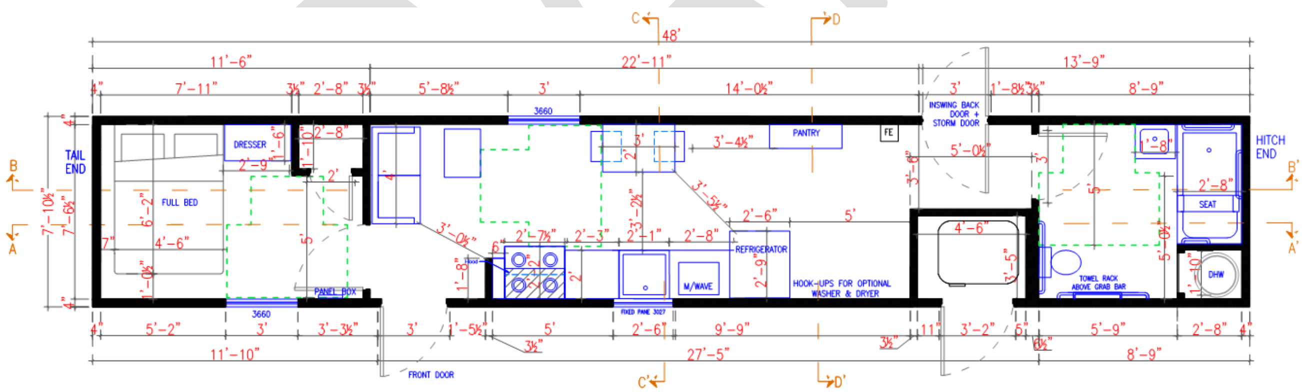

Figure 1 Express Unit Floor Plan

The 3-Bedroom Unit is the largest MHU with three bedrooms and two bathrooms. All areas are considered “accessible” except for the third bedroom, as required by Uniform Federal Accessibility Standards (UFAS), Architectural Barriers Act (ABA), and Emergency Transportable Housing (ETH) requirements. The designs of the 1, 2, and 3 bedroom units take a modular approach. The 2-bedroom unit is essentially identical to the 1-bedroom but with an additional bedroom added to one end. The 3-bedroom unit has two bedrooms and a bathroom added to the end of the 1-bedroom design. This modular approach is intended to simplify manufacturing, component sourcing and service/ maintenance. It also simplifies testing in that testing the 3 bedroom unit can help verify the operation and functionality of the one and two bedroom units as well. The 3-bedroom plan is shown in Figure 2.

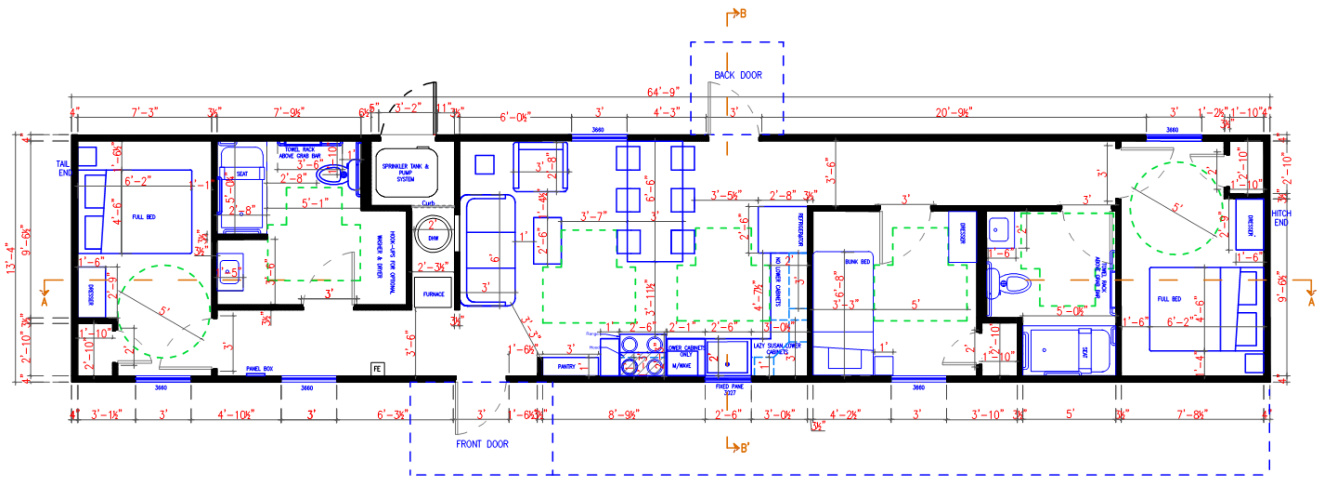

Figure 2 Three Bedroom Unit Plan

Characteristics to be tested

This task will involve the construction, transportation, set up, monitoring, and data analysis from the prototype MHUs with the following physical characteristics tested:

