ROXUL

Hygrothermal Simulations and Analysis of Solar-Driven Inward Water Vapor

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Executive Summary

This summary highlights key points from the research report entitled **Hygrothermal Analysis of Solar-Driven Inward Water Vapor"**. This hygrothermal analysis was conducted in U.S. Department of Energy (DOE) climate zones 1-4[1], where inward solar vapor drives are of particular concern. This summary provides an overview of the issues investigated, the research methods used, the results of the research, and conclusions and recommendations. The key purpose of the research was to develop recommended wall systems for using high vapor permeance stone wool as a continuous exterior insulation layer in different climate zones. Limitations and systems that are not recommended are also noted.

Background

Solar inward vapor drives can cause moisture accumulation inside the enclosure, particularly at low vapor permeance layers, potentially causing mold growth and other durability issues. Solar vapor drives are greatest in wall assemblies that have an absorptive exterior cladding such as masonry, adhered stone veneer, or some types of stucco. Water is absorbed into the cladding, and the wall is warmed by the sun, and exterior environment; this combination of heat and moisture pushes water inward in the form of vapor. The amount of vapor that travels inward depends on the vapor permeance of the building materials and the vapor pressure gradient of the assembly. More vapor permeable materials allow water vapor to travel through them more easily, while larger vapor pressure gradients "push" more water vapor through the assembly, from higher-pressure areas to lower-pressure areas. Vapor pressure gradients can push water vapor inward or outward (Figure ES-).

In general, inward vapor drives can be minimized by using non-absorptive claddings, providing a ventilated cavity or capillary break behind the cladding, or using a lower vapor permeance layer between the absorptive cladding and the structure.

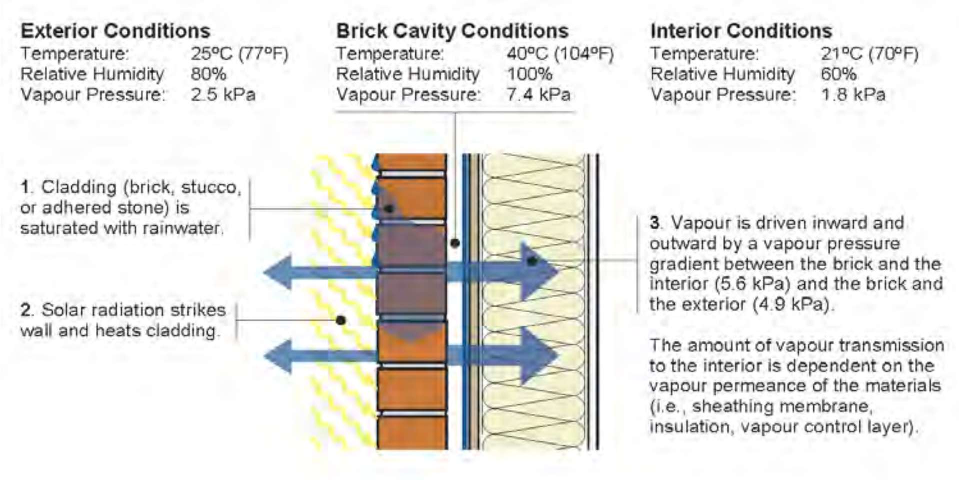

Figure ES-1: Inward vapor drive schematic.

[1] The 2012 International Energy Conservation Code – Table 301.3(2) defines climate zones based on heating and cooling degree days.

Research Approach

The research described here used WUFI® Pro computer modeling software to investigate moisture-related durability risks due to solar-driven inward vapor in wood framed residential wall assemblies. Specifically, it examined walls with COMFORTBOARD™ IS used as continuous exterior insulation. WUFI combines known data about building materials and climactic conditions to predict where heat and moisture will go in an assembly, which in turn helps to predict the potential for moisture damage.

The Walls

This study investigated performance in six representative cities from DOE Climate Zones 1 to 4. First, sensitivity analysis was conducted for key variables. Sensitivity analysis involves determining upper and lower limits for durability in order to help with experimental design and data interpretation. Analyses were conducted for the following variables:

- Driving rain
- Cladding selection (ventilated vs unventilated brick)
- Interior vapor control
- Sheathing membrane permeance selection
- Interior temperature
- Rainwater leakage.

Based on sensitivity analysis, two wall assemblies were designed and then modeled for all cities, with variations modeled in select cities to suggest design alternatives where potential risks were identified. An orientation was chosen for each city that maximized both driving rain and solar energy on the surface of the wall, thus maximizing the potential inward solar drive. The same insulation was used for all simulations: R13 COMFORTBATT™ in the studspace and 1" of continuous R4 COMFORTBOARD™ IS on the exterior of the sheathing.

The two walls modeled in all cities used a type of brick (labeled in WUFI as "Solid Brick Masonry") that is representative of commonly used bricks. One wall was ventilated (at 10 ACH) and one was unventilated. 10 ACH represents a normal average ventilation rate for vented brick. The basic configuration of these walls is shown below.

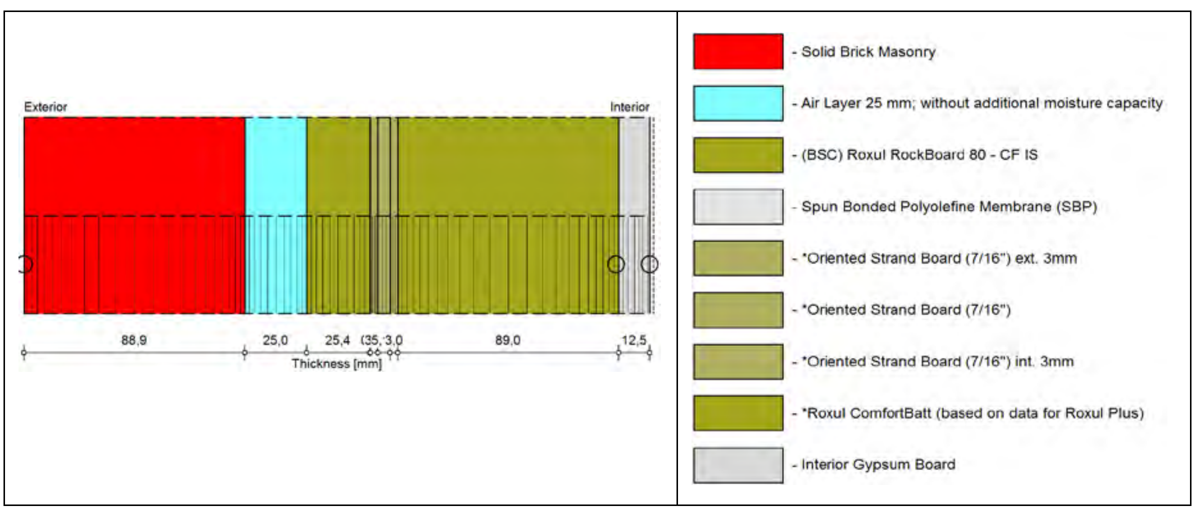

Figure ES-2: Ventilated Solid Brick wall assembly. Note: the OSB sheathing was modeled with an interior and exterior three 3mm layer because this produces results similar to those obtained through field measurements.

Evaluation Criteria

Assemblies were evaluated based on the predicted sheathing moisture content and the predicted relative humidity at the exterior surface of the interior gypsum board. In cases where the RH at the interior gypsum was elevated, the predicted moisture content of the interior gypsum board was determined and assessed[2].

Table ES-1: Evaluation Criteria

CRITERIA	SAFE LEVELS (Very little risk)	ACCEPTABLE LEVELS (Some risk, but design can be successful)	HIGH-RISK LEVELS (This design is not recommended)
Sheathing moisture content	Peak sheathing moisture content less than 20%	Peak sheathing moisture content between 20% and 28%	Peak sheathing moisture content >28%
Relative humidity at the exterior surface of interior gypsum board	<90% RH, or >90% RH with <1% moisture content[3]	>90% RH with 1-2% moisture content[3]	>90% RH with >2% moisture content[3]

Note: Moisture content analysis of the drywall was conducted for any wall assemblies that showed relative humidity over 90% at the exterior surface of the gypsum wall board.

