Systems SBRA Building Research Alliance

FEMA Manufactured Housing Units For Disaster Relief: A Comprehensive Research Portfolio

Summary of Tasks

A. Architectural Design and HVAC Assessment

A thorough and detailed set of designs and specifications of proposed standard floorplans providing FEMA MHU suppliers with guidance on how to construct the next generation of MHUs.

B. Foundation System Design and Assessment

Standard foundation designs for use with the next generation FEMA MHUs that are refined through field prototyping and testing.

C. Process Engineering and Management

Value Stream Mapping and lean process analysis of the entire MHU-delivery process from procurement through occupancy and home recycling/reuse. The task will identify streamlining opportunities, minimizing the total cycle time required to get MHUs into service and the resources required.

D. Moisture and Thermal Performance Testing of CONUS Assemblies

Identifying candidate envelope components, modeling their hygrothermal and thermal performance and field-testing the viable options for durability under CONUS conditions.

E. Develop and test an Internal TPS design

Development of a sprinkler tank and pump system (TPS) capable of being placed within the conditioned thermal envelope of the MHU including related prototyping and testing.

F. Facilitate the Design, Testing and Evaluation of a Ruggedized Chassis System Design

Facilitate the identification and testing of methods for constructing more robust MHU chassis system design(s) that are sufficiently durable to withstand the rigors or long distance shipping and difficult road conditions. Technical lead: Oak Ridge National Laboratory.

G. MHU Completion Process: Compressing Time from MHU Delivery to Occupancy

Significantly reduce the time between when an MHU is available at the installation site and its availability for occupancy, focusing on solutions for providing power and potable water and black water containment/removal.

H. Bulk Water Testing

Design, selection and testing of fenestration products, including standards, details and installation specifications that ensure an effective barrier to water intrusion.

Task Descriptions

A. Architectural Design and HVAC Assessment

The goal of this task is to conduct a thorough and detailed evaluation of the proposed MHU standard floorplan designs, assessing them from critical perspectives and refining the designs based on the results. Using prototype MHUs built to the preliminary floor plans and specifications, an assessment will be conducted to verify efficient utilization of space, accessibility, design and working of the space conditioning, ventilation and other key systems. Tasks include the following:

- **Prepare a test plan** that provides a detailed description of the components and systems to be tested, the method of testing including instrumentation, data to be collected, physical location of the tests, test conditions, and related matters. It is anticipated that two prototype test homes will be constructed and placed in two locations with extreme heating and cooling/humidity conditions (tentatively assumed to be FEMA facilities in Selma, AL and Cumberland, MD).The units will be moved between locations to capture peak weather conditions.
- **Convene SME**. The test plan and anticipated results will be presented to the SME panel for review. The Plan will be revised to reflect SME comments.
- **Secure test sites**. Sites will be identified for the testing and arrangements made for site placement, provision of power, and internet service. The selected sites will need to be secure and a technician available to service the unit if needed during the data collection process
- **Select builders, construct test units**. Contract documents will be developed for the construction of the two units. For the construction of each module, several competing bids will be sought. As part of this task, key materials, systems, components and products will be sourced at no cost to the project from partners
- **Oversee unit manufacturing.** The construction of the units will be supervised by the team to assure strict compliance with design intent and proper installation of products and materials. Issues associated with home fabrication will be documented for later analysis.
- **Commission test units**. Move and install the test units to the test locations and commission. Set up and calibrate equipment. Ensure all systems are working properly and that interior conditions are stable.
- **Conduct tests and collect data**. The tests described in the Test Plan will be carried out and documented. Depending on the type of evaluation, design changes may be made based on initial results (alternative configurations of the HVAC equipment, relocating cabinetry for better accessibility, etc.).
- **Interim reporting.** Interim results will be reported to FEMA and SME on a quarterly basis for guidance on changes to be made and additional tests to be conducted.
- **Decommission, disassemble and dispose of units**. This task includes removing sensors and testing equipment, disconnecting test structures from utilities, and recycling or disposing of all elements of the test structures. This task will be carried out following any subsequent use of the units for other tests.

