Comparison of wall assembly options for FEMA MHUs

(March 27, 2018)

Goal: Identify and demonstrate wall components that can be used in a CONUS application based on ability to meet future energy standards and minimize the propensity of moisture-related problems

Highlights of interim findings

- 10 walls selected that meet future code and vary by vapor transmission
- First step: WUFI analysis for selected 10 walls
- Failure modes: walls are defined as failing based on mold growth potential at the OSB. Mold is expected to result if one or more of the following conditions are met.
  1. If % MC > 21% in OSB for heating season of years 2 and 3 in repetition
  2. If % MC increased from year 2 to year 3 even if it did not exceed 21%
  3. The relative humidity at the surface of the OSB reaches a 30-day running average of exceeding 80% when the 30-day running average surface temperature is between 5 C (41 F) and 40 C (104 F).
- Simulation results: a wall consisting of **2x4** framing with R-13 insulation and an exterior layer of 1" XPS foam was initially considered the ideal blend of satisfactory moisture flow control, thermal integrity and ease of factory manufacture
- Two MHUs were built with this wall; separately a CONUS test unit was built with four walls designs that based on simulation results are expected to perform well, and one wall (the only wall that did not have foam insulation) representing a more industry typical wall design (**2x6** framing with R-19 batt insulation).
- Testing at Ham Lake, MN consisted of the following: one CONUS test structure housing the five wall types with extreme interior conditions intended to represent worse case analysis; and, two MHUs with RH set to average occupancy conditions (30% RH).
- Initial MHU test results: the MHU walls behave as expected verifying WUFI results.
- CONUS results suggested that extreme design conditions take a toll on all walls. Additional testing will seek to assess intermediate RH levels (between 30 and 60% RH).
- Industry feedback is strongly opposed to the options using exterior foam sheathing products, included the 1" material used on the MHUs. Objections were based on negative impact on manufacturing and material availability.
- The team is proposing to develop a strategy for proving a wall configuration that does not require foam and minimizes the potential for condensation and moisture accumulation. The wall might be built of 2x4 or **2x6** framing with fiberglass insulation. Follow on research will need to resolve issues such as: appropriate location of the vapor retarder, need to pressurize the MHU, etc.
- Final conclusions of the current study will be provided after summer testing.

Comparing wall assembly options for FEMA MHUs

GOAL

The next generation of FEMA MHUs must be capable of being installed in any location in the contiguous United States, termed as “CONUS“. Ten candidate wall assemblies were developed with the intention of meeting this goal as well as complying with thermal provisions of the future anticipated HUD code.

WUFI SIMULATION OF 10 OPTIONS

The wall assemblies were first simulated using WUFI PRO 6.1, a hygrothermal modeling software. The software simulates movement of heat and vapor through the construction materials, predicting moisture accumulation and the potential for condensation. After conducting the simulation in locations representing each of the five IECC climate zones, the risk of building component failure and the long term durability of each of the assemblies was evaluated.

ANALYSIS AT OSB:

The OSB sheathing in each of the wall assemblies is a potential condensation surface. It is subject to mold growth under certain temperature and moisture conditions. Therefore, the analysis focused on the hygrothermal conditions of the OSB sheathing. A monitoring position was placed at the interface of the OSB and the wall cavity insulation, to gather simulation data on temperature, relative humidity and moisture content on the surface of the OSB.

FAILURE MODES FOR SIMULATION

Each assembly was modeled over a three year period. The following conditions were considered to indicate prolonged mold growth and a high risk of failure:

- If % moisture content of the OSB > 21% for year 2 and year 3 in repetition.
- If % moisture content increases from year 2 to year 3 even if it does not exceed 21%.
- The relative humidity at the surface of the OSB reaches a 30-day running average of exceeding 80% when the 30-day running average surface temperature is between 5 C (41 F) and 40 C (104 F).