1. **Hygrothermal integrity of building envelope:** Based on hygrothermal modeling of various wall, roof and floor options, assemblies that were found to be most effective in terms of moisture resistance were selected for further testing. The most promising assemblies among them were specified for the two test homes for long-term testing, as seen in Figure 3. This testing will be conducted in parallel with hygrothermal testing of all shortlisted wall options under Task E-CONUS.

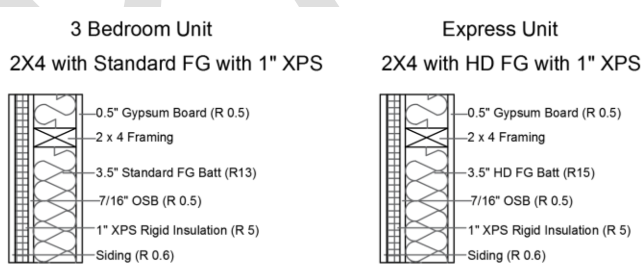

Figure 3 Wall assemblies: Test Units

2. **Comfort achievement with space-conditioning technologies:** In the 3 bedroom unit, an SPVU and a standard split system will be installed, with the furnace placed in the mechanical room of the home. In the Express unit, an SPVU and a ductless heat pump will be installed along with through-wall transfer fans that move conditioned air between living spaces, obviating the need for ducts. These HVAC systems will be tested one at a time to determine their capability of maintaining comfort in each of the homes. Along with verifying performance metrics for comfort, ease of installation, maintenance, dehumidification capability and operability of the systems will also be evaluated. Figure 4 and Figure 5 show the the HVAC systems to be installed in the test homes for long term testing.