- **Final report**. A final report will be prepared documenting the entire research process, including analysis of all of the key architectural elements and systems in units. The report will contain final design recommendations and an updated set of home designs and specifications (incorporating the findings from other tasks as appropriate).

B. Foundation System Design and Assessment

The goal of this task is to develop and refine through prototyping a standard foundation design for use with each of the four FEMA units. A set of standard designs and installation specifications would facilitate a consistent quality of construction and the ability to provide precise guidance to installers. Separate foundation designs may be required for certain areas prone to seismic events. Tasks include the following:

- **Describe design conditions**. Identify and characterize the range of foundation-related design conditions that could occur for homes used by FEMA for disaster relief. Review with FEMA staff and SME to identify the most critical design criteria.
- **Develop solutions**. Develop foundation-design solutions based on these criteria for the four MHU types defined by FEMA. Factors to be considered include the following: footing types, such as ABS vs. precast concrete; piering options, such as steel piers vs. concrete blocks; anchoring for lateral resistance; total installed cost (materials and labor); ease of installation in difficult soils; lateral stability; resistance to wind and seismic forces assuring adequate resistance during design events; required site preparation, etc. Include specific recommendations for grading, drainage, organic material removal, etc. Temporary use during warehousing will also be considered and those needs addressed by the recommendations.
- **Assess options.** Comparatively assess the options, identifying solutions that offer the greatest value, all major design factors considered. Include considerations such as their ability to be used in a range of design conditions, lowest cost, ease of installation, and other qualitative and quantitative factors important to FEMA.
- **Find sites**. Identify representative sites for assembly of foundation designs using the MHU prototypes. Secure rights to use the sites for testing.
- **Draft guidelines**. Prepare draft installation guidelines and install the homes at the site(s) using that protocol.
- **Evaluate performance**. Assess the performance of the foundation designs from a variety of critical perspectives including: skills required, cost, installation time, propensity for installation error (fool-proofness) and flexibility for use under a range of site conditions (topographies, soil conditions, etc.), availability of materials, and other logistical challenges, among other factors.
- **Develop report**. Prepare a report documenting the findings of the site evaluation and providing recommendations for a universal foundation solution (with local variations as required).
- **Develop guidelines**. Prepare a final set of home installation guidelines for use by FEMA. Assure that these guidelines are compatible with the manufacturers' model installation instructions. The guidelines will include suggested periodic inspection items for home and installation to ensure maximum durability during storage.

C. Process Engineering and Management

The goal of this task is to streamline the entire home-delivery process from procurement through occupancy and home recycling/reuse, minimizing both the total cycle time required to get MHUs into service and the resources required by the entire process, while ensuring a high level of construction quality, durability and overall MHU performance. Tasks include the following:

- **Develop general understanding of the overall FEMA process** for providing emergency housing and how it is provided. Review FEMA documents, meet with FEMA staff (as required) and document the following: emergency housing need (e.g., number of MHUs–by type–that will be needed at each site); emergency housing inventory strategy (number of MHUs–by type–will be inventoried in each storage facility); how the inventory will be managed to assure readiness for use; overall "heads-in-beds" process flow and timing (documenting activities from the decision to provide new emergency housing to its readiness for occupancy).
- **Analyze and refine results** and develop the following system-planning parameters: overall heads-in-beds lead times and production rates required from manufacturers (developed by comparing emergency housing need versus inventory); top-level Value Stream Map (VSM) of the overall heads-in-beds process, documenting each primary activity (e.g., order placement/design, parts procurement, production, delivery and set-up) and associated cycle times, focusing on FEMA involvement in the process.
- **Enhance the VSM**. Information will be added to the VSM depicting manufacturer involvement in the process. Work with selected manufacturers in the following sub-tasks including: (1) review emergency-housing designs; document manufacturer involvement in the process, including activities from order placement/design to MHU delivery and set-up on site. Identify likely changes to existing operations, including: materials, tools/equipment, layout, methods, labor requirements and cycle times. This analysis will also include indirect production activities, such as material handling, storage and inspection; (2) observe the existing production process, verify likely changes needed, and assess relative difficulty of each change; (3) assist in identifying and assessing possible design changes that could reduce impact on the existing production process while maintaining design intent; (4) develop a prototype production monitoring plan; (5) observe and document production of prototypes; and, (6) assess the impact of the designs on key production performance metrics (safety, quality, timing/line flow, labor content, floor space and facility/equipment costs).
- **Evaluate the overall heads-in-beds process**. Examine each activity in the VSM and assess how well it supports FEMA objectives. Identify critical challenges that must be addressed and develop options to address these challenges (for example, component parts with long lead times may need to be inventoried to assure timely availability for manufacturing). A report will be developed summarizing approach, analyses, findings, conclusions and recommendations.
- **Tools for process monitoring and quality assurance**. The above tasks will identify areas where QC procedures can be strategically applied to maintain quality and minimize system and product failures at every point in the home-delivery process. This task will create a suite of tools and forms (e.g., checklists, procedures, protocols) that FEMA and its contractors can use to