SIMULATION RESULTS

Table 1a and 1b show the results of the WUFI simulation for the 3-bedroom and Express MHUs for each of the five climate zones. The fields in green show instances with acceptable moisture content and are considered least risky. The fields in red designate moisture content greater than 21%, indicating higher risk for condensation. The fields in yellow are instances with 16-21% moisture content, indicating a moderate risk of condensation.

Table 1a WUFI Wall Assembly results, 3-Bedroom MHU

Representative climate location	Fargo, ND		Chicago, IL		Oklahoma City, OK		New Orleans, LA		Miami, FL	
	%MC Max OSB		%MC Max OSB		%MC Max OSB		%MC Max OSB		%MC Max OSB	
Wall Assembly	Year 2	Year 3	Year 2	Year 3	Year 2	Year 3	Year 2	Year 3	Year 2	Year 3
Option A: 2x4 + R 15 + 1" XPS	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%
Option B: 2x4 + R 15 + 1" EPS	16 - 21%	16 - 21%	16 - 21%	16 - 21%	21% >	21% >	21% >	21% >	21% >	21% >
Option C: 2X 4 + R 15 + 1" polyiso	5 - 15%	5 - 15%	16 - 21%	16 - 21%	16 - 21%	16 - 21%	21% >	21% >	21% >	21% >
Option D: 2x4 + R 13 + 2" XPS	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%
Option E: 2x4 + R 13 + 2" EPS	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	16- 21%	16- 21%	16- 21%
Option F: 2x4 + R 13 + 2" polyiso	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	16 - 21%	16 - 21%	5 - 15%	16- 21%
Option G: 2x6 + R 19	21% >	21% >	21% >	21% >	21% >	21% >	21% >	21% >	21% >	21% >
Option H: 2x6 + R 21	21% >	21% >	21% >	21% >	21% >	21% >	21% >	21% >	21% >	21% >
Option I: 2x6 + R 19 + 1" XPS	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%
Option J: 2x6 + R 19 + 1" Polyiso	16- 21%	16- 21%	16- 21%	16- 21%	16- 21%	16- 21%	16- 21%	21% >	21% >	21% >

Table 2b WUFI Wall Assembly results, Express MHU

Representative climate location	Fargo, ND		Chicago, IL		Oklahoma City, OK		New Orleans, LA		Miami, FL	
	%MC Max OSB		%MC Max OSB		%MC Max OSB		%MC Max OSB		%MC Max OSB	
Wall Assembly	Year 2	Year 3	Year 2	Year 3	Year 2	Year 3	Year 2	Year 3	Year 2	Year 3
Option A: 2x4 + R 15 + 1" XPS	16- 21%	16- 21%	16- 21%	16- 21%	16- 21%	16- 21%	5 - 15%	5 - 15%	5 - 15%	5 - 15%
Option B: 2x4 + R 15 + 1" EPS	16- 21%	16- 21%	16- 21%	16- 21%	21% >	21% >	21% >	21% >	21% >	21% >
Option C: 2X 4 + R 15 + 1" polyiso	16 - 21%	16 - 21%	16- 21%	16- 21%	21% >	21% >	21% >	21% >	21% >	21% >
Option D: 2x4 + R 13 + 2" XPS	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%
Option E: 2x4 + R 13 + 2" EPS	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	16- 21%	16- 21%	16- 21%	16- 21%	16- 21%
Option F: 2x4 + R 13 + 2" polyiso	5 - 15%	5 - 15%	5 - 15%	5 - 15%	5 - 15%	16- 21%	16- 21%	16- 21%	16- 21%	16- 21%
Option G: 2x6 + R 19	21% >	21% >	21% >	21% >	21% >	21% >	21% >	21% >	21% >	21% >
Option H: 2x6 + R 21	21% >	21% >	21% >	21% >	21% >	21% >	21% >	21% >	21% >	21% >
Option I: 2x6 + R 19 + 1" XPS	16 - 21%	16 - 21%	16- 21%	16- 21%	16- 21%	16- 21%	5- 15%	5- 15%	5- 15%	5- 15%
Option J: 2x6 + R 19 + 1" Polyiso	16 - 21%	16 - 21%	16- 21%	16- 21%	21% >	21% >	21% >	21% >	21% >	21% >

SELECTION OF WALLS FOR CONUS WALL TEST STRUCTURE

The best performing walls were found to be Options A, D and I. For the CONUS test structure, five walls were selected for testing as listed below.

