Comparing HVAC equipment options for FEMA MHUs

Interim report (March 20, 2018)

Background

Prototyping and field testing of two MHU designs (Express unit and 3-bedroom MHU) included evaluation of two space conditioning equipment combinations in each unit capable of providing heating and cooling year round in all climates of the 48 contiguous US states (CONUS). For the Express unit, where interior space is at a premium, a mini-split heat pump and package unitary system were compared. The 3-bedroom prototype featured packaged, unitary equipment compared to an electric furnace with exterior, frame-mounted AC compressor. The systems were sized to meet heating and cooling design loads in extreme climate conditions. Humidity control and fresh air ventilation were also addressed in the designs.

The construction of the prototypes at the Hi-Tech facility in Indiana was observed and documented. The test MHUs were monitored during the heating season in a cold climate (Ham Lake, MN) and will be relocated to a hot-humid climate (Selma, AL) for monitoring system operation during the summer months. Temperature in all of the living spaces and humidity levels are monitored by sensors.

Observations

The observations that follow provide an initial assessment of the two HVAC solutions in each of the two MHUs. These are interim findings that will be expanded following the hot-humid climate testing. A summary of findings and initial recommendations for design revisions are provided in the Commentary section below.

Observations are sorted between positive (Pros) and negative (Cons) attributes. The list is intended to depict qualities that will help in deciding which system is the preferred solution for each MHU type. Qualities are further separated by what are considered Primary and Secondary factors, defined by their relative importance in the selection process. Points that are expected to be of particular importance in initial system type selection are indicated by an asterisk (*).

A potential consideration, not included in the discussion, is operating efficiency or cost of operation. Operating costs are a less important consideration for FEMA as the MHUs are typically intended to be placed in service for less than two years, are required to be electrically powered (limiting HVAC type selection) and performance varies widely by climate. In general, however, a heat pump

system is expected to be more efficient than either the packaged unitary or standard split system designs with the relative savings increasing in proportion to the heating load.[1] Under certain conditions, for example MHU powered by a generator in a cold climate, providing space heat more efficiently will reduce refueling demands and service frequency.

Table 1 Comparison of HVAC systems used in FEMA MHU prototypes

Equipment type (MHU type)	**Pros**	**Cons**
Packaged unitary (All MHU types)	**Primary factors** • **MHU design**: No floor space required inside the MHU (benefit for Express unit, in particular).* • **Installation**: No HVAC technician required for charging of units (system is pre-charged).* • **Ventilation**: Ventilation integrated with the system and can be adjusted as needed to meet code requirements. **Secondary factors** • **System performance**: Complete heating and cooling provided without the need for supplemental heat. Heating climate operation met the target set temperature. • **Operation**: Simple control with a wall thermostat.	**Primary factors** • **Noise**: Sound level in the bedroom adjacent to unit during operation was up to 69 decibels.† The unit provides direct contact to the outside allowing external noise into the MHU.***** • **Comfort:** Path to exterior allows uncontrolled air flow through the unit into the bedroom, potentially causing drafts, thermal losses and moisture flow.***** Large amounts of return airflow must pass through the master bedroom to reach the return air grille (750 cfm in 3 bed; 350 cfm in express), potentially leading to drafty conditions. • **Thermal Impact**: Celling ducts required for air distribution, displacing ceiling insulation and degrading envelope performance. • **Dehumidification**: Supplemental dehumidification required for the 1, 2 and 3 bedroom (as per calculations – testing planned for summer 2018). • **Product quality**: There were several product failures noted during the testing of the demonstration units.

[1] Both the packaged unitary and the split furnace system are available in heat pump versions for additional cost.

Equipment type (MHU type)	**Pros**	**Cons**
		Secondary factors • **Design integration**: Large amounts of return air needed into master bedroom require large return air pathways through door/wall conflicting with sprinkler pipe runs. • **Installation**: If continuous foam insulation is used, lumber with pre-drilled holes required to be installed before fastening the unit to the exterior wall potentially slowing production and/or requiring off-line assembly. • **Code compliance:** HUD AC letter required.
Split system—Furnace with outside condenser (1- 2-, and 3-bedroom MHUs)	**Primary factors** • **System performance**: Complete heating and cooling solution without the need for supplemental heat.* • **Installation**: Setting of furnace and running ducts are routine operations for the plants.* • **Ventilation**: Ventilation can be integrated in the system. **Secondary factors** • **Thermal impact**: No system components are installed through exterior walls. • **Product quality**: No indication of performance issues during testing in the field. • **Noise**: Sound level in bedroom adjacent to exterior compressor 55 dB. †	**Primary factors** • **Installation**: HVAC technician required for running refrigerant lines. Charging of refrigerant lines required in the plant and/or in the field.* • **MHU design**: Floor space required inside the MHU (not feasible for Express).* • **Dehumidification**: Supplemental dehumidification required (as per calculations – testing forthcoming in summer). • **Thermal Impact**: Celling ducts required for air distribution, displacing some of the ceiling insulation and degrading envelope performance. **Secondary factors** • **Design integration**: Return air grills needed above the bedroom doors.