Limitations

Several limitations of this research design should be kept in mind:

- WUFI predictions for moisture-related durability issues in gypsum are very sensitive to the material property data entered. Slight variations can significantly change the results.
- Predicted wood moisture contents of OSB should be kept in context. Good engineering judgment is required to determine the moisture risk to the sheathing.
- Rain water intrusion and air leakage can be the most damaging and also the least predicable damage mechanisms. For this study, it was assumed that the rain water management details and air barrier details were constructed adequately such that bulk water accumulation from the sources does not exist. Any additional moisture from these sources would dramatically alter the performance of the systems.
- Occupant behavior is not included in modeling and may impact durability. For example, placing cabinets, mirrors, etc. directly against the interior gypsum board could prevent vapor from diffusing out of the wall at that location.
- In the field, ventilation rates of the space behind the cladding are influenced by temperature, wind, and workmanship.

Wall Analysis

Sensitivity analysis for interior finish permeance showed significant differences in performance at different permeances, ranging from no predicted moisture-related damage at 7.5 and 10 perms to a significant risk of damage at 2.5 perms or less. The permeability of the sheathing membrane interacted with and could offset this risk: for example, walls with a 2.5 perm interior finish became safe (in terms of solar-driven vapor) when

[2] CMHC Research Highlight, “Relationship Between Moisture Content and Mechanical Properties of Gypsum Sheathing”, Technical Series 07-100, February 2007

a less permeable sheathing membrane was chosen[3]. For cladding selection, sensitivity analysis showed a modest effect of adding 10ACH of continuous ventilation behind the brick. Other sensitivity analyses also produced minor effects. Predicted risk was not increased by either increasing the driving rain coefficients or adding a rain leak to the model. Changing the interior temperature setpoint did have a small effect on the relative humidity at the exterior surface of the interior gypsum board. In some cases, because of the sensitivity of the gypsum board moisture content to relative humidity, this could play a role in affecting the durability of the interior gypsum board.

The main analyses were conducted on ventilated and unventilated Solid Brick Masonry walls with continuous stone wool insulation and a 5 perm latex paint interior vapor control layer (on the interior face of the gypsum board) and a 50 perm spun-bonded polyolefin sheathing membrane. In these assemblies, OSB moisture contents were at safe levels for all climate zones. The unventilated wall was also modeled with an impermeable (1 perm) interior finish in Orlando, Atlanta, Charlotte and St. Louis, which caused predicted moisture related failure of the OSB in all cases.

The second risk evaluation criteria, relative humidity at the surface of the gypsum board, indicated a higher level of risk. Moisture content in the gypsum was investigated in cases where RH was predicted to exceed 90%. For both ventilated and unventilated Solid Brick Masonry assemblies, a 5 perm interior finish caused moisture content peaks above 2% in nearly all locations. In Miami and Houston, peak moisture content was above 3.5%. However, increasing the vapor permeance of the interior finish to 7.5 perms in Miami and Houston resulted in moisture contents under 2%. Changing the permeance of the sheathing membrane to 6.5 perms further reduced peak moisture contents to 1.2%.

Alternate cladding materials were subsequently investigated. A less-absorptive brick type (“Red Matt Clay Brick”) was used for simulations in Miami, Houston, and St. Louis . Vinyl siding was used for simulations in Miami and Houston. Relative humidity at the surface of the gypsum board was well below 90% for all of these simulations.

Conclusions

Many variables can contribute to solar inward vapor drives and associated durability risks. Based on sensitivity analysis, the most critical variables appear to be the vapor permeance of the sheathing membrane and the interior finish of the gypsum wall board. Less-permeable vapor control layers on the interior were particularly risky. Because rockwool can redistribute moisture and dry quickly, added moisture from driving rain and simulated rain leaks did not significantly add to solar-driven vapor risks. Rain leaks were applied to the interface of the continuous rock wool insulation and sheathing membrane.

Based on predicted OSB sheathing moisture contents, none of the walls with a 5 perm interior vapor control layer showed evidence of moisture-related durability issues. Relative humidity at the surface of the gypsum board indicated a higher level of risk than the OSB analysis criteria. With a 5 perm interior finish, the two Solid Brick Masonry walls showed elevated risk levels in nearly all locations. This result is inconsistent with BSCI’s field experience, which has shown that latex paint is an effective finish for these assemblies in Climate Zones 1 to 4 in terms of managing solar driven inward vapor. It could be that the vapor permeance of installed paint in successful assemblies may be closer to 10 perms than 5 perms. This hypothesis is supported by the simulated result that a 7.5 perm interior finish reduced risk to acceptable levels in the modeled walls.

Modeling also showed that the type of cladding is an important design choice. All predicted solar-driven vapor risks were minimized or eliminated when the highly absorptive Solid Brick Masonry was exchanged for vinyl siding or less absorptive Red Matt Clay Brick.

Overall, this study demonstrates that continuous high vapor permeance exterior insulation can be used in Climate Zones 1 to 4 without solar-driven inward vapor causing problems. However, there is some risk and steps to reduce risk should be followed.

[3] Note that it is never recommended to use vapor barriers (i.e. impermeable, Class I vapor control layers) on both the interior and exterior of an assembly. This would prevent drying in the event of incidental moisture. A 2.5 perm control layer is Class III, and will allow some drying.

Recommendations

Based on this analysis and BSCI's field experience, we recommend the following to reduce the risk of solar-driven vapor problems in Climate Zones 1 to 4 for an assembly consisting of:

- Brick veneer cladding
- ROXUL exterior continuous insulation
- OSB
- ROXUL cavity batt
- Gypsum wall board

First, use a sheathing membrane with a vapor permeance of 6.5 perms or less in between the exterior insulation and the sheathing. Many products can meet this need, including self-adhered membranes, fluid applied membranes, and some mechanically fastened sheet applied sheathing membranes.

Second, only use latex paint on the interior of the gypsum wall board. Low permeance interior finishes such as vinyl wallpaper should be avoided. Picture frames, mirrors, whiteboards, cabinets, and other low vapor permeance items that could retard vapor movement should be installed with spacers to allow ventilation behind the low permeance wall coverings.

Third, minimize the water entering and stored in the assembly with proper flashing of all windows, and penetrations, and suitable overhangs. Vinyl siding eliminates all of the problems of solar driven inward moisture but often that is not the aesthetic that is desired. Using a lower absorptivity cladding and good water management design (i.e. suitable overhangs, etc.) will also reduce the amount of water in contact with the assembly. Ensuring the ventilation cavity in the enclosure is as free as possible of obstacles will help reduce the solar driven inward vapor by removing vapor in the cavity through ventilation.

To validate modeling results, full scale field testing is recommended.

Introduction

Building Science Consulting (BSC) was retained by Roxul to conduct hygrothermal analysis of wall assemblies constructed with rockwool continuous exterior insulation in DOE climate zones 1 to 4. Hygrothermal analysis of these wall assemblies was conducted with WUFI® Pro 5.1. WUFI is a transient heat and mass transfer model which can be used to assess the heat and moisture distributions for a wide range of building material classes and climatic conditions. Hygrothermal modeling is used to determine the moisture-related durability risk, including wetting and drying due to vapor transmission through the assembly materials from the interior and exterior. In this particular study, we will be analyzing the risk of solar driven inward vapor in the enclosure assembly.

The objective of this analysis and report is to develop recommended wall systems when using high vapor permeance continuous rockwool exterior insulation in different climate zones. When found, limitations or systems that are not recommended will be noted.

Background

Solar inward vapor drives occur in building enclosures when an absorptive exterior cladding such as masonry, adhered stone veneer, and some types of stucco are installed. Water is absorbed into the cladding, and the wall is warmed by the sun. This produces very high inward vapor pressures (combination of heat and moisture). The amount of vapor diffusion is dependent on the vapor pressure gradient, that is, the difference in vapor pressures between two points in the assembly, and the vapor permeance of the building materials. The larger the vapor pressure gradient, the higher the potential vapor movement. A schematic of inward vapor drives is shown in Figure ES-. Inward vapor drives can be minimized by using non-absorptive claddings, ensuring a ventilated cavity/capillary break behind the cladding, or using a lower vapor permeance layer between the absorptive cladding and structure.

