Chapter Four: Preliminary Results of the Building Sciences Evaluation[1]

Introduction

The Building Sciences component of the AHPP evaluation will assess the performance of the MAHP units. This is critical since housing that is durable, affordable and energy efficient will best serve the needs of MAHP participants and the larger community. Durability and energy efficiency are particularly relevant as the "life cycle" costs are ultimately borne by the owner, typically well after the initial influx of post disaster financial assistance. The building sciences evaluation includes: a review and assessment of the unit designs, unit production processes, and delivery and installation of the homes; short-term and long-term durability assessments; and performance assessments following severe weather events, such as Hurricane Gustav in September 2008.

This chapter summarizes the building sciences evaluation activities and preliminary results for the MAHP. As of September 2008, the Park Model and Mississippi Cottages have undergone a number of building sciences evaluation tasks, including:

- A design review;

[1] The chapter was authored by Dana Bres of HUD's Office of Policy Development and Research. It is based on building sciences evaluation activities completed by the National Association of Home Builders (NAHB) Research Center. While the rest of the report covers implementation activities through August 2008, this chapter includes building sciences observations through early September 2008 to capture unit performance during Hurricane Gustav, which made landfall on September 1, 2008.

- Observational monitoring in the housing factories; and
- Several building sciences field tests, such as installation observations, blower door tests to estimate building air tightness and an initial durability assessment to measure the units' post-disaster performance following Hurricane Gustav.

Unit Design

MEMA's approach was to design a single-wide, manufactured unit, to be produced in one-, two- and three-bedroom sizes. More than one-fifth of the two- and three-bedroom units were designed to be compliant with the Uniform Federal Accessibility Standards (UFAS). MEMA also designed an "Eco Cottage" to demonstrate an environmentally friendly, efficient and attractive design that effectively blends building sciences technology and design. The Eco Cottage is yet to be produced and is not addressed in this document.

The goal of MAHP was to produce units that could be manufactured and installed quickly for temporary housing, yet also would be suitable as permanent housing. For this reason, MAHP units were designed to meet both the current HUD code for manufactured housing and the International Residential Code (IRC), which is the model building code for new construction of units most commonly adopted by states, cities and counties in the United States. In terms of building performance, neither code confers a specific advantage, as both establish a minimum standard and the MAHP units were designed to exceed those minimums.

Structural Design

The final specifications for Park Models and Cottages met or exceeded the requirements of the HUD code and the International Residential Code in several areas that directly affect the strength of the units.

The units were designed to resist the more stringent IRC standard of 150 miles per hour wind speed. Under the IRC, there are two standards for the coastal areas of Mississippi, and the selection of the 150 miles per hour standard allowed the MEMA units to be placed anywhere temporarily.

The metal roofing selected for the Cottages provides both additional durability and structural strength by using a "hip roof" configuration. A hip roof slopes to all sides of the home and does not have gables. Hip roofs are stronger than traditional gable roofs, as the structural components of the roof are better aligned to resist wind loads. (Neither the HUD code nor IRC require a specific type of roofing.)

The siding MEMA selected for the Cottages is a fiber cement product that has demonstrated excellent impact, wind and insect resistance, as well as outstanding durability. The performance of fiber cement siding provides greater durability than wood siding in event of storms, as well as for routine maintenance. Because fiber cement does not absorb moisture (as wood siding does), paint applied to such siding will last significantly longer.

Interior Space

As described in Chapter One, five core models were produced: a one-bedroom (Park Model) at 396 square feet, two- and three-bedroom Cottages, and two- and three-bedroom UFAS-compliant Cottages. The UFAS models are variants of the standard two- and three-bedroom units, which total 728 and 840 square feet each. As with many manufactured homes, production of multiple units provided an opportunity to refine and perfect the interior design and use of space.

Aesthetic Design

MEMA was very deliberate in the designs they selected for the MAHP units. The architectural vernacular of the Cottages lends itself to acceptance at the local level. Many traditional style homes in the coastal South are built in the "shotgun" style and include a front porch. The standing seam metal roof of the Cottages continues this traditional design, as do the variety of bright paint colors chosen for the exteriors. As a result, the Cottages blend with the community, a stark difference from the visual impact of the plain white FEMA travel trailers and many manufactured housing units.