document parts of the process and verify quality and performance-compliance at every stage in the home-delivery process.

D. Moisture and Thermal Performance Testing of CONUS Assemblies

The goal of this task is to identify candidate envelope components, model their hygrothermal and thermal performance and field-test viable options for their durability under CONUS conditions. Top performing combinations of assemblies will be considered for final envelope specifications and recommendations will be made based on hygrothermal performance, manufacturability and cost. Tasks include the following:

- **Identify and vet alternative combinations** of envelope constructions. Develop alternative construction options. Identify combinations of envelope components (ceiling, wall, and floor combinations) that meet the most stringent thermal requirements under the draft DOE energy standards. Combinations of envelope measures will be developed for all four MHU building types. Industry best practices and cost (materials and labor) will be considered in developing the component specifications. Convene SME; critique options. Hold a meeting of the SME panel for the purpose of reviewing the specifications and critiquing the proposed envelope assemblies.
- **Hygrothermal modeling for CONUS candidate assemblies**. Conduct hygrothermal modeling of each assembly type in representative U.S. locations. Make predictions about each envelope assembly's propensity for moisture accumulation. Document the simulation and analysis results of each assembly type or combinations of assemblies in terms of propensity for moisture accumulation, ease of manufacturing, cost, and other performance metrics that might impact component viability. Recommend assemblies for testing.
- **Plan and commission test modules**. Prepare a test plan that provides a detailed description of the envelope components to be tested, the method of testing including type of sensors and their placement, the design of the test chamber, the data to be collected, the physical location of the tests, application of internal loads and conditions, and related matters. It is anticipated that two such chambers will be constructed (one each for a location with extreme heating and cooling/humidity conditions). Other site conditions, such as unit direction and site shading will be specified. Each chamber will consist of multiple ceiling, wall and floor component designs. Convene SME. The test plans and anticipated results will be presented to the SME panel for review. The plan will be revised to reflect SME comments. Secure test sites. Sites will be identified for the testing and arrangements made for site rental, provision of power and internet service. The selected sites will need to be secure and a technician available to service the module if needed during the data-collection process. Select builder of test modules. Contract documents will be developed for the construction of the two modules. Since the modules are likely to be separated by a considerable distance, the option of contracting with two separate building companies will be explored. For the construction of each module, several competing bids will be sought. Build test modules. The modules will be constructed as per the test plan with team oversight. It is anticipated that each module will consist of multiple envelope components that are thermally and hygrodynamically isolated from each other but are exposed to the same boundary conditions (interior temperature and humidity, site orientation, etc.). The

module will be equipped with space-conditioning and ventilation equipment. Throughout the process, cost, time spent, and any buildability issues will be recorded. Temperature and humidity monitoring equipment will be installed within walls, floors, and ceilings, as well as outdoor and indoor points of reference. A weather station will track ambient weather conditions. Data collection will be remotely monitored. Commission test units. Move and install the test units to the test locations and commission. Set up and calibrate equipment. Ensure all mechanical systems are working properly and that interior conditions are stable.