1. Option A: 2x4 + R 15 Batt + 1" R 5 XPS
2. Variation of Option A: 2x4 + R 13 Batt + 1" R 5 XPS
3. Option D: 2x4 + R 13 Batt + 2" R 10 XPS
4. Option G: 2x6 + R 19 Batt
5. Option I: 2x6 + R 19 Batt + 1" R 5 XPS

Options A, D and I were selected for further consideration as they performed best according to the WUFI simulation. A variation of Option A from the simulation, with standard batt insulation instead of high density insulation was also selected for future consideration as that assembly is a more common construction option.

Further, given the atypicality of foam insulation use by the industry, an option based on **2x6** framing with standard R-19 batt insulation but without foam was added to the testing plan (Option G), even though it fared poorly in the simulation.

SELECTION OF WALLS FOR PROTOTYPE MHUs

Among the walls that were chosen for the CONUS test structure and that the simulation deemed acceptable, Option A and Variation of Option A were identified as being the most manufacturing friendly while exhibiting good moisture flow resistance properties. Hence they were chosen as the wall assemblies to be installed in the two MHU prototypes. The **2x4** wall with standard batt insulation and foam was installed in the 3-bedroom and the **2x4** wall with high density batt insulation and foam was installed in the Express (the higher R-value per inch material helped satisfy overall thermal integrity goals).

TEST UNITS BUILT AND TRANSPORTED

A site in Ham Lake, MN was chosen for the extreme cold condition. The prototype MHUs and CONUS test structure were built and transported to the test location for the heating season.

TEST CONDITIONS: RH

FEMA MHUs tend to have a high occupancy relative to their size and number of bedrooms. In order to test a worst case scenario and thoroughly evaluate moisture control abilities, a relative humidity (RH) of 60% was maintained in the CONUS test structures. In the MHUs, a lower, more “common” daily RH profile based on the unit occupancy was maintained, averaging about 30%.

PERFORMANCE OF PROTOTYPE MHU WALLS

In the testing to date, the wall in the prototype MHUs performed well, as predicted by the simulation studies. Figure 1 and Figure 2 show that the temperature at the OSB surface of both the walls did not reach their dew point temperature. Also the RH of both the walls did not exceed 58%, with 80% being the acceptable threshold for good performance. These results are for reasonable sensible and latent loads as per expected occupancy, however, do not mimic extreme high occupancy or latent moisture generation such as might occur in a worst-case scenario.

INCLUDING THE 2x6 WALL OPTION

Even though the findings from the field tests indicate that the **2x4** wall with foam performs well hygrothermally (as expected given the WUFI simulations), from a manufacturing standpoint, there is a strong industry preference to have a wall solution that requires no exterior foam board. Reasons include the following: required production challenge, impact on labor time and use of a special order material. Accordingly, the 2x6 wall solution without foam was included in the CONUS test unit to determine if this assembly type can be used successfully under design conditions.