Design Approval Process

The initial Mississippi grant application included unit design concepts that were refined following grant award. In Mississippi, modular home designs are reviewed and approved by the State Fire Marshal. Following development of the designs and their acceptance by the MAHP project staff, they were approved by the project's professional engineers and submitted for review by the Fire Marshal (for the IRC) and to the Design and Approval Primary Inspection Agency (DAPIA) (for HUD code compliance). Production design reviews and approvals were conducted on-site by the Fire Marshal and the HUD code In Plant Inspection Agency (IPIA). FEMA involvement in the design process was focused on compliance with structural engineering principles associated with the foundation designs. FEMA's Mitigation Division performed plan review and provided comments. With the exception of accessibility features in UFAS-compliant units, FEMA did not approve or disapprove of the plans. The MAHP project team also conducted design reviews during the initial development of the construction contracts and production of the housing units.

Evaluation of Unit Designs

At the beginning of the overall evaluation effort, HUD and FEMA collaboratively selected the building sciences evaluation activities and criteria. These were selected to prevent foreseeable design failures, to predict unit energy usage and to estimate the labor effort required to produce and install the units. Certain results of the evaluation were communicated to FEMA and by FEMA to MEMA immediately. This was an operational decision based on the need for the housing units to succeed. FEMA identified and communicated to the grantee any identified design or construction flaw that might jeopardize the viability of the units.

Evaluation of the MAHP unit designs involved different types of reviews. The building sciences evaluation team reviewed the unit designs and modeled the expected energy

performance of the units as a first step in a complete energy assessment, which will eventually include an evaluation of actual energy consumption. The models predicted that MAHP units will be close to satisfying EnergyStar requirements.

As part of a complete durability assessment the building sciences evaluator reviewed Cottage designs using HUD's "Durability by Design" guidelines11 and offered an initial durability assessment. As part of this effort, evaluators provided a "best practices" moisture assessment of the design and provided feedback to help MAHP avoid preventable moisture problems. The evaluator also placed moisture sensors in a small sample of units. Based on reviews of the unit designs, observed construction processes, and the materials used in the units, it is not expected that these monitors will detect moisture problems, but the results are forthcoming. The initial durability assessment also incorporated estimates for how long the unit will be able to be used if installed as temporary or permanent housing. The building sciences evaluator also summarized design characteristics of the Cottages using FEMA's web-based Joint Housing Assessment Tool, which catalogues manufacturer information for later use.

Similar to the initial durability assessment where evaluators visited housing factories to review construction processes, other tasks required both design review and on-site observations. Evaluators assessed MAHP designs to determine what skills were required to install a unit and observed installation procedures on-site. FEMA experts also evaluated plans for accessible Mississippi Cottages for compliance and inspected constructed units in-person. Unlike other evaluation components, the UFAS process was an absolute process under which the proposed UFAS-compliant unit was declared acceptable by the FEMA subject matter expert.

Procurement and Manufacturing

RFP and Selection Process

MEMA advertised for the construction of the Cottages through a Request for Proposal (RFP) process. Following receipt of proposals, MEMA reviewed the proposals with the intention of making multiple awards that included options to order additional units without further competition.

The ability of the awarded contracts to allow for additional orders streamlined the production of the units. This approach allowed MEMA project staff to allocate additional orders to high-performing manufacturers based on the quality of units delivered and the manufacturer's responsiveness. The manufacturers understood that they were demonstrating their qualifications and capacity for additional unit orders on an ongoing basis.

Manufacturing

MAHP units were produced in multiple manufacturing plants. Exhibit 4-1 shows the number of units produced by each manufacturer at each location. The proximity of unit production was an important strategy to help minimize the costs of producing and transporting the units to the Gulfport receiving yard.

In addition to IRC and DAPIA compliance reviews, the building sciences evaluation team visited the factories to gather production information, observe construction and install moisture sensors in the floors, walls and ceilings of selected units. These instruments allow moisture in the walls to be measured in a non-invasive manner. The building science evaluation effort also includes collection of cost and schedule information. The results from this collection effort will be included in future evaluation reports.