- **Data collection and analysis. Monitor data collection**. On a periodic basis, quality check and monitor data. Address any outlying data issues. Data analysis, model calibration, and culmination of results. At the end of the monitoring period, compile, tabulate and graph data. For best-performing assembly types, create a whole-building hygrothermal model considering the interaction of these assemblies, as well as interior and exterior conditions. Draw conclusions based on year-long simulations in extreme design conditions. Interim reporting. Report test-module interim results to FEMA and SME on a quarterly basis. Suggest any important changes to conditions or data-collection techniques.
- **Decommissioning and disposal**. Decommission and disassemble units. Remove sensors and testing equipment. Disconnect test structures from utilities. Dispose of test structures. Recycle or dispose of all elements of the test structures in proper locations.
- **Document results**. Prepare a final report documenting the entire research process that includes analysis of the data collected from both locations, assessing the hygrothermal and thermal performance of the building assemblies. Provide recommendations for a combination of wall, roof, and floor assemblies for each unit based on the test results, cost and manufacturability of each assembly.

E. Develop and test an Internal TPS design

The goal of this task is to develop and demonstrate the design of a sprinkler tank and pump system (TPS) capable of being placed within the conditioned thermal envelope of the MHU. Internal placement of the TPS is intended to simplify logistics, reduce costs, cut the total time to occupancy, protect the system from ambient climate and result in a more durable fire protection solution. Placing the TPS within the MHU raises a host of challenges addressed by this work. Tasks include the following:

- **Solicit participation by TPS manufacturers in a product design process.** Reach out to tank-and-pump system providers inviting them to participate in the design process developing interior TPS prototypes.
- **Revise MHU designs to accommodate an internal TPS.** Modify MHU floor plans as necessary to accommodate the space and services associated with an interior placement of the TPS. Review designs with FEMA, SME Panel and TPS providers.
- **Develop specifications for TPS designs to be developed by suppliers.** Based primarily on FEMA's prior experience with TPS systems, create a detailed list of requirements for the interior TPS system. Specifications will have two parts: MHU responsibilities in constructing a container for the TPS and the specifications to be applied by the TPS suppliers in developing product

solutions. The requirements will be vetted by FEMA staff and TPS supplies. This will involve an iterative process resulting in a final set of design specifications.

- **Monitor the design/development process. Liaison with TPS suppliers.** Provide specifications to the TPS suppliers and monitor and facilitate their development efforts. Provide milestones and a timeline for design development. Keep all parties on track by facilitating communication, answering questions, and providing update and feedback. Convene conference calls as necessary.
- **Design and construct a test apparatus to evaluate the TPS designs. Test products.** Identify all components that are part of the TPS including those to be provided by the TPS suppliers and MHU manufacturers. At a suitable venue (possibly a FEMA storage facility) mock up the TPS cabinet. The cabinet will be used to allow each TPS supplier to demonstrate how their design would be installed, secured for transport readied for service, tested and maintained. Observe the process and provide feedback to the TPS vendors for design refinement. The simulation will serve to evaluate the plug-and-play nature of the design, including routine maintenance and servicing of the products.
- **Modify the TPS specifications incorporating the lessons learned from the design process.** Using lessons learned from the previous step, identify elements of each design that worked well and those that inhibited the installation and/or testing process. Modify the TPS specifications as required and conduct review with TPS providers.
- **Modify the MHU specifications incorporating the lessons learned from the design process.** Change MHU specifications to incorporate the test results. Review with FEMA, SME Panel and TPS providers.

F. Facilitate the Design, Testing and Evaluation of a Ruggedized Chassis System Design

This task will develop and test methods of constructing the MHU chassis system that are sufficiently durable to withstand the rigors or long distance shipping and difficult road conditions. The effort will be conducted as a joint undertaking with Oak Ridge National Laboratory. ORNL task responsibilities (ORNL) are included below for clarity:

- **Develop a preliminary set of design changes** to the frame, axle, running gear, chassis system based on the field reviews by ORNL and FEMA guidance (ORNL). TLP to review and comment on the design.
- **Prepare a test plan to evaluate the ruggedized chassis design.** The plan would call for testing two or more MHUs, one or more with the new design and one or more with the existing design. The plan would stipulate how the units will be tested and what constitutes failure. (ORNL) TLP to review and comment on the plan.
- **Facilitate SME and other experts in frame/transportation system design review and critique the test plan and proposed design.** This feedback would be used to fine tune the design and flesh out the test regimen (TLP to facilitate/ORNL to implement agreed upon changes)