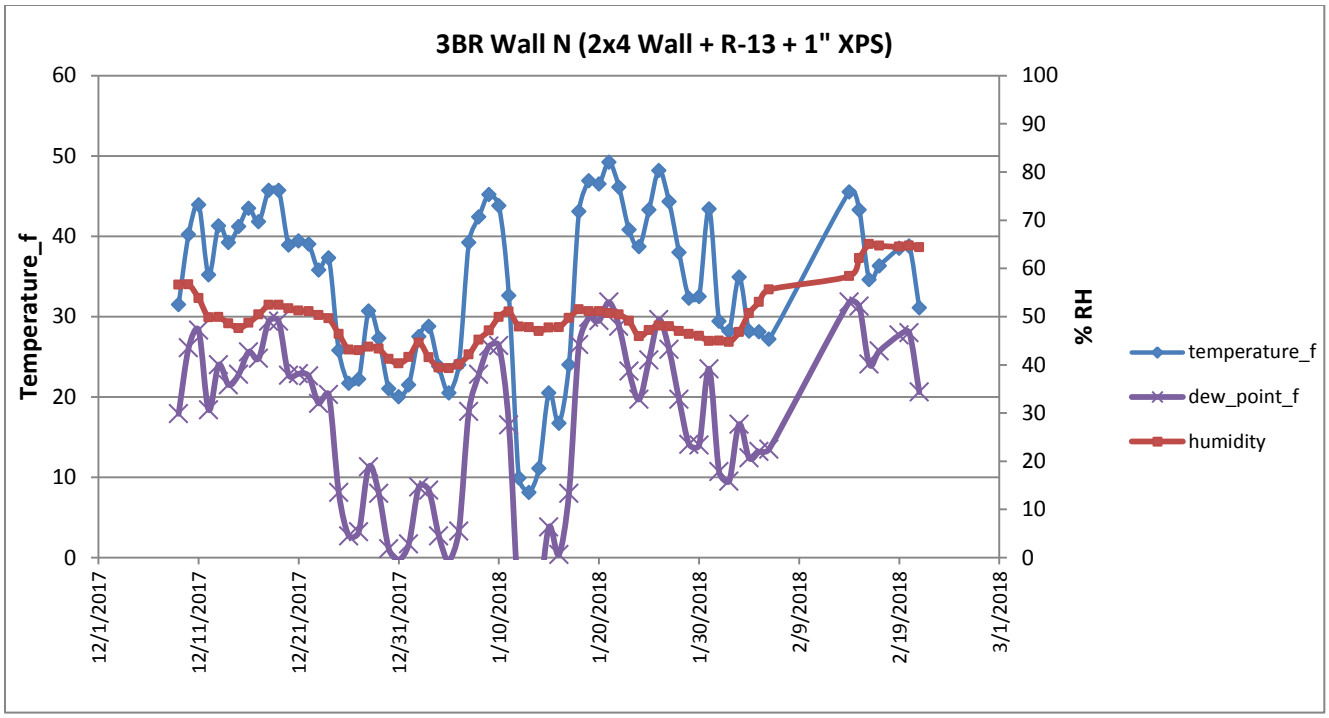

Figure 1 Measured temperature and RH at OSB for the 3 bedroom North wall

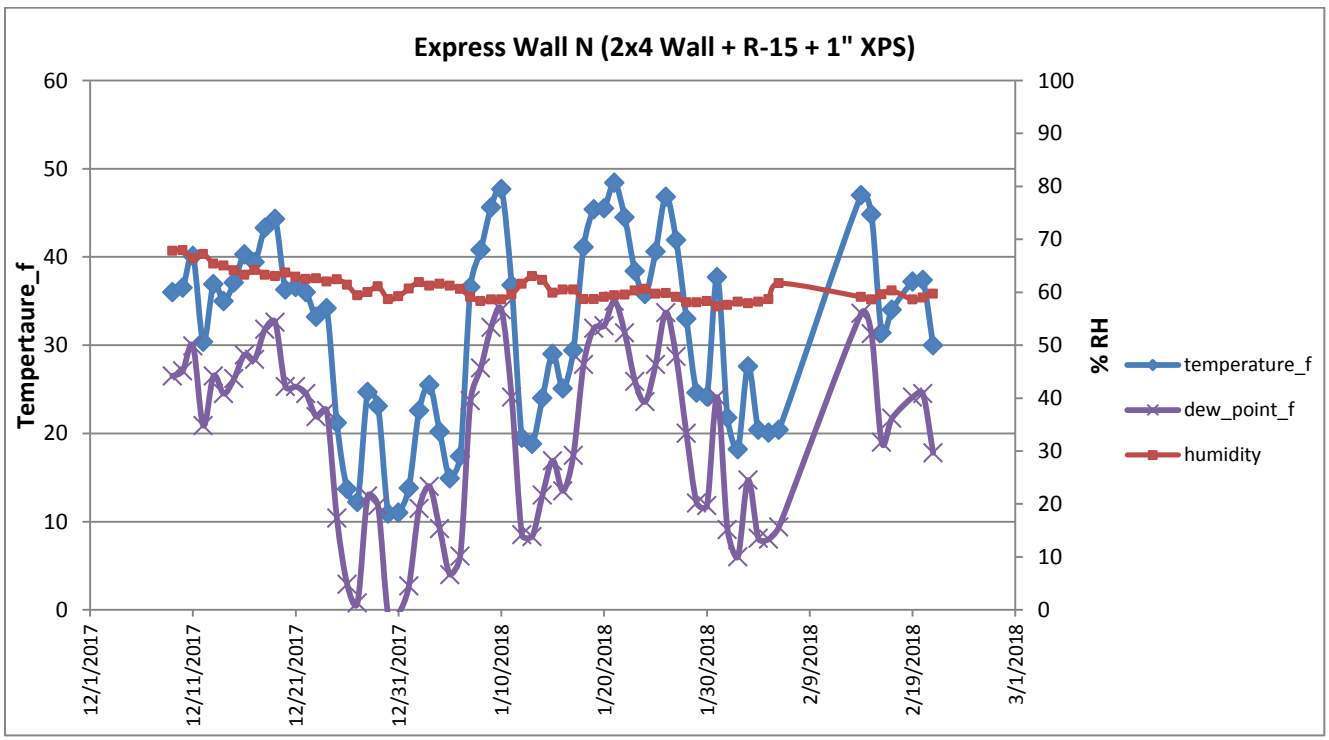

Figure 2 Measured temperature and RH at OSB for the Express North wall

PERFORMANCE OF 2x6 CONUS WALL

As stated previously, the moisture content and the RH at the OSB sheathing are an indicator of potential for condensation and mold growth. Also as per ASHRAE 160, if the 30-day running average of OSB surface RH > 80% when the 30-day running average surface temperature is between 5° C (41° F) and 40° C (104° F), the conditions are conducive to mold growth. The simulation results show that the **2x6** wall has a high risk for condensation due to high moisture content. Also during initial testing, the RH at the OSB of the **2x6** wall in the CONUS test unit increased over the 80% threshold for prolonged periods of time, suggesting the propensity for mold growth. This could lead to decay of the OSB and ultimately cause failure of the wall. However, since this result was obtained with a worst-case elevated RH of 60% and during the winter alone, it is recommended that the wall be tested under more typical operating conditions before drawing conclusions about the risks of using this type of construction.

OTHER CONCERNS WITH 2x6