Development of Accessible (UFAS) Units

The Uniform Federal Accessibility Standards (UFAS) establish a common set of design standards to accommodate people with mobility impairments in federally funded projects. Since the MAHP is funded with federal grant dollars, UFAS standards required a portion of MAHP units to be UFAS-compliant. FEMA managed the review and approval of the UFAS compliant units. This was done through design review and on-site inspection. Because FEMA was not in a position to provide design guidance directly to the manufacturers, the review and approval process was iterative. As a result, the deployment of UFAS compliant units was slower than non-compliant units and involved greater costs on the part of the manufacturers.

Site Development and Installation

The building sciences evaluator reviewed MAHP installation and site preparation specifications and conducted site visits to observe and assess the installation of Park Models and Cottages. MEMA deployed the majority of the units on privately owned lots. A smaller portion of the units were installed in existing commercial trailer parks. At least initially, site development efforts on private land generally were modest, and temporary modifications were performed on the site. After deciding where the unit would be

Exhibit 4-1: Number of units produced by each manufacturer and production site

Manufacturer	Production Site	1 BR Park Model	2 BR	3 BR	2 BR UFAS	3 BR UFAS	Total
Forest River	Wakarusa, IN	400					400
Patriot	Alabama	300					300
Patriot	Indiana	200					200
Oak Creek	Lancaster, TX	300					300
Oak Creek	Fort Worth, TX	200					200
Cavalier	Alabama		300	150	100	50	600
Deer Valley	Guin, AL		300	100			400
Lexington	Lexington, MS		400				400
	Total	1400	1000	250	100	50	2800

installed, the location and design of the anchoring, utilities and access were determined. Units placed on individual lots replaced the FEMA travel trailers that were installed immediately following the storm.

MAHP Cottages were connected temporarily to existing utilities. Water, electrical and communications service were easier to install than sewer service because slope was not an issue. MEMA subsequently also installed units in areas along the Gulf that were not serviced by public utilities or septic systems. In these cases, septic services had to be installed before the unit could be placed.

MAHP units were installed temporarily with anchoring systems similar to those typically used for non-permanent installation of manufactured housing. This requires a determination that the soil can bear the weight of the unit, as well as resist pull-out of the anchors. If the soil beneath a unit is too soft (poor bearing capacity) and is not able to withstand the weight of the MAHP unit, the blocks under a unit might "sink" into the soil. Weak soils also may be unable to hold the screw anchors, so they might be pulled out of the ground slightly if the unit is subjected to high winds.

To accomplish both bearing and hold-down, hold-down screw anchors are installed in the ground. The unit is then positioned on the site and jacked up so that the pier foundation blocks can be stacked. A series of concrete block columns is installed to provide the necessary elevation for the unit. Clips along the structure of the unit are connected and the unit is attached to the ground anchors with galvanized metal strapping. A ratcheting wheel is tightened, tensioning the metal strapping and firmly anchoring the unit to the ground.

Unit plumbing is attached, and sewer piping is extended to an available sewer connection. Because the Cottages have been installed as a temporary housing, the waste lines are installed above the ground. While this has served to expedite the installation process, it does not present a visual sense of permanency.

The temporary installation strategies selected for the MAHP units, may have contributed to the sense that these units were quite similar to the travel trailers and mobile homes that the Cottages replaced. The visibility of the wheels and piping suggested that the units were yet another round of temporary housing—a visible contradiction to the goal of advancing individual and community recovery.

In addition, the accessible ramps examined by the building sciences evaluators were not impressively crafted. This rough construction generally was on the edge of compliance, with anecdotal reports of ramps on similar units (non-MAHP) being built and rebuilt until compliance was achieved. In the case of the MAHP units, while the ramps may have been serviceable, they were not particularly durable.

Building sciences observations also included reports of the plywood panels for hurricane protection being discarded. Those actions might result in damage to the building

envelope as the panels were integral to the storm protection of the units.

These observations suggest a need for a reconsideration of the systemic issues of the installation. Planning for the installation process may not have been as detailed as the planning for the construction and receipt phases. Installation problems likely did not impact the overall longevity of the units, as the unit design and construction resulted in units with significant structural strength and potential durability.