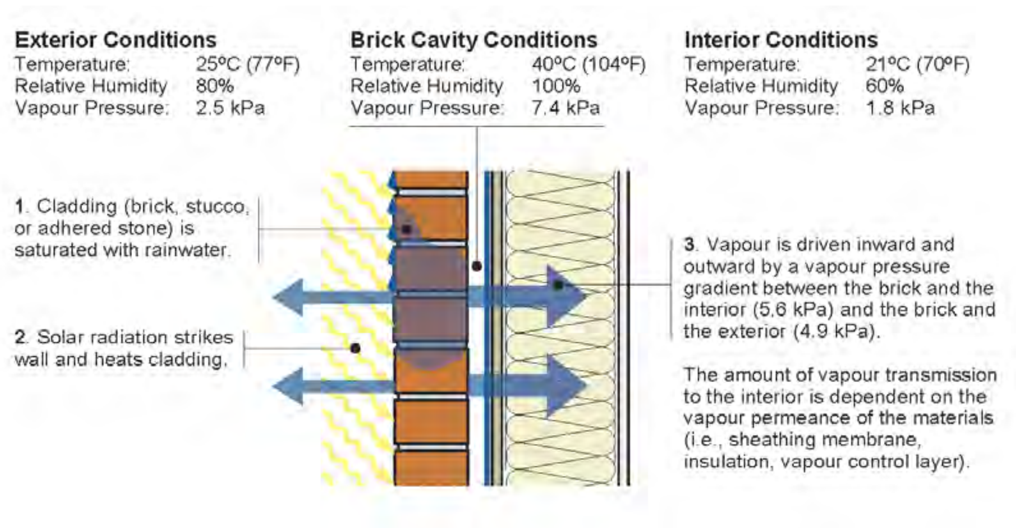

Figure 1: Inward vapor drive schematic.

Approach/Scope

This assessment of inward vapor drive risks was conducted using WUFI-Pro, a hygrothermal analysis tool used to assess the heat and moisture distributions for a wide range of building material classes and climatic conditions.

This analysis was conducted in six locations over Department of Energy (DOE) climate zones 1 through 4, as defined in the IECC[4]. The specific cities analyzed in this study are shown in **Table 2**.

Table 1 : Cities included in hygrothermal analysis

Climate Zone	Representative City
1	Miami
2	Houston
2	Orlando
3	Atlanta
3	Charlotte
4	St. Louis

This analysis was used to determine the risk of solar driven inward moisture accumulation in various enclosure assemblies in the chosen cities. A sensitivity analysis was conducted on some simulation parameters to determine the performance under very challenging boundary conditions. Additional simulations in each climate zone showed the effect of modifying some of the critical parameters.

It should be noted that the scope of this analysis is limited to vapor diffusion and assumes that the two largest sources of moisture, bulk rainwater and air leakage condensation, are sufficiently handled by good design and construction. The largest potential source of moisture is rain water intrusion, and the second is air leakage, since air carries significantly more moisture than can be moved by vapor diffusion. In hot humid climates, air infiltration can be a problem with warm humid air being drawn in through enclosure in towards the interior gypsum board which is often below the dewpoint of the exterior air.

In the relatively cooler climate zones 3 and 4, with elevated interior relative humidity levels, winter time moisture accumulation from outward vapor drives may be possible, especially on the North orientation. This was not included in the scope of this analysis and report. The potential for wintertime moisture accumulation in the sheathing decreases with the addition of continuous exterior insulation.

An orientation was chosen for each city that maximized both driving rain on the surface of the wall, and the incident solar energy on the surface thus maximizing the potential inward solar drive. This orientation was typically South East, but could have been directly South or East based on the boundary conditions, and was identified for each city.

The R-value of insulation was chosen for each climate zone based on The Group R category in Table C402.2 of the 2012 IECC. This category technically refers to residential construction greater than three stories in height, and not residential construction three stories or less in height. The reason this code was chosen was because it requires exterior insulation, even in DOE climate zone 1 and 2, which the residential codes do not, and this analysis is based on the installation of exterior continuous rockwool insulation.

The insulation used in analysis was the same for every city, R13 Roxul ComfortBatt in the studspace, and 1” of continuous R4 Roxul ComfortBoard IS on the exterior of the sheathing. A schematic of the wall is shown in Figure ES-2 below. The material properties for all of the materials used in simulations for this analysis are included in the appendix.

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[4] International Energy Conservation Code – Table 301.3(2) defines climate zones based on heating and cooling degree days. 2012

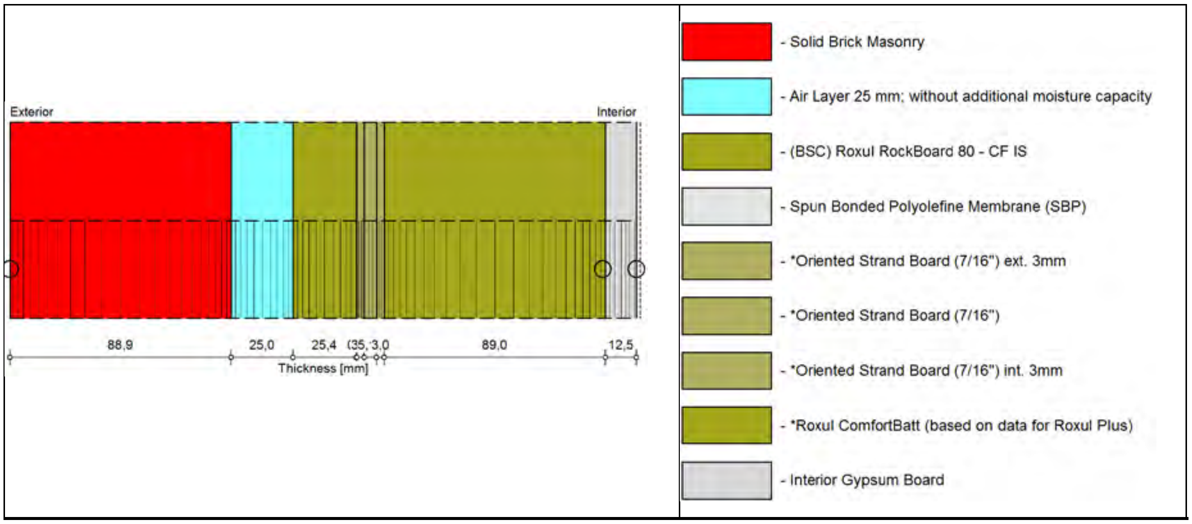

Figure 2 : Example of typical wall assembly for analysis

All of the simulation results were taken based on data developed once the assembly had reached equilibrium with both the interior and exterior conditions. For most simulations 4 years were simulated and the final year data was utilized.

It should be noted that neither rain water penetration nor air leakage condensation are considered sources of water in this analysis. Rain water intrusion and air leakage can be the most damaging and also the least predicable damage mechanisms. For the purposes of this analysis report, it was assumed that the rain water management details and air barrier details were constructed adequately.

In hot humid climates, air leakage condensation typically occurs when hot humid exterior air infiltrates through the enclosure and the coldest surface will be the exterior surface of the interior drywall due to air conditioning of the interior space. In this report, it is assumed that the sheathing membrane is installed as an effective air barrier on the exterior which significantly decreases air leakage.

Evaluation Criteria

The criteria for summer time solar inward vapor drive analysis is the predicted sheathing moisture content and the predicted relative humidity at the exterior surface of the interior gypsum board. The exterior of the interior gypsum board was monitored in order to quantify inward vapor drives that contact the surface of the gypsum. The RH at the surface of the drywall is critical because it determines the moisture content of the gypsum board based on the sorption isotherm of the gypsum. At approximately 90% the moisture content of the gypsum board begins to increase very quickly into “unsafe” ranges.

For this analysis, gypsum moisture contents that did not exceed 1% were designated as safe, and moisture contents between 1% and 2% were still considered acceptable provided variables such as interior humidity level, air leakage and water intrusion do not add to the moisture load of the gypsum. These moisture content limits are based on a 2007 Canada Mortgage and Housing Corporation (CMHC) study that states:

> “as a general rule, the mechanical properties of gypsum sheathing would not meet the ASTM standards (C1177 for exterior grade gypsum, C1396 for fibre-faced gypsum) at moisture-content levels above 1%. However, whether the ASTM Standards are appropriate indicators of in-service performance…is questionable, as some specimens did not meet the criteria even when oven-dried”

Moisture content analysis of the drywall was conducted for any wall assemblies that show elevated relative humidity at the exterior surface of the gypsum wall board.

It is our experience that predicted moisture related durability issues with respect to gypsum are highly dependent on the variables used in the sorption isotherm. If the material properties are even slightly different, the conclusions can vary significantly with respect to “passing” or “failing”.