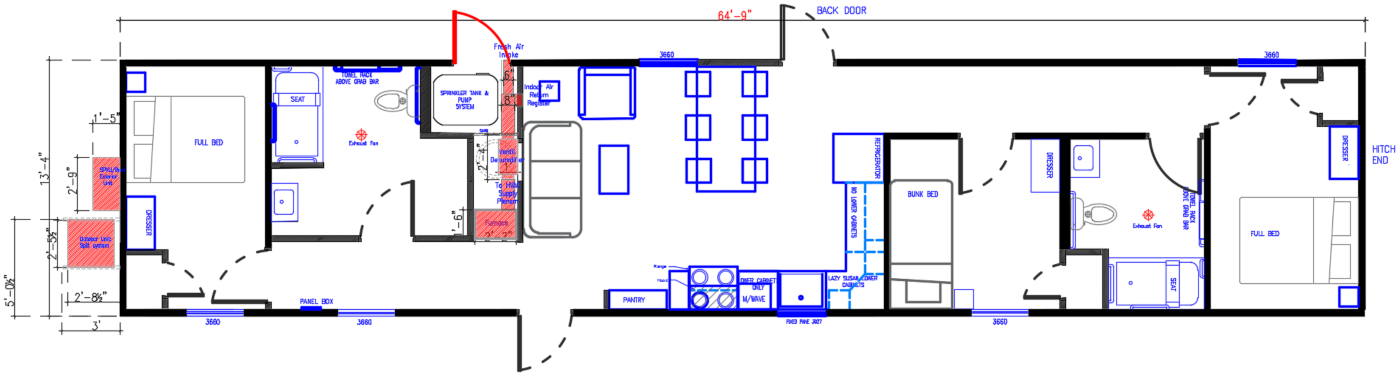

Figure 4 HVAC Systems for testing in the 3 bedroom Unit

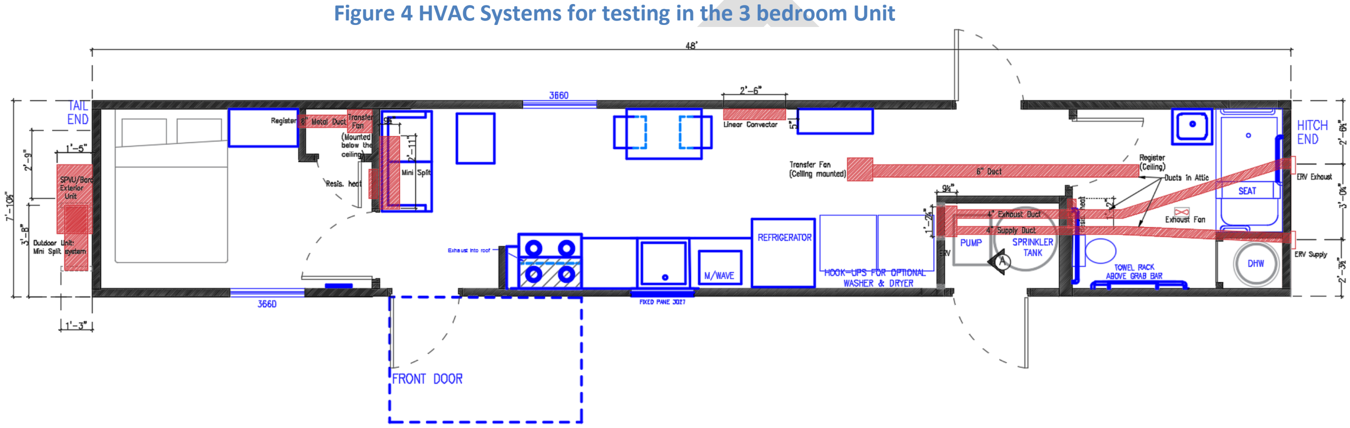

Figure 5 HVAC Systems for testing in the Express Unit

3. **Comfort and compliance of the whole-house ventilation system:** A dehumidifying ventilator will be installed in the mechanical room of the 3 bedroom unit. The Express Unit will incorporate an ERV in the TPS closet with its supply and return running through the attic to the hitch end. Compliance with the ventilation rate capacity requirements of the HUD Code as well as ASHRAE 62.2 will be assessed.The location of the ventilation systems in the test homes is shown in Figure 4 and Figure 5.

4. **Accessibility:** Interior spaces will be inspected for compliance with Uniform Federal Accessibility Standards (UFAS), Architectural Barriers Act (ABA), and Emergency Transportable Housing (ETH) requirements. If measures are required to be performed on site to attain full accessibility (e.g., changing out appliances or adding ramps), the process will be documented and assessed with regard to simplicity, expense, and ease of implementation.

5. **Quality and Utilization of space:** All spaces will be visually inspected to ensure that the layout is efficient and compact and the space alloted for each function is sufficient.

6. **TPS planning, layout, and connection:** Prototyping of the TPS system will evaluate the adequacy of allotted space, constructability of the system, functionality of the compartment, operation of the system and efficiency of the layout (with regard to access, maintanence, installation, removal, operation, etc.).

7. **Bulk water resistance:** In coordination with Task A, water tests will be conducted to evaluate if assemblies and components are resistant to bulk water intrusion.

8. **Transportation durability:** In coordination with ORNL, the two test units will be transported over a specified distance and road conditions, after which they will be inspected for damage and other effects of the wear and tear of the road.

Performance Metrics

The characteristics listed above will be evaluated against the following performance metrics:

1. **Hygrothermal integrity of building envelope:** The hygrothermal integrity of the envelope will be checked by equipping the wall cavities with moisture sensors in wood sheathing to ensure that the readings obtained are within an acceptable threshold not conducive to microbial growth (roughly 16% in wood (Doggett, 2013)). Moisture content in roof trusses, as well as temperature and RH in the attic, will be measured to evaluate the roof-venting method in conjunction with overall roof construction and insulation.

2. **Comfort achievement with space-conditioning systems:** The space conditioning system must meet heating and cooling sensible and latent loads in all rooms of the house. Performance of the MHUs will be compared to ASHRAE 55 and ACCA Manual RS comfort standards. A summary of the major requirements of these two standards is provided in the tables below.

Table 1 Thermal Comfort Metrics as per ACCA Manual RS 2005

Comfort item	Heating	Cooling
Thermostat setpoint (design)	70˚F	75˚F
Relative humidity (RH)[1]	30% RH maximum (20 – 30% RH is desirable)	55% RH maximum (25 – 50% RH is desirable)
Dry-bulb temperature at the thermostat	Setpoint temperature ±2°F	Setpoint temperature ±3°F (single-zone) Setpoint temperature ±2°F (multi-zone)
Dry-bulb temperature in any conditioned room	Setpoint temperature ±2°F	Setpoint temperature ±3°F (single-zone) Setpoint temperature ±2°F (multi-zone)
Room -to-room temperature differences	4°F maximum	6°F maximum (single-zone) 4°F maximum (multi-zone)
Floor temperature (slab floors or floors over unconditioned space)	65°F minimum at 4" above the floor for 70°F thermostat setting (not applicable near outside walls)	NA

Table 2 Thermal Comfort Metrics as per ASHRAE Standard 55

Comfort Item and Standard	Allowable limits
Section 5.2.1.1-1: Operative temperature	As per acceptable limits ASHRAE 55 Section 5.2.1.1-1 (determined by Section 7 and Appendix C).