- **Fabricate two new MHU(s)** to be used for the tests; one with the new chassis design for the test units, one with the current design. (costs included in FEMA procurement, ORNL/TLP to supervise production)
- **Conduct tests per plan, observe results, prepare a report of findings/recommendations.** (ORNL) There is the possibility that there will be some iteration in the design/test process.
- **Facilitate SME and other experts in frame/transportation system design review** and comment on test results and recommended design changes.
- **Incorporate findings into Master Specifications.**

G. MHU Completion Process: Compressing Time from MHU Delivery to Occupancy

The goal of these tasks is to identify, test and recommend technologies that significantly reduce the time between when an MHU, built for disaster relief, is available at the installation site and its availability for occupancy (that is, fully operational). This "installation period" routinely ranges from about a week (optimum) to several weeks or even months, depending on a range of factors and conditions. The task will characterize commonly-encountered installation process bottlenecks and identify, develop and evaluate methods to alleviate these delays, and outline methods by which FEMA can transition back to traditional sources once the delays have been resolved. The focus of this task is on identifying factors that can be addressed through technical, product and building process changes or approaches. While the study will not propose steps for remediating other types of bottlenecks, notably process and administrative related delays (e.g., obtaining building permits), they will be documented. Specifically, the effort will assess and recommend alternative technologies associated with the following three service types most prone to installation bottlenecks that delay occupancy:

- **Electrical service** (temporary and full service)—provision of power when connection to local electrical service is not available or delayed
- **Potable water** (temporary and full service)—domestic water supply when connection to site water (well or community) is not available or delayed
- **Septic/sewage** (temporary and full service)—waste collection and retention when connection to local sources is not available or delayed.

H. Bulk Water Testing

The goal of this task is to develop a protocol including product standards, details and installation specifications that when used in the selection and construction of fenestration systems provide an effective and durable barrier to water intrusion. The results of the tests will inform the specification of windows and doors in future FEMA MHU construction. Tasks include the following:

- **Develop fenestration components designs** (doors and windows) and specifications that represent best practices with regard to protecting against water penetration.
- **Vet the designs** with the SME panel to assess cost and production impacts. Make changes as required.

- **Build the door and window components** per the new specification into the homes to be tested (see B). Supervise and document construction. Transport homes to the test site.
- **Test the components** built to the new specification together with fenestration built under the current procurement guidelines following an industry standard protocol (e.g., AAMA 502). Tests to be conducted FEMA personnel using protocols provided by IBTS.
- **Report results**, and if failures are recorded, iterate through the design process making adjustments to address underlying design weaknesses. Repeat until the fenestration specifications can be shown to routinely produce components that are effective at keeping water from penetrating through the envelope.
- **Document findings and incorporate the final specifications** into the prototype design documentation. Recommend a future test protocol for FEMA for rechecking and verifying performance in the future.