Ventilation and Air Quality Testing

In conjunction with the Federation of American Scientists, MEMA has implemented a mechanical ventilation system that includes an exhaust fan that is not controlled by the occupant. This is similar to HUD's manufactured housing code which requires either a mechanical or passive system designed to provide outside air. In the Gulf Coast areas, outside air may bring excessive moisture into the home, particularly in the summer months. The choice of a ventilation system should consider the capacity of the heating, ventilation and air conditioning (HVAC) system to handle the thermal and moisture loads. There is a tension between ventilation and energy costs, as increasing ventilation in a unit will increase the energy demand of the unit.

Twenty-two units were subjected to a blower door test by the building sciences evaluation team to assess how air sealed, or "tight," the home is. During the series of tests on 22 separate units, the blower door results place the units solidly in the "moderate" tightness category. An extremely tight home would benefit from little energy loss, but could be prone to indoor air quality issues. Given the issues surrounding air quality in post-disaster housing, providing additional ventilation is a reasonable approach.

Indoor air quality (IAQ) testing, including testing for formaldehyde, has not yet been conducted. Testing was scheduled and then delayed. Formaldehyde has received a great deal of attention in the media and within FEMA. Some rudimentary testing of selected MEMA AHPP units was conducted by advocacy groups in Mississippi, and suggested elevated formaldehyde levels in the MAHP units. Although the tests reported by those groups suggested higher than "acceptable" levels of formaldehyde in the MAHP units, press coverage of the formaldehyde tests indicate consumer satisfaction with the units. Compared to a travel trailer, the increased window areas, multiple doors and capacity for natural ventilation of MAHP units provides fresh (outside) air that will result in improved indoor air quality.

Durability

While assessing the durability performance of MAHP units is premature at this juncture, preliminary evidence suggests that the units will perform well in both regards. Moisture is generally the root cause of durability problems in housing, and most durability assessments focus on that topic. The building sciences evaluation will include the examination of the moisture in walls and external examination of common durability

issues. MEMA's maintenance records will also provide detail regarding the performance of the units. This information will be assessed further along in the evaluation.

While long-term performance information is not yet available, nature did test the MAHP Cottages on September 1, 2008, when Hurricane Gustav made landfall on the Louisiana Coast as a Category 2 storm. The following section reviews the performance of the units from a building sciences standpoint. The upcoming 2009 interim report will further detail MAHP's emergency and organizational response to Gustav.

Hurricane Gustav

Following Hurricane Gustav, MAHP and its insurer conducted separate assessments of MAHP Cottages damaged by the storm. MAHP's insurer ultimately decided that 249 units were destroyed and uninhabitable. All damage was related to flooding. Flood damage ranged from the wetting of the insulation under the units with no evidence of other damage, to the unit or the installation materials destroyed because wave action pushed the unit off its foundation piers. According to MEMA, the insurance company declared any unit that had wetting of the subfloor to be a total loss. This apparently was a preemptive assessment, based on the potential for mold growth below the carpet and tile.

A HUD building sciences expert visited Mississippi after Gustav to assess the damage. An examination of the units that were displaced from their foundations revealed significant water damage, but no evidence of structural compromise. In units that experienced several feet of water inside, the ceilings were damaged by floating furniture and debris, but the crown moulding was intact and straight. Some units that experienced wave action lost siding on the windward side. The conclusion was that failure of MAHP units during Hurricane Gustav was due to location decisions and not unit design. In some cases, further elevating the units might have prevented water damage, but it would have masked the real issue, which was the MEMA and FEMA decision to allow a one-for-one replacement of FEMA travel trailers with Cottages in coastal and other areas prone to flooding.

Preliminary Findings

Mississippi's decision to embrace factory built construction resulted in higher quality, lower cost units, which could be produced faster than stick-built housing, be re-used and have a reduced impact on the disaster-affected area.

Generally, factory built homes are considered to be less expensive than site built housing and the finished construction is more consistent. In a factory production process, the availability of tooling, supervision and highly refined production processes can yield a very consistent product. While consistency and high quality are not necessarily linked, when combined with a strategy to produce high-quality units, factory-built housing can result in a first-rate product. The observations of the units produced by MAHP manufacturers suggest they are of high

quality and closely reflect the goals and vision of the designers and MEMA.