Equipment type (MHU type)	**Pros**	**Cons**
	• **Operation**: Simple control with a wall thermostat. • **Code compliance**: HUD AC letter not required	• **Installation**: Outdoor condenser unit required to be mounted, secured, protected and transported on a chassis extension.
Mini-split heat pump (Express unit)	**Primary factors** • **Ducts**: Reduced ducts required for air distribution via transfer fan duct(s)**.*** • **MHU design**: No floor space required inside the unit. (benefit for Express unit, in particular).* • **Dehumidification**: Supplemental dehumidification not required (as per calculations – testing planned for summer 2018). • **Noise**: Quietest operation of the systems tested: 54 dB. † **Secondary factors** • **Design Integration**: Return air grills not required at bedroom doors. • **Product quality**: No evidence of performance issues with equipment during testing in the field. • **Thermal impact**: No system components installed through exterior walls.	**Primary factors** • **Comfort**: Cooling in bedrooms is subject to ability of transfer fan to provide conditioned air (to be tested in summer).* • **System performance**: Supplemental heat required in addition to the heat pump.* • **Design**: Limited track record of performance in manufactured housing. Additional verification of in situ performance and design evaluation through prototyping would be prudent.* • **Installation**: HVAC technician required for running refrigerant lines. Charging of refrigerant lines required in the plant and/or in the field.* • **MHU design**: Closet space required for installation of the bedroom transfer fan as currently configured. • **Ventilation**: A separate ventilation system required. **Secondary factors** • **Design integration**: Return air grills required for rooms served by transfer fan. • **Installation**: Outdoor condenser unit required to be mounted on frame or brackets, secured, secured and transported to site. • **Code compliance**: HUD AC letter required

† Decibel (dB) readings are a measure of loudness, each increment of 10 dB translates as a doubling of the loudness level. A decibel reading of between 50 and 60 dB is considered quiet to fairly quiet, above 70 is characterized as loud.

Commentary and recommendations

Express Units

Among the overarching criteria in selecting the HVAC system for the Express unit is that the system not reduce the available interior floor area. This consideration suggested two options:

1. An exterior unitary product with conditioned air distributed through ducts with integral ventilation. Separate supplemental dehumidification would be required. This system type is commonly used in MHU construction currently; and,
2. A ductless mini-split heat pump system with an interior wall mounted head(s) and exterior wall mounted condenser. Dehumidification capability is subject to future hot-humid climate assessment. Separate dedicated ventilation would be required.

In consideration of the factors noted above, and with the caveat that testing in a hot-humid climate is in the future, both systems have significant drawbacks, and neither are ideal candidates as currently configured. However, the mini-split system offers greater latitude in making design changes that overcome several of the drawbacks noted above. That is, the flaws identified in the unitary system are more systemic in nature (noise, comfort) and less able to be addressed through design changes. Conversely, while there are several significant shortcomings with the mini-split system as configured, some of the key limitations can be addressed by design changes. Specifically, based on the information collected thus far, we recommend developing a mini-split solution that uses two internal heads (instead of one) with one or two outside condensing units. This configuration would eliminate the transfer fan between bedroom and living room, would reduce (and possibly eliminate) supplemental heating needs, and would provide for better temperature balance and humidity control. Further testing would facilitate the evaluation and refinement of a modified mini-split design.

1-, 2- and 3-Bedroom MHUs

Two system types were considered for the 1-, 2- and 3-bedroom MHUs:

1. An exterior unitary product with conditioned air distributed through ducts with integral ventilation. Separate supplemental dehumidification would be required. This system type is commonly used in MHU construction; and,
2. An industry standard electric furnace with overhead duct distribution, an indoor coil for cooling mounted over the furnace and an outdoor compressor sitting on a frame extension. This system has also been used for FEMA MHUs.

Pending summer testing, both options likely require standalone dehumidification and do include ducts in the attic space that reduce the thermal integrity of the ceiling, requiring higher insulation levels to achieve the target performance (projected code requirements).

The standard split system requires an enclosure within the MHU and a technician in the plant to run and charge the refrigerant lines. The industry's familiarity with the furnace/duct installation process and ready availability of system hardware is a positive and the components of the cooling system are likely to be available from the same suppliers.

The unitary system presents three major challenges based on the experience with the tested product: noisy operation, potential for thermal comfort issues and, several service issues (the propensity for product failure was not studied but rather observed anecdotally). It is possible that steps can be taken/assurances provided to address the service concerns. Noise and comfort, however, may be difficult to address, albeit other products may be identified in the future that don't have these operational issues. While the product presents some plant installation challenges that likely can be mitigated in the future, the self-contained nature of the unitary system (no need to run refrigerant lines) is a significant advantage of this system type.

While further testing is anticipated in Selma that will test both systems, in the aggregate the split system offers compelling advantages and perhaps a more dependable and reliable solution that is likely to be better received by occupants and manufacturers.