Design Samples

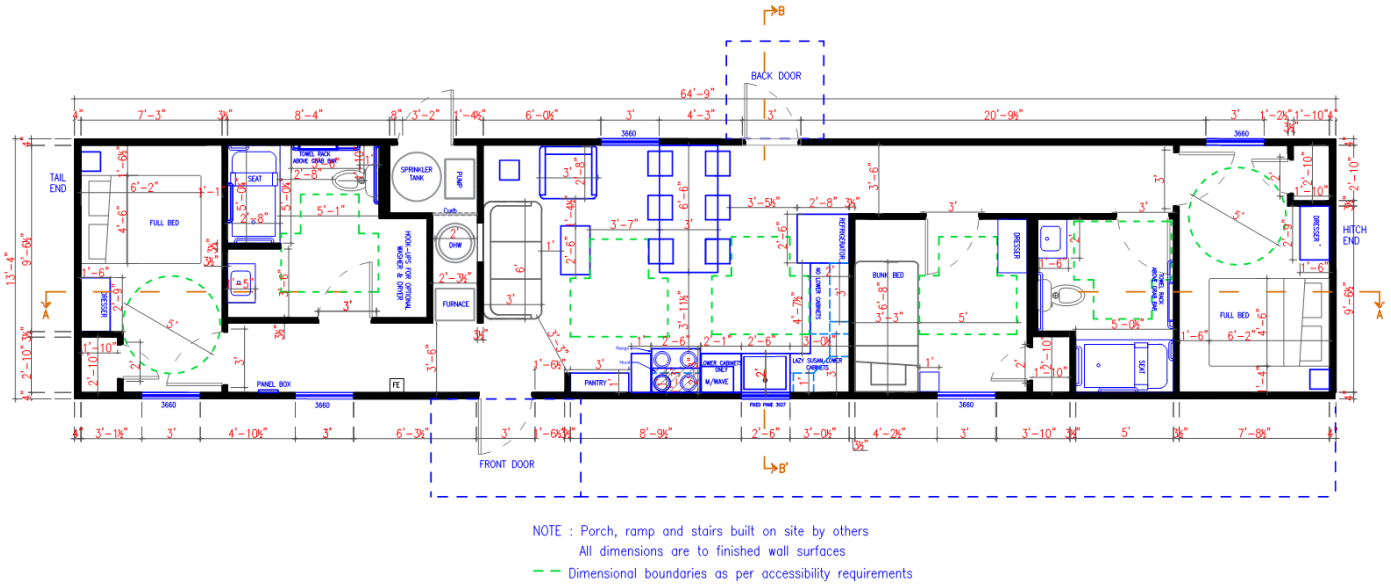

Figure 1 Floor Plan of the 3 Bedroom Unit

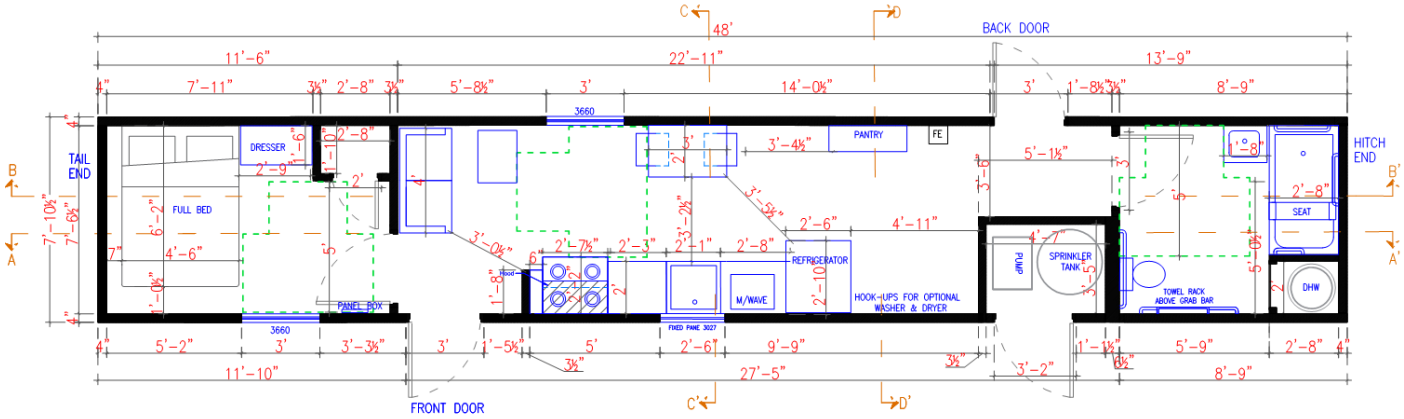

Figure 2 Floor Plan of the Express Unit