Another benefit of factory-built construction is speed and minimal impact on the disaster-affected community. Conventional site built construction frequently requires many months to complete. It is not unusual to see site built construction durations in excess of two months, compared to factory construction durations of about 10 days, followed by a short period of transport and installation. The use of factory-built homes with undercarriages for transport enabled MAHP to install units temporarily and remove, refurbish and redistribute a unit to another household in need or a permanent development. Stick-built homes do not have such flexible re-use possibilities.

Multiple vendors producing similar units provided both a measure of competition as well as a reduction of risk for the overall program.

The competition among manufacturers, combined with the incremental procurement process, allowed MEMA to produce a large number of units quickly and to control the pace of production according to need and capacity to install units. As the manufacturers developed greater experience with the production of the homes, they were able to benefit from that experience, which helped offset increases in costs. The contracts were awarded during a period when there was rapid escalation in construction material costs, and efficiencies in the production process contributed to the maintenance of unit quality and cost effectiveness.

Establishment of a staging area, or transition site, in Gulfport provided an opportunity to increase the consistency of the units produced, reduce costs and control the inventory of units.

The transition site allowed MEMA to receive, document and inspect the units prior to installation. The site also provided a central location where construction issues with the units could be addressed by the manufacturer. This improved the timeliness of the repairs and also reduced the costs for both MEMA and the unit producer. Using a staging area was a departure from the typical way of producing manufactured housing for the market, in which the manufacturer builds a unit and ships it to a local or regional retailer. While these inspections may have been seen as increasing the cost to the manufacturers, providing a single location where the issues identified could be addressed made the process more efficient.

MEMA implemented a successful strategy for incremental delivery of units to the transition site to avoid excessive inventory build up. By limiting the transition site to about 300 units, with additional completed units held at the manufacturer's facility, MEMA was able to avoid attracting negative attention similar to that displayed following Hurricane Katrina, where media outlets showed FEMA holding areas with thousands of unused travel trailers and mobile homes.

Temporary installations may have impeded acceptance of MAHP units as viable permanent housing solutions.

Above-ground utilities, particularly sloping sewer lines, may have contributed to a lack of

awareness about the capabilities of MAHP Cottages to be permanently installed. Any future disaster housing program producing units that can be used temporarily or permanently should develop a robust strategy to address this assumption.

Observed installations suggested a need to revisit installation plans and procedures.

Installation of the units seemed to lag behind the production pace because multiple arrangements had to be coordinated prior to installing a unit. While several factories were producing MAHP units, installation required time-consuming processes including screening and selection of the recipients, gaining local approvals and permits for the site, site preparations, and the actual installation of the unit. Given the complexity of the task, production, delivery and installation of the units appears to have been well managed. MAHP's experience suggests disaster-housing programs need to realistically anticipate the pace of installation and coordinate production accordingly.

Building sciences evaluators suggested that some unit installations were imprecise and did not follow installation procedures. However, these installations were not believed to impact the long-term durability of the units. The evaluators also found evidence of poor quality ramps installed for accessible units. This suggests that temporary installation procedures should be reviewed to the same degree as the design and production phases. Furthermore, this suggests an intensive quality control component is required for all phases of a disaster-housing program, from design to installation.

Design reviews and initial testing indicate MAHP units balance the need for improved indoor air quality with energy efficiency.

MAHP units are moderately air tight according to the blower door test. This allows for adequate ventilation and still maintains reasonable energy efficiency. The building sciences evaluators will conduct indoor air quality (IAQ) testing as part of the evaluation and provide results in a future report.

Preliminary evidence suggests MAHP units will be durable and maintain structural integrity after adverse weather events.

MAHP Park Models and Cottages are constructed to meet or exceed IRC and HUD code. The units are strong and can resist up to 150 miles per hour wind speeds, have hip roof configurations constructed of metal roofing, and offer cement fiber siding. They maintained structural integrity during Hurricane Gustav with the only damage resulting from flooding. A design review anticipates minimal moisture and durability issues. A full durability assessment will be part of future evaluation reports.