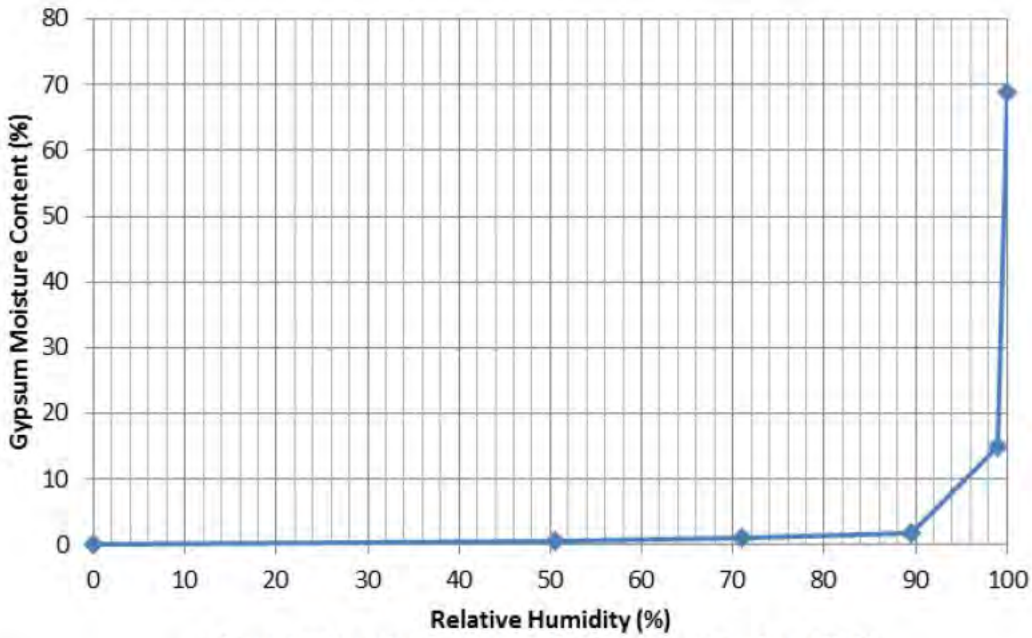

Figure 3 : Sorption Isotherm of interior gypsum from WUFI

The OSB sheathing was divided into three layers because the moisture durability issues are generally caused by elevated moisture contents in the surface of the sheathing. The response of the OSB surface can vary significantly from the core of the sheathing. 3mm thick layers on the interior or exterior of the sheathing are monitored to determine the effects on the material surface. **Figure 4** shows an example of predicted WUFI output for the moisture content of the sheathing which is divided into three components. The moisture content gradient across the sheathing can be seen with peak moisture content at the innermost surface of 12%, and a peak of the middle component of 10%. If the entire thickness of sheathing was used to predict the moisture content, the elevated moisture content at the interior surface would not be captured in the analysis. If slices on the interior and exterior are less than 3mm, the moisture content output of the interior slice would be predicted to be even higher due to the moisture content at the very surface. Our experience has shown that analysis with 3mm does produce similar results when field measurements are compared to hygrothermal analysis.

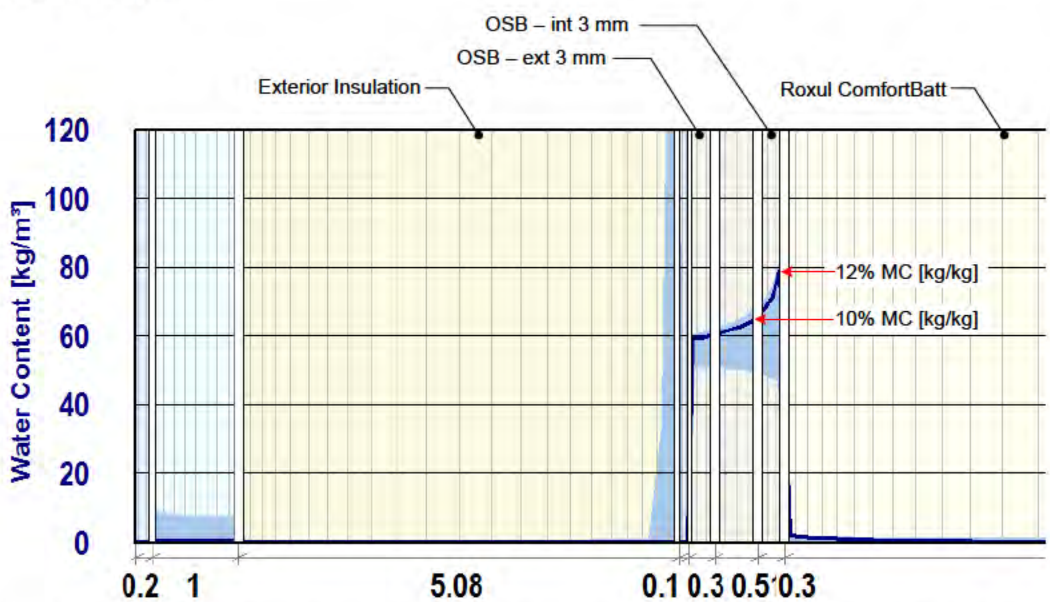

Figure 4 : Example Sheathing Moisture Content Analysis of 3mm wood sheathing slice thickness

OSB sheathing moisture is used as the performance criteria because this is generally where moisture will accumulate and the wood sheathing is a moisture susceptible material. The peak annual OSB sheathing moisture content was determined and the risk was assessed based on the following criteria:

1. Peak OSB sheathing moisture content less than 20%, no mold growth - very little risk
2. Peak OSB sheathing moisture content between 20% and 28% - potential for mold growth eventually, depending on frequency and length of wetting, and temperatures during wetting. This design can be successful but conservative durability assessments usually require corrective action
3. Peak OSB sheathing moisture content >28% - Moisture related problems are expected and this design is not recommended.

Predicted wood moisture contents of OSB are generally assessed with respect to relative risk as opposed to being judged on a pass/fail criterion. The predicted moisture content should be kept in context and good engineering judgment is required to determine the moisture risk to the sheathing. For example, elevated wood moisture contents during colder temperatures are much safer from a mold growth perspective, than similar moisture contents in the summer, when mold will grow more quickly. Also, high moisture content for a short period followed by drying is not necessarily risky, as wood framed structures are able to manage high moisture contents for short periods without exceeding the safe storage capacity of the assembly. The safe storage capacity is the amount of moisture an assembly is able to manage in the hygroscopic materials without suffering any moisture related issues

Boundary Conditions and Testing Variables

The boundary conditions are the interior and exterior environments that influence the performance of the enclosure during the simulations. The interior temperature is a constant 22°C throughout the year, and the relative humidity varies as a sine curve with the min and max as shown in **Table 2**.

The exterior climate was based on weather data included in WUFI for most of the cities analyzed. For both Orlando and Charlotte, climate files for analysis were constructed from TMY3 weather data files. The exterior climate and driving rain rose for each city are included in the analysis section for each city.

Table 2 : Simulation insulation levels and interior relative humidity levels for each climate zone

Climate Zone	Representative City	Wood Framed Residential Minimum Insulation R-value	Interior Relative Humidity Min (Jan 1) /Max (July 1)
1	Miami	R-13 + R-3.8 ci	45 / 60
2	Houston	R-13 + R-3.8 ci	45 / 60
2	Orlando	R-13 + R-3.8 ci	45 / 60
3	Atlanta	R-13 + R-3.8 ci	35 / 60
3	Charlotte	R-13 + R-3.8 ci	35 / 60
4	St. Louis	R-13 + R-3.8 ci	30 / 60

Driving Rain

The amount of rain incident on the wall is critical to the risk of solar driven inward moisture. If the brick is dry, there is no moisture to drive towards the interior. In this analysis, ASHRAE 160[5] section 4.6 was used to calculate the rain load on the building every hour based on the equation shown in **Figure 5**. For the analysis, WUFI values of 1.0 for the rain exposure factor and 0.5 for the rain deposition factor were used. The definitions for both the rain deposition factor and rain exposure factor are below.

[5] AINSI/ASHRAE Standard 160-2009 Criteria for Moisture-Control Design Analysis in Buildings

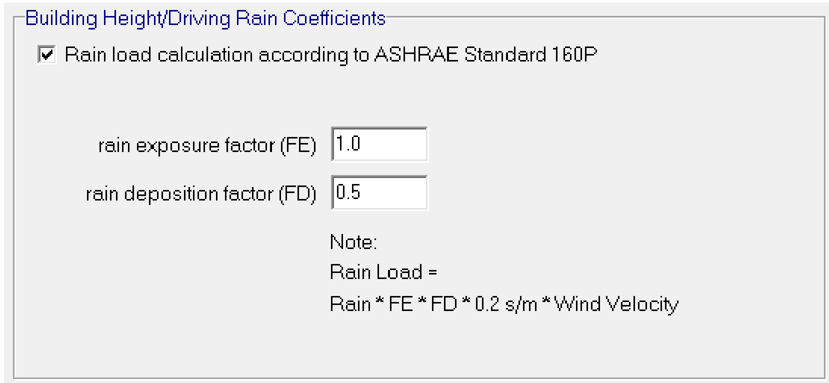

Figure 5 : Driving rain load calculation (WUFI screen capture)

The exposure factor (FE) is influenced by the topography around the building and the height of the building. **Table 3** shows exposure factors as a function of height and terrain. Severe exposure includes hilltops, coastal areas, and funneled wind. Sheltered exposure includes shelter from trees, nearby buildings, or a valley. Rain Deposition Factors (FD) are defined in ASHRAE 160 as;

a. Walls below a steep-slope roof : FD = 0.35

b. Walls below a low-slope roof : FD = 0.5

c. Walls subject to rain runoff : FD = 1.0

Although it is noted in the standard that deposition factors contain a large amount of uncertainty.