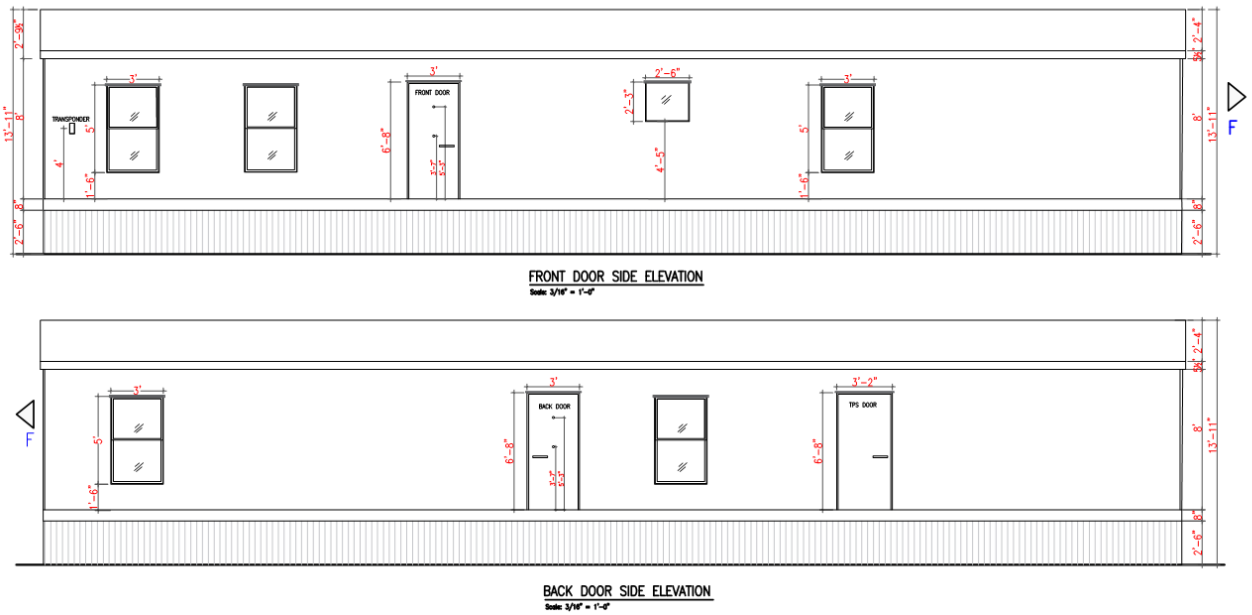

Figure 3 Exterior Elevations of the 3 Bedroom Unit

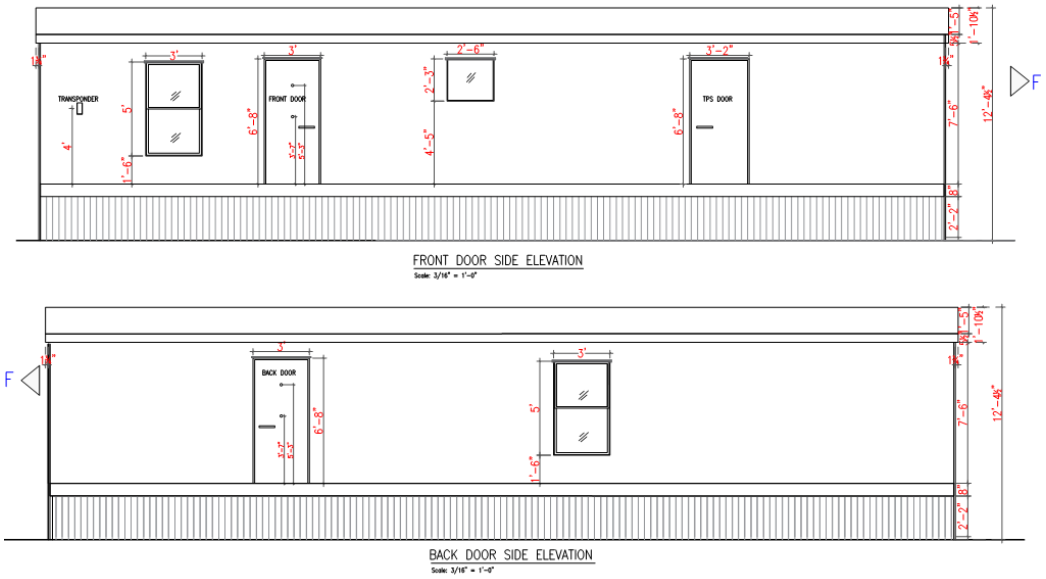

Figure 4 Exterior Elevations of the Express Unit