[1] Humidification is optional, but desirable in many situations. The potential for visible or concealed condensation determines maximum RH for a specific dwelling in a specific location.

Comfort Item and Standard	Allowable limits
Moisture Content	Roughly less than 16% moisture content in wood, according to (Doggett, 2013)
Humidity	Systems designed to control humidity must be able to maintain a dewpoint temperature of 16.8°C (62.2°F). Below 0.012 as per Humidity limits Section 5.2.2.
Section 5.2.4.1: **Local discomfort due to radiant temperature asymmetry** **Section 5.2.4.4:** **Local discomfort due to floor surface temperature**	Ceiling not allowed to be more than 5°C (9.0°F) warmer than other surfaces. Wall may be no more than 23°C (41°F) warmer than the other surfaces. Ceiling not allowed to be more than 14°C (25.2°F) cooler than the other surfaces. Wall may be no more than 10°C (18°F) cooler than the other surfaces. Floor temperatures stay in the range of 19–29 °C (66–84 °F).
Section 5.2.4.3: **Local discomfort due to vertical air temperature difference**	Not greater than 3 °C (5.4 °F) from ankle height to head height.
Cyclic variations: positive or negative (drifts/ ramps)	In any 15-min period, up to 2°F change In any 30-min period, up to 3°F change In any 60-min period, up to 4°F change In any 120-min period, up to 5°F change In any 240-min period, up to 6°F change

MHU comfort will be considered successful if in compliance with ASHRAE 55 at least 95% of the time. ACCA Manual RS temperature setpoints will be used. RH maximum threashold will be based on a maximum dew point of 62.2°F (given a maximum indoor temperature of 78°F, the max relative humidity would be 58%). Condensate measurements will be taken for cooling systems and any dehumidifiers present.

Additional evaluation metrics for the HVAC system will be:

- Quiet operation of equipment: Maximum equivalent continuous sound level L_{eq} of 30 **dB_A** in bedrooms and 50 in other rooms **dB_A**.
- Ease of installation, maintenance, and operation.

3. Compliance of the whole-house ventilation system

The whole house ventilation system must meet HUD Code ventilation-rate requirements. Per the HUD Code, the whole house ventilation system capacity must be at least 0.035 cfm/sf floor area with a minimum of 50 cfm (although there is a proposed change to allow compliance with ASHRAE 62.2-2010). There is no requirement for a continuous or hourly continuous equivalent ventilation rate. Incorporating a continuouos ventilation rate will be considered using one of the ASHRAE 62.2 standards:

- ASHRAE 62.2 2010: is 7.5cfm/person plus 1cfm/100 square feet floor area
- ASHRAE 62.2 2013 and 2016: 7.5cfm/person plus 3cfm/100 square feet floor area

Table 3 Continuous whole house ventilatIon rates for each MHU and ASHRAE standard

MHU	Design occupancy (people)	ASHRAE 62.2, 2010	ASHRAE 62.2, 2013 and 2016
Express	2	19 cfm	27 cfm
1 Bed	3	28 cfm	38 cfm
2 Bed	4	36 cfm	49 cfm
3 Bed	6	54 cfm	71 cfm

Another performance metric for the whole house ventilation system is the quiet operation of equipment. The ENERGY STAR New Homes program requires continuously operating ventilation fans to be rated at 1 sone or less. This will be the performance target for the whole house ventilation system.