Table 3 : Exposure factors from ASHRAE 160

TABLE 4.6.1 Exposure Factor

Building Height, m (ft)	Type of Terrain		
	Severe	Medium	Sheltered
<10 (<33)	1.3	1.0	0.7
10–15 (33–49)	1.3	1.1	0.8
15–20 (49–66)	1.4	1.2	0.9
20–30 (66–98)	1.5	1.3	1.1
30–40 (98–131)	1.5	1.4	1.2
40–50 (131–164)	1.5	1.5	1.3
>50 (>164)	1.5	1.5	1.5

More detailed information regarding the driving rain can be found in ASHRAE 160.

A sensitivity analysis was conducted on the driving rain coefficiencts for Miami, Orlando, and Houston. For each of these three cities the rain exposure factor was increased to 1.5, the maximum value in **Table 3**, and the Deposition Factor was increased to 1.0, the maximum rain deposition factor. **Figure 6** shows some minor elevations in the OSB moisture content, and less drying in some cases, but does not result in any predicted moisture durability issues of the enclosure.

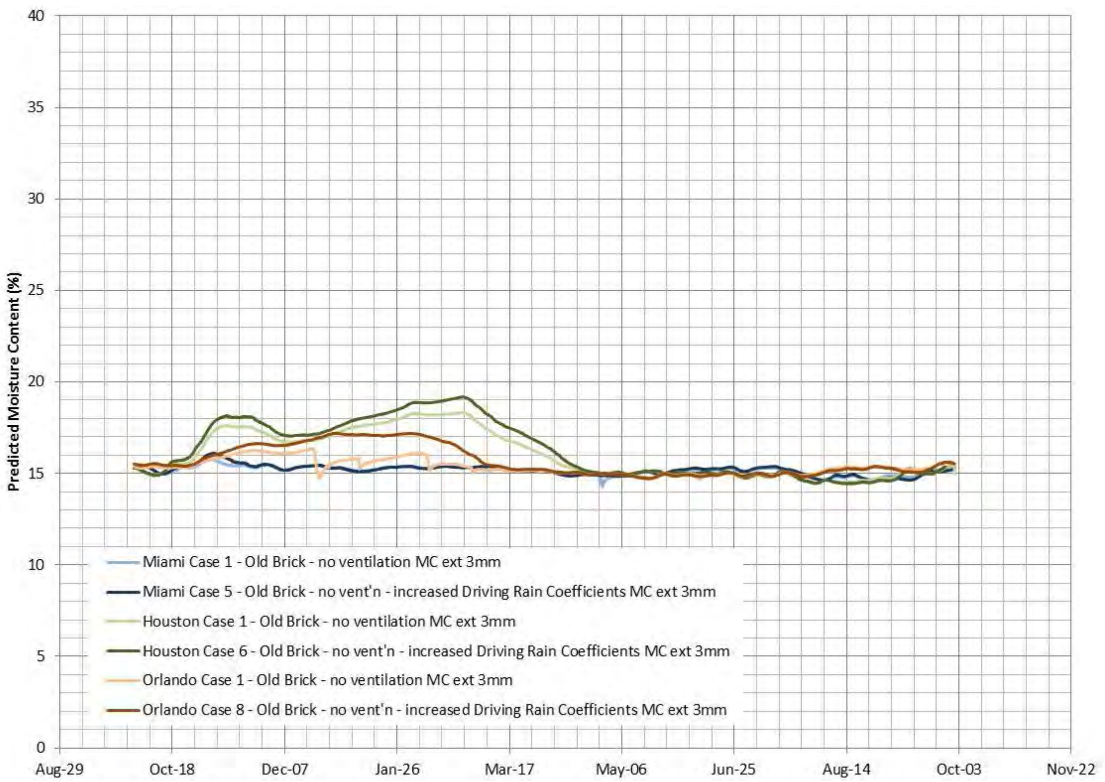

Figure 6 : Sensitivity analysis of the driving rain coefficients

Cladding Selection

For inward solar vapor drive simulations, a brick cladding was used that will store water during rain events, and the orientation was chosen (between South and East) to allow the greatest combination of driving rain and solar radiation to heat the exterior surface of the wall. There are many cases of inward vapor drives in hot humid climates resulting in moisture accumulation in the stud cavity, or at low permeance interior layers such as vinyl wallpaper, or even the back side of mirrors, cupboards, and white boards etc. These problems are worst with storage claddings that do not have a ventilated gap or that are direct applied materials. Therefore, the brick in the current analysis was unventilated to simulate worst case scenario conditions, although a sensitivity analysis was conducted in Miami, Houston and Orlando to determine what effect brick ventilation had on the moisture related durability of the wall assembly. In the field, the amount of ventilation will be dependent on temperature, wind, and workmanship.[6]

The type of brick used is also important.[7] **Figure 7** shows an analysis of OSB moisture content related to the type of brick, where bricks are varied by absorptivity or A-value [$kg/m^2s^{1/2}$]. Comparing low-absorptivity bricks (e.g. Calcium Silicate Brick, A=0.018) to high-absorptivity bricks (e.g. solid Brick Masonry, A=0.11), it is clear that lower absorptivity is related to decreased OSB sheathing moisture contents. For the current analysis, a brick with higher absorptivity (A=0.11) was considered representative, based on Building Science Corporation research that has measured the A-value on more than 140 different bricks from 11 buildings to date (see **Table 4**). Solid Brick Masonry was chosen as the cladding for solar inward vapor drives for this analysis because it represents the worst case scenario for predicted OSB moisture content of the bricks simulated and very closely matches the average measured laboratory water uptake for tested masonry. It should be noted that any choice of brick will involve a degree of error, as laboratory testing has shown a large range of absorptivity values for different bricks, and even bricks taken from the same building can range significantly.

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[6] Straube, J., Finch, G., Research Report-0907 “Ventilated Wall Claddings: Review, Field Performance, and Hygrothermal Modeling”. www.buildingscience.com, 2009

[7] Lst burek, J., Research Report-0104 “Solar Driven Moisture in Brick Veneer”. www.buildingscience.com, 2001

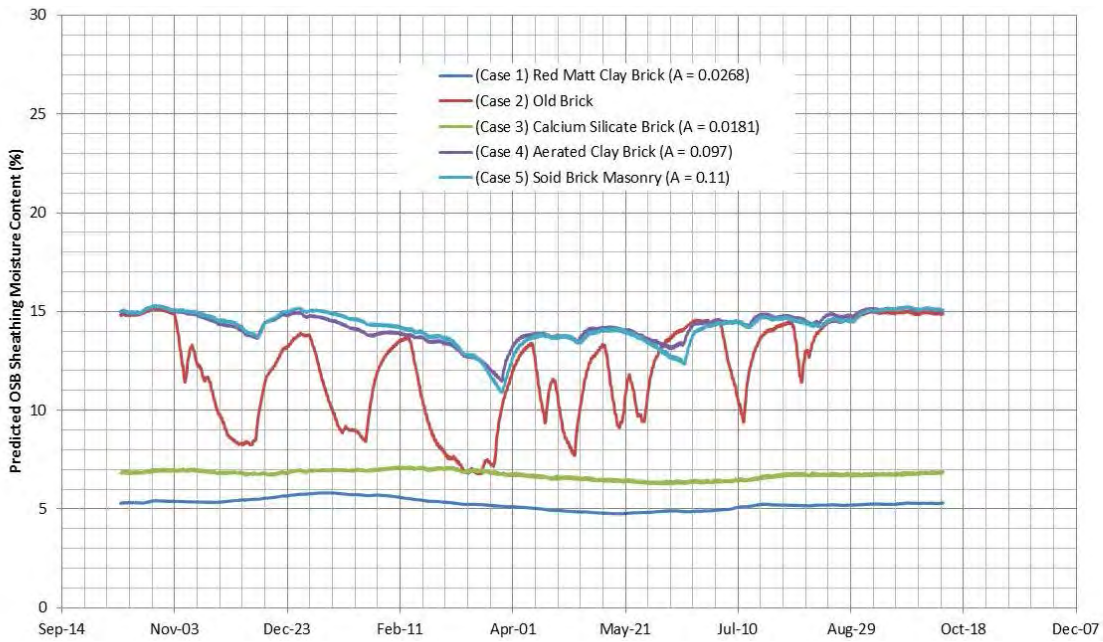

Figure 7 : OSB Sheathing Moisture Content in Miami as a Function of Brick Cladding