The **2x6** wall has not yet been tested in the summer which is critical to determine an appropriate location of the vapor retarder. The HUD-code stipulates a vapor retarder on the interior surface of the wall, as installed in the CONUS test structure. However, for hot-humid climates, an exterior vapor retarder is often deemed advisable by the building science community. The location of the vapor retarder is critical to the performance of this wall type. For a CONUS solution, three options are possible:

1. VR on the interior of the insulation, a location that would satisfy the HUD code but raises moisture-related concerns in hot-humid climates of, for example, the Gulf Coast.
2. VR on the outside of the insulation, a better solution for the hot-humid climates but not ideal nor allowed by HUD code for other locations; and,
3. No VR on the wall, also not allowed by HUD code (necessitating an AC letter with technical justification).

Further testing would be needed to determine the best option and conditions for using that option (e.g., pressurizing the MHU on a continuous basis).

It should also be noted that substituting the 2x6 wall for the 2x4 with foam increases the wall thickness by 1” potentially requiring a rework of the Express floor plan.

CONCLUSION

The **2x6** wall should be fully developed into a solution for the MHUs and tested under design summer and winter conditions. RH values would be set to climate and occupant use typical values. Because of the interdependency of the HVAC system and moisture movement, future tests should be based on a near final selection of the heating, cooling and ventilation system.