4. **Accessibility:** The architectural design in all units must meet the following design and accessibility requirements:
    - HUD Code as defined in 24 CFR 3280 & 3282.
    - UFAS, ABA, and ETH requirements for accessibility.
    - FEMA rugged base performance specifications.
5. **Quality and Utilization of space**: The MHUs must be well designed with appropriate space utilization.
6. **TPS planning, layout, and connection:** The fire sprinkler system, consisting of the Tank-Pump System as well as the distribution system, must comply with all the requirements of NFPA13D. It must also be evaluated for the following:
    - Overall sizing and layout: does a TPS adhering to the provided specification fit in the TPS closet? Can the system be installed in the MHU without difficulty?
    - Parts configuration: is the TPS serviceable? Can it be periodically tested as specified? Is any maneuvering of furniture, etc. required for testing or servicing? Can the controls be easily accessed by maintenance personnel but not by the occupant?
    - Can installation be improved? Are any installation processes specifically subject to causing damage (e.g., of the Neopor floor membrane, interference with drains/pipes or mechanical systems)?
    - Is the tank/pump easily filled by connecting the TPS to a standard water supply?
    - Do all alarms work?
    - Does alarm silencing work?
    - Is the water level visible in the tank or otherwise monitored?
    - Are the controls easy to operate? Is the interface interpretable?
    - Is the TPS easily drained? How is this accomplished?
    - Are the supporting structural system and foundation sound?

    In order to test the TPS system,it must be installed in the MHU and connected to water and power. This will be done after installation:

    - Water and electrical connections will be made as dictated by the TPS instructions provided. Any alterations required should be noted.
    - Plug-and-play parts are placed, as instructed.
    - The pump/tank is filled, and the system is turned on.
    - Tests are completed, including any self-test features and maintenance tests.

- The unit is decommissioned—turned off and drained.

Additionally, while constructing the MHU, it will be noted whether the sprinkler-distribution system and soffits are easily installed. After transportation to the site, the distribution system will be visually checked for deformation or separation from walls/ceilings to ensure that the system and its installation holds up to transportation.

7. **Bulk water resistance:** Water tests will be conducted in coordination with Task A; likely using the AAMA Standard 502-08 standard under a protocol developed in that ask.
8. **Transportation durability:** A specific long-haul transportation damage inspection protocol will be developed in collaboration with FEMA that will include inspections for drywall cracking, structural member (floor and truss component) separation or loosening, floor separation from joists, chassis-system deformation, nail/screw popping, shifting of internal furnishings and fixtures, and any other obvious damage. The checklist will be based on typical manufacturer inspection checklists and/or existing FEMA protocols. Ship-loose design details and strategies will also be evaluated by observing any broken or shifted furniture pieces, appliances, doors, and stored parts. This subtask will be coordinated with the ORNL chassis and running gear evaluation and development effort in order to test ORNL recommendations as available at the time of the build and obtain performance data. TLP will be responsible for damage evaluation of the MHUs with the exception of the chassis/running gear, which will be the responsibilkity of ORNL.

Measurement Protocols

Hygrothermal measurements

Compliance with hygrothermal criteria will be measured as follows (data collected at 1-min (maximum)) intervals:

1. RH measurements of interior spaces.
2. RH measurements and moisture content in cavities.

Upon setup in the northern location, the plumbing system will be filled with water to determine if pipes freeze. Thermocouples (2) will be located on water pipes in vulnerable locations.

Comfort measurements

Equipment used to assess comfort are listed in Table 4 and Table 5. All data is to be collected at 1-minute intervals.

Table 4 Monitoring Equipment for comfort measurements

Description/Purpose	Make and Model of Monitoring Equipment (or equal)	Qty per MHU
Data logging equipment	Campbell Scientific datalogger, model: CR1000 & power supply – data acquired every 60 seconds and collected remotely	1
	Campbell Scientific, Multiplexer model: AM16/32B	1
	Raven Cell Modem	1

Description/Purpose	Make and Model of Monitoring Equipment (or equal)	Qty per MHU
Power measurements	Wattnode Power Meter (Continental Control Systems, WNB-3Y-208-P)	3

Table 5 Monitoring Sensors

Description/Purpose	Make and Model of Monitoring Sensors	Qty / location per MHU
Air and surface temperature	Watlow thermocouples	**3 (Express) 6 (3-Bedroom);** 5 ft above the floor, > 5 ft from heating/cooling systems and exterior walls; at 60” above floor in each room; **6**; 2 on floor, 2 on ceiling and 2 on walls at rooms farthest from heating/cooling source
Air temperature/RH	Campbell CS215 Probe	**1 in space**
T/Humidity and wood Moisture Content	Omnisense S-1 Wireless sensor monitors	**6**; (In N & S walls, 2 in roof cavity, 2 in floor)
In-situ dehumidification capacity of HVAC system	Campbell Scientific TE525-L Rain Gage with 6 in. Orifice (condensate measurement)	**1** (Southern Site only)
Total House Power	Continental Control Systems, ACT-0750-100	**1**
Heat pump Power	Continental Control Systems, ACT-0750-20	**2**
Heat pump Reversing valve		**2**
Dehumidifier		**1** (3 Bed only)
Transfer fans		**2** (Express only)
Bath fan		**1** (3 Bed only)

The rain gauge will be used to measure the amount of moisture the cooling and dehumidification equipment removes vs. its rated capacity. This will be used to determine whether a different setting is required on the equipment, a different capacity of dehumidifier should be installed, or if the cooling equipment is performing better than expected and the MHU does not need a dedicated dehumidifier.