Table 4 : Absorptivity test results (A-value) for 142 bricks at BSCI

	Mean	Median	Standard Deviation
A-value [$kg/m^2s^{1/2}$]	0.14	0.11	0.13

Interior Vapor Control

As stated previously the amount of solar driven vapor, and degree of risk, is based on the vapor pressure gradient across the enclosure, the vapor permeance of the layers, and the order of the layers. It is well known that vinyl wallpaper is not a recommended interior finish on exterior walls in the southern United States.[8,9] The reason for this is because vinyl paper has a very low vapor permeance and hence can trap moisture in the drywall. This often results in an accumulation behind the vinyl wall paper, elevated relative humidity, moisture content, and mould growth. Moisture related problems have also been experienced behind low permeance wall coverings such as cabinets, mirrors, white boards, etc. on exterior walls.

Based on observed failures, a sensitivity analysis was conducted on 5 different interior vapor permeance layers. Typically latex paint is between 5 and 10 US perms depending on application and number of layers.

The sensitivity analysis for interior vapor control was conducted on the South East orientation in Houston with "Solid Brick Masonry" cladding based on the earlier sensitivity analysis on cladding type. **Figure 8** shows the predicted relative humidity at the exterior surface of the interior gypsum with five different interior vapor control layers on the interior surface of the gypsum. It can be seen that with the vapor control layers of 1 perm and 2.5 perms, the relative humidity is elevated and sustained long enough to result in moisture related durability issues. At 5 perms, the RH is sustained at approximately 92% for a short period of time, and it is uncertain whether or not this will have an effect on the long term durability of the enclosure. The interior vapor permeances at 7.5 and 10 perms do not exceed 90% and are not expected to result in moisture related durability issues.

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[8] Lst burek, J. Building Science Digest 108 : Investigating and Diagnosing Moisture Problems. www.buldingscience.com

[9] Lst burek, J. Building Science Insight 015 : Top Ten Dumb Things To Do In the South. (Point Number 7), www.buildingscience.com

Figure 9 and **Figure 10** show the predicted moisture content of the exterior 3mm and interior 3mm of the OSB sheathing respectively. Analysis of a 5 perm interior finish indicates a peak predicted moisture content of 22% for a very short time which is not expected to result in a durability related issue of the sheathing. When the permeance is decreased to 2.5 perms, the moisture content of both the interior and exterior layer exceeds 40% which will result in moisture durability issues of the sheathing as well as the drywall.

This sensitivity analysis demonstrates the importance of the vapor permeance of the interior surface. It is for this reason it is often recommended to add strapping or spacers between interior wall coverings and the interior surface of the drywall. Even when the analysis section for the chosen cities shows no risk of moisture related issues as a result of solar driven inward moisture, the durability still might depend on the interior level of vapor control.

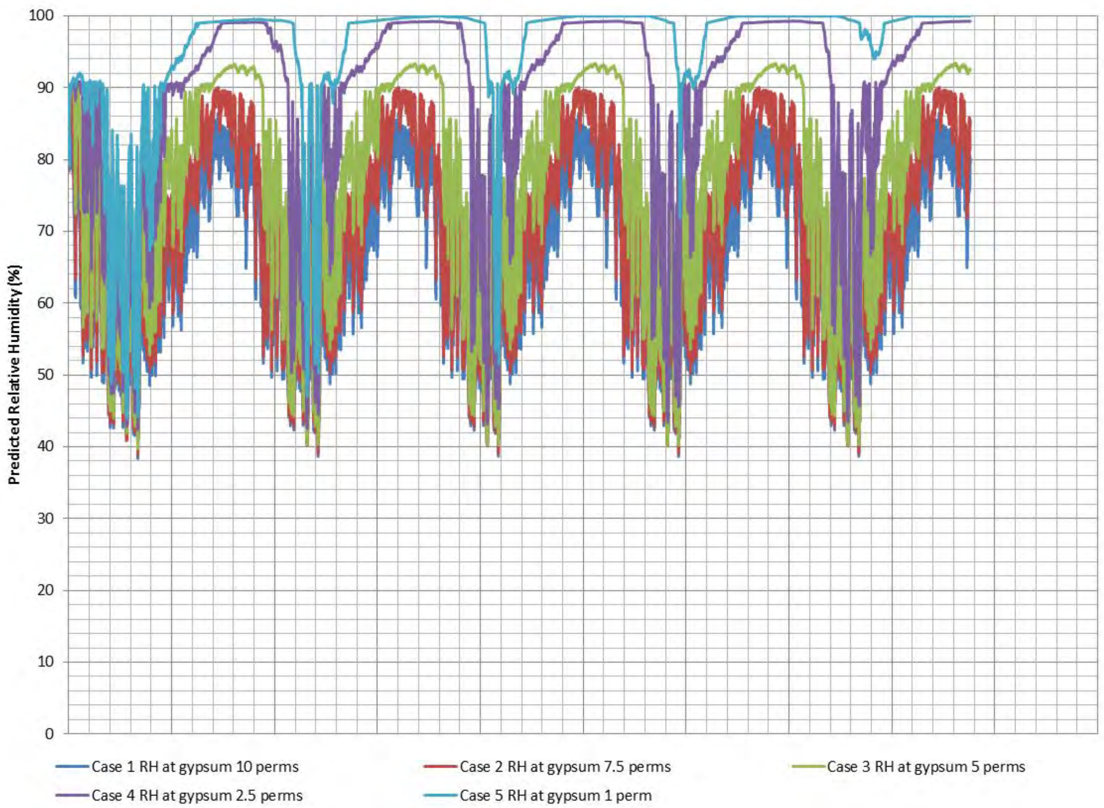

Figure 8 : Predicted RH at the exterior surface of the interior gypsum board

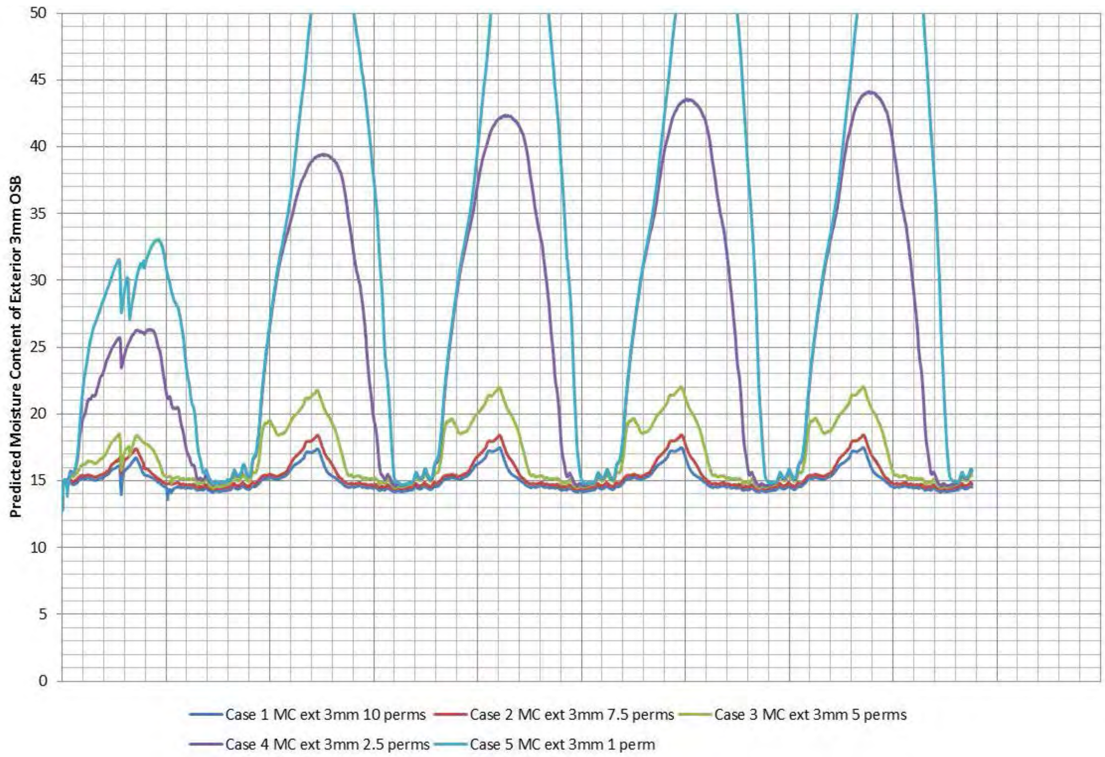

Figure 9 : Predicted Sheathing moisture content at the <u>exterior</u> 3mm layer of the OSB Sheathing