Ventilation measurements

Measurements of the continuous and non-continuous air flow rates will be made of all ventilation systems and exhaust fans – including kitchen and bathroom. One-time measurements will be made during commissioning. If ventilation rate is dependant on other system operation (i.e. air handler) then the ventilation rate will be measured when the other system is on (at multiple speeds if applicable) and long term system operation measurements will be used to extrapolate 24-hour average ventilation rates over the monitoring period.

Table 6 Ventilation Tests

Test	Purpose	Equipment/method
Ventilation rates	Rate of whole house ventilation and local exhaust	Powered capture flow hood: Energy Conservatory FlowBlaster or similar

Other measurements

Additional measurements will be made to evaluate energy efficieny and quality of construction. One-time measurements will be made during commissioning (Table 7). Long-term energy measurements will be made over the course of the monitoring period () and will use the same data logging and transmission equipment as the comfort measurements.

Table 7 Commissioning Tests

Test	Purpose	Equipment/method
Enclosure leakage	Quantify airtightness of enclosure	Multipoint, pressurization and depressurization using Energy Conservatory blower door system or similar
Duct leakage (as applicable)	Quantify airtightness of ductwork	Pressurization using Energy Conservatory duct blaster or similar. Space conditioning ducts only; not transfer fan ducts wholly within the conditioned space.
Air handler air flow (as applicable)	Forced air system airflow	Energy Conservatory duct blaster or similar
Thermal imaging (Optional)	Detect and document insulation quality, also to investigate enclosure air leakage pathways	RESNET protocol
Pressure balance	Determine relative pressure across the envelope during operation	Monometer measurements with and without ventilation system operation
Bedroom pressure balance	Check if door closure creates unbalanced pressures in the MHU	Monometer measurements across closed bedroom doors with and without ventilation system/space conditioning system in operation
Sound levels	Quantify aural comfort based on MHU equipment	Sound meter to measure average continuous sound level in bedrooms and living room

Subtasks

Key tasks to be performed at the plant are listed below.

Subtask 1: Construction of Test MHUs

Two MHUs, one 3 bedroom unit and one Express Unit will be constructed and moved to the sites selected for testing. It may be preferred to choose sites that are near or co-located with the production facility to simplify coordination and logistics for the research team. However, climate location will take priority. The MHUs will be built under team supervision and the entire process will be well documented. Production will also be documented and assessed as part of the production process evaluation, Task F.

Production efficiency as it relates to specific MHU design and construction details will be assessed during production by documenting key process times and labor requirements. The MHUs will be outfitted with the furniture and mechanical equipment as per the specifications. Monitoring equipment such as building cavity embedded sensors and wiring will be installed during the manufacturing process.. A pre-shipment inspection will be conducted to later compare to a post-shipment inspection in order to document any damage that occurred during transport.

Duration: 1 month

Subtask 2: Transportation and Installation of MHUs in Northern Site

This subtask includes a long-haul transportation evaluation (in coordination with ORNL), installation/foundation evaluation (in coordination with Task C: Foundation System Design and Assessment.) Once the MHUs are constructed, a visual inspection will be completed with comprehensive documentation before they are transported. The transportation road test protocol will be followed: The distance between the factory and the test site will be incorporated into the transportation test. . The transportation damage inspection protocol will be completed prior to installation so as to distinguish between transportation and installation-related damage. An abbreviated inspection will take place after installation. On-site construction work includes the installation of a ramp and stairs.

Duration: 1 month

Subtask 3: Conduct Visual Inspection

Once the test MHUs are installed, a visual inspection will be conducted to inspect for installation-related damage and check if the layout of the MHUs is compact and efficient and complies with UFAS and ABA so that the MHUs are designed with universal accessibility.

Through a visual inspection, it will be verified that the unit meets the following requirements:

- HUD Code as defined in 24 CFR 3280 & 3282.
- UFAS, ABA, and ETH requirements for accessibility.
- FEMA Rugged Base Performance Specifications.

The key aspects requiring verification are as follows:

- Accessibility: Approaches, turning spaces, reaches, operability, controls, thresholds, and other misc. accessibility compliance.
- The location, safety, and accessibility for maintenance of all mechanical equipment. Ensure that controls are not easily lost or breakable.
- The location, safety and accessibility of electrical mains, switches and connections.
- The location and accessibility of water mains, pipe connections, and shut-off valves.
- The components of the sprinkler system: well concealed and properly distributed without obstructions.

Any concerns with respect to the design and planning of spaces or their accessibility will be noted and suggestions for improvements will be described in the subsequent report.

Duration: 1 week

Subtask 4: Short Term Testing and Instrumentation

After installation several short term tests commissioning will be performed as described in Table 7 and site-installed data collection equipment will be set up and tested.

Duration: 1 week

Subtask 5: Long Term Testing - North

The test MHUs will be monitored for an entire heating season to evaluate the operation of the HVAC equipment. During the testing period, the MHUs will be operated as follows:

Thermostat set points: The heating set point will be 70°F and the cooling set point (if needed) will be 75°F (per ACCA Manual RS).

Internal gains: Sensible and latent internal heat gains impact energy consumption and comfort. Latent loads will be simulated during the monitoring period through the use of ultrasonic humidifiers using methods previously employed by NREL (Fang et. al 2011). Sensible gains will be simulated with electric resistance heaters. Internal gains will controlled by the data logger and operate per the Building America protocol based on the number of occupants predicted by FEMA for the specific MHU type.

Ventilation system: The ventilation system will be operational.

Multiple HVAC Systems: Multiple systems will be operated in alternate periods (approximately weekly or bi-weekly changeovers, depending on weather conditions) to evaluate both and compare them.

Duration of Testing: Approximately 6 months in Northern site

Subtask 6: Transfer MHUs to Southern Site

Secure MHUs for transport, remove from foundations and haul to southern site. Once installed at Southern site, repeat commissioning tests and re-commission data collection system. Conduct damage inspections before transportation and upon arrival at southern site.

Duration: 1 week

Subtask 7: Long Term Testing - South

The test MHUs will be monitored for an entire cooling season to evaluate the operation of the HVAC equipment. Testing will be similar to the northern testing procedure.

Duration of Testing: Approximately 6 months in Southern site

Subtask 8: TPS System Installation and Testing

The Sprinkler Tank-Pump Systems will be installed in the MHUs on site and the installation process will be evaluated. Once installed, the systems will be connected to water and power and tested. Working of other aspects of the Fire sprinkler system such as the distribution system, soffits, fire alarms and controls will also be assessed.

Duration of Testing: Approximately 6 months

Subtask 9: Bulk Water Testing

At the southern site the MHUs will be tested for bulk water intrusion in coordination with Task A: Bulk Water Testing. Any failures will be thoroughly investigated and repaired before MHUs are transported in the following subtask.

Duration: 1 week

Subtask 10: Reporting of Results

All the measurements and results obtained from the testing will be recorded and included in a detailed report. Issues will be identified and corrective recommendations made. In the case of multiple systems testing, the analysis will compare them in terms of total costs (acquisition and operation) effectiveness, energy efficiency and practicality.

Duration: 4 months

Subtask 11: Decommissioning and Disassembling of MHUs

After testing is complete, the MHUs will be decommissioned. Sensors and other monitoring equipment will be removed, the sprinkler tank/pump system is drained and the MHUs will be dismantled and disposed or turned over to FEMA. Any potentially destructive testing or inspections will be conducted at this point.

Duration: 3 months

Summary of Subtasks:

The sequence of events and the their corresponding time period is shown in Table 8

Table 8 Sequence of subtasks

	Subtask	Subtask summary	Start date	End date
1	Construct MHUs	• **Source materials and components** for construction • **Build and oversee construction of MHUs** at the factory • **Equip the MHUs** with furniture and mechanical equipment • Test the **sprinkler system** pressure and flow for compliance with NFPA13D.	September 5, 2017	Nov 4th, 2017
2	Transport and Install MHUs	• Move MHUs to the Northern test site and conduct **transportation** testing • **Install MHUs** and other site components at test site • Coordinate with Task C: **Foundation System Design and Assessment**	Nov 4th, 2017	Nov 10, 2017
3	Conduct Visual Inspection	• **Visually examine** accessibility and efficiency of spaces, access to equipment for maintenance, sprinkler distribution system, electrical controls and other features.	Nov 11, 2017	November 20, 2017