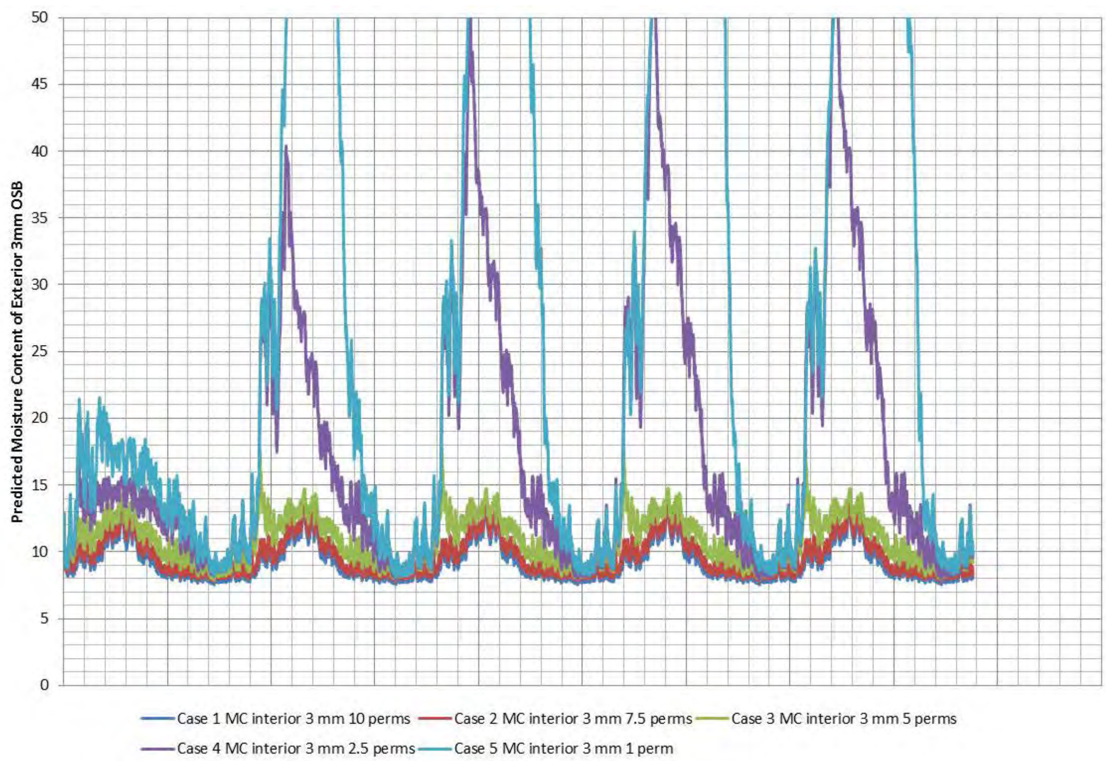

Figure 10 : Predicted Sheathing moisture content at the <u>interior</u> 3mm layer of the OSB Sheathing

Sheathing Membrane Selection

The vapor permeance of the sheathing membrane will determine the amount of vapor that passes into the enclosure as a result of a solar induced vapor pressure gradient. A sensitivity analysis was conducted using six different vapor permeances in Houston. The interior vapor control was chosen for this sensitivity analysis to be 2.5 Perms (142.5 ng/Pa·s·m^2), as that was shown to result in predicted moisture related durability issues previously in this report, and this analysis shows that even with an lower than desirable interior vapor control, moisture related durability issues can be avoided by decreasing the vapor permeance of the exterior. The sheathing membrane used for the analysis in this study was the default WUFI Spun Bonded Polyolefine Membrane (SBP) with a vapor permeance of 50 Perms (2817 ng/Pa·s·m^2). It should be noted, that it is never recommended to use vapor barriers on the interior and exterior. The interior vapor control layer even at 2.5 perms is a Class III, and will still allow some drying to the interior of incidental moisture.

The 6 sheathing membrane vapor permeances are;

- 0.1 perms (5.7 ng/Pa·s·m^2)
- 1 perm (57 ng/Pa·s·m^2)
- 6.5 perms (370 ng/Pa·s·m^2) (Dow Weathermate Plus)
- 10 perms (570 ng/Pa·s·m^2)
- 25 perms (1425 ng/Pa·s·m^2)
- 56 perm (3192 ng/Pa·s·m^2) (Tyvek HouseWrap)

Figure 11 shows the predicted OSB moisture content of the exterior 3mm edge over the range of analyzed sheathing membrane vapor permeances. Only the sheathing membranes with vapor permeances of 25 perms and 56 perms resulted in any risk of moisture related durability of the sheathing.

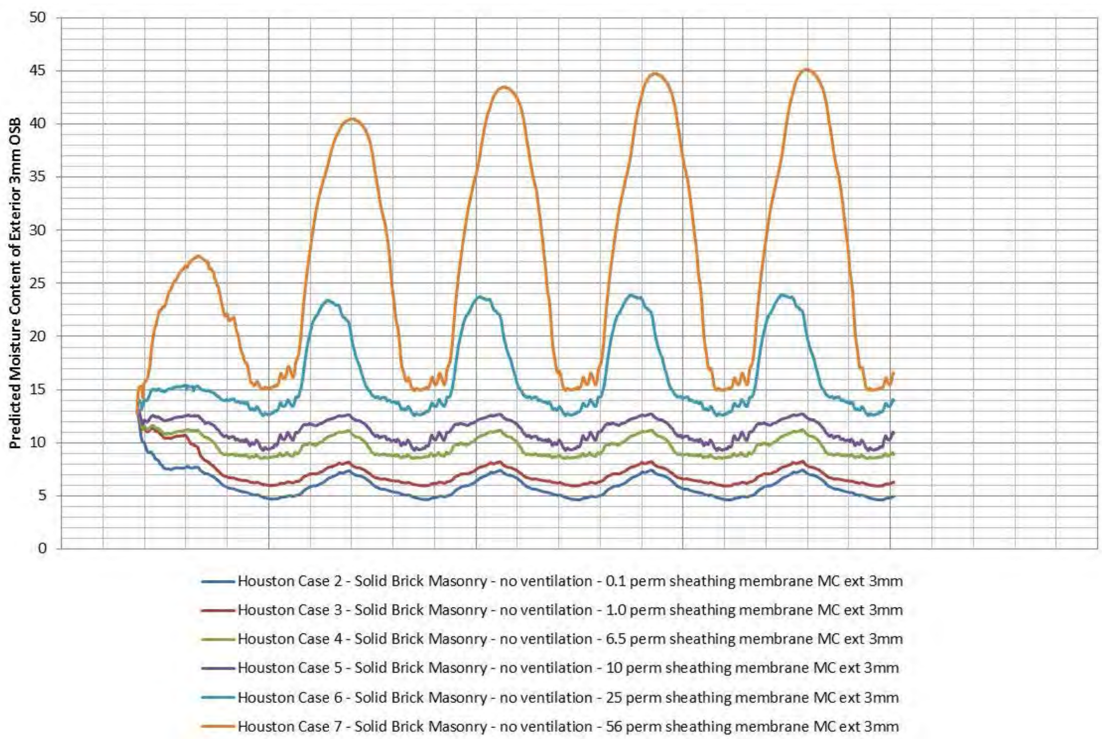

Figure 11: Analysis of predicted OSB moisture contents with different sheathing membranes

Analysis of the predicted relative humidity at the exterior surface of the gypsum board shows that vapor permeances of 10, 25, and 56 perms result in sustained relative humidity in excess of 90% which is not desirable. Analysis of the predicted interior gypsum board moisture content showed that only the 0.1 and 1.0 perm sheathing membranes resulted in moisture contents less than 1%, and that a sheathing membrane permeance of 6.5perms resulted in peaks less than 2%. It should be noted that this analysis is based on the interior vapor permeance being decreased to challenging levels, and that this analysis is very sensitive to the gypsum board sorption isotherm.