	Subtask	Subtask summary	Start date	End date
4	**Conduct Short Term Testing and Install Monitoring Devices**	• Conduct **short term tests** to evaluate the envelope leakage, TPS operation, airflow, etc. • **Install and commission** monitoring devices needed for the evaluation of the MHUs. • **Calibrate equipment** and ensure all systems are working properly.	Nov 11, 2017	November 20, 2017
5	**Long Term Testing: North**	• **Monitor the MHUs** for one heating season for comfort and energy use. • Note the ability of the system to **meet the latent loads** and ensure humidity control by measuring air temperature and RH in the MHU. • Test the efficacy of the **ventilation system**.	Nov 11, 2017	April 15, 2017
6	**Transfer MHUs to Southern Site**	• Move MHUs to the Southern test site • **Install MHUs** and other site components at test site	April 15, 2018	April 30, 2018
7	**Long Term Testing: South**	• **Monitor the MHUs** for one cooling season for comfort and energy use. • Note the ability of the system to **meet the latent loads** and ensure humidity control by measuring air temperature and RH in the MHU. • Test the efficacy of the **ventilation system**.	April 30, 2018	September 30, 2018
8	**TPS Installation and Testing**	• **Install the Sprinkler Tank-Pump** Systems in the MHUs on site. • **Assess the installation process** and working of components such as the distribution system, soffits, fire alarms and controls.	May 14, 2018	May 30, 2018
9	**Conduct Bulk Water Test (coordinate with Task A)**	• Conduct **bulk water tests** to evaluate if the building components are resistant to bulk water intrusion	July 1, 2018	July 30, 2018
10	**Prepare Report**	• **Analyze and document the data** measured, observations made and results obtained during the testing process. • **Identify any concerns** with the design and recommend changes. • Determine the **ideal HVAC system** of those tested.	July 1, 2018	October 31, 2018
11	**Decommission MHUs**	• **Remove sensors and testing equipment**, disconnect test structures from utilities • **Recycle or dispose** off the test structures or turn over to FEMA	September 1, 2018	October 31, 2018

Team Info

Key team members and partners involved in the project are listed in Table 9 below.

Table 9 Key personnel contact information

Company	Name	Email	Contact No.
		Manufacturing Plant Staff	
Hi-Tech Housing, Inc.	Doug Mills	doug.mills@hi-techhousing.com	(574)-848-5593
		Subject Matter Expert Panel	
Cavalier Homes	Michael Wade	mwade@cavhomesinc.com	(256) 612-7265
Cavco Industries	Manuel Santana	manuels@cavco.com	(602) 283-9090
Champion Homes	Jeff Frederick	Jfrederick@championhomes.com	(248) 614-8213
Clayton Homes	Tom Rehrig	tom.rehrig@clayton.net	(865) 243 5101
Deer Valley Homes	Chet Murphee	cmurphree@deervalleyhb.com	(205) 468-8400
Hi-Tech Housing	Charles Fanaro	charles44@gmail.com	(847) 441-6608
	Larry Stephan	lstephan3@gmail.com	(847) 441-6090
Lexington Homes	Harold Weaver	Hweaver@lxhi.biz	(662) 834-0292
	Matt Riley	mriley@lxhi.biz	(662) 834-0292
Mark J. Mazz, AIA, LLC	Mark Mazz	Mark.j.mazz@verizon.net	(301) 440 4276
Oak Creek Homes	Charley Boyer	cboyer@hstr.com	(256) 747-7504
Palm Harbor Homes	Bert Kessler	bkessler@palmharbor.com	(972) 763-5044
Platinum Homes	Mike Terrian	mike.terrian@hstr.com	(205) 412-2609
River Birch Homes	Brad Mikels	Brad.Mikels@ClaytonHomes.com	(205) 935 1997
Windstorm Holdings	Ken Cashin	kcashin@wind-storm.net	(850) 757-4709
		Administrative and Technical Support	
The Levy Partnership	Emanuel Levy	elevy@levypartnership.com	(917) 817-3385
	Jordan Dentz	jdentz@levypartnership.com	(212) 496-0800 x130
	Zoe Kaufman	zkaufman@levypartnership.com	(415) 205-4123
	Radhna Saxena	rsaxena@levypartnership.com	(412) 652-8174
	Kaushik Biswas	biswask@ornl.gov	(865) 574-0917
Mountain Energy Partnership	Ed Hancock	cehancock3@aol.com	(303) 517-8238
	Greg Barker	gbarker123@aol.com	(303) 651-9788