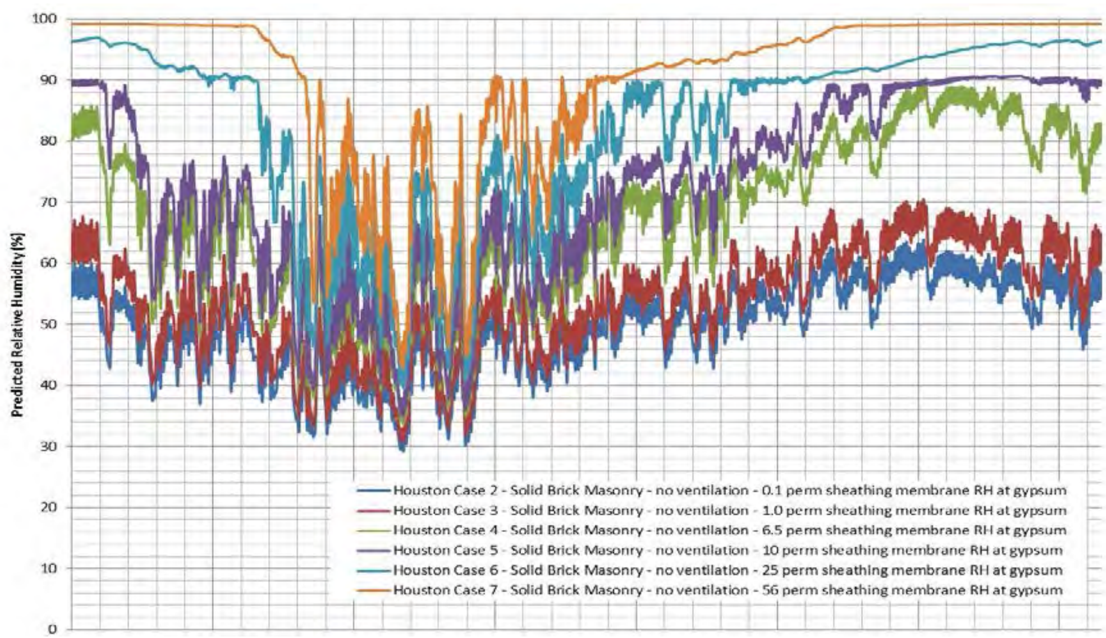

Figure 12 : Analysis of predicted RH at the surface of interior gypsum board with different sheathing membranes

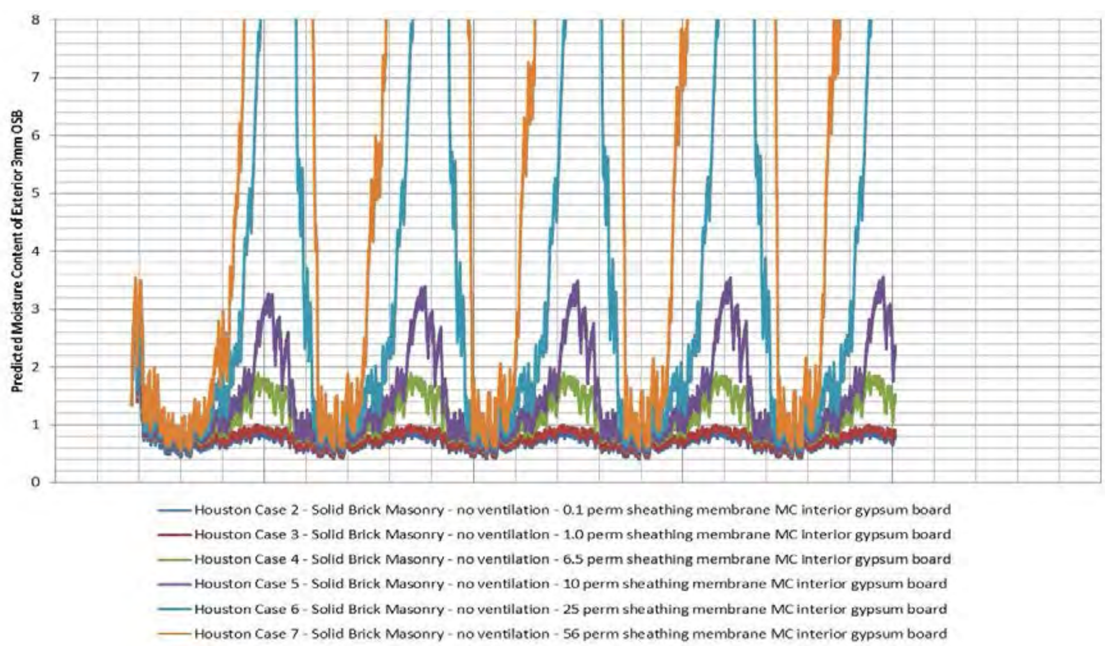

Figure 13 : Analysis of predicted gypsum board moisture content with different sheathing membranes

Interior Temperature

The interior temperature was kept constant at 22°C for the entire year for this analysis (Case 1 in **Figure 14**). Because relative humidity is based on temperature, two cases were analyzed with different interior temperatures 18°C and 26°C in Miami, but all other variables being identical between the simulations. Changing the interior temperature did have an effect on the relative humidity at the exterior surface of the drywall as shown in **Figure 14**. As the temperature decreases, the RH increases.

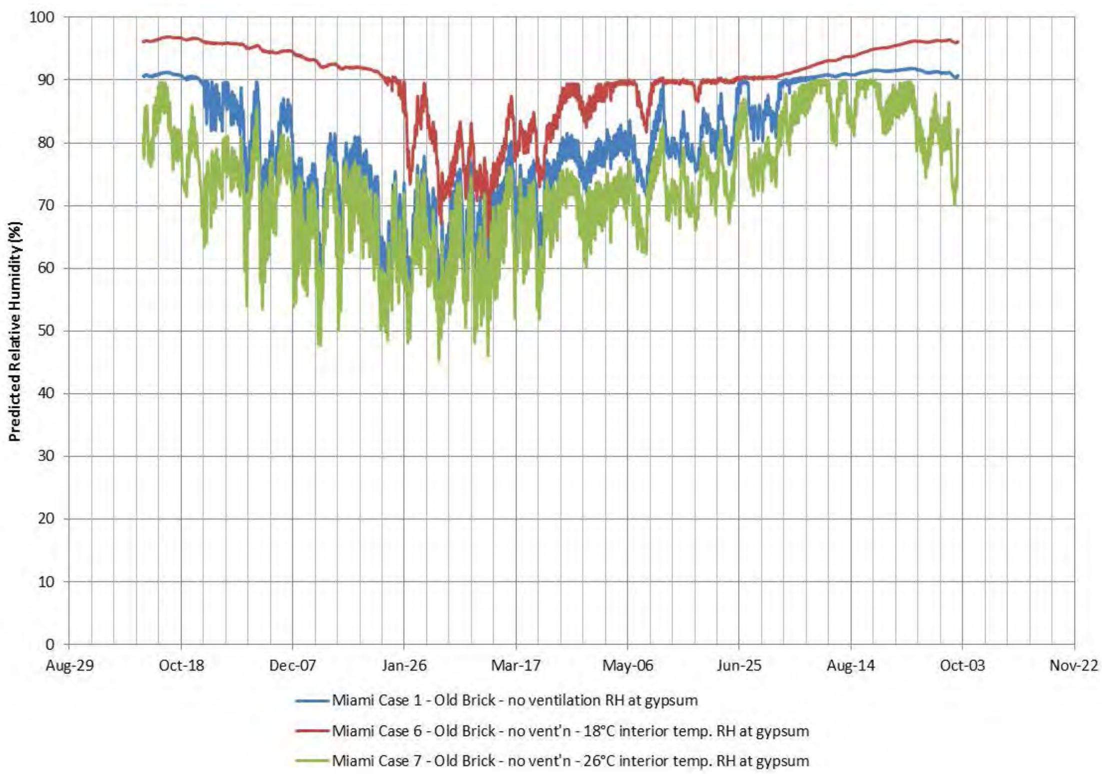

Figure 14 : CZ1 Miami - Relative humidity at the exterior surface of gypsum board as a function of interior temperature only

Rainwater Leakage

An analysis was conducted in Houston and St.Louis regarding rain water leakage. For this analysis a percentage of the driving rain was considered to leak tothe back surface of the ComfortBoard IS between the insulation and the sheathing membrane. This was chosen because the sheathing membrane is technically the drainage plane, although any rain water should drain effectively down the exterior surface of the ComfortBoard IS. The water was distributed over the back half of the insulation. The amount of rainwater that was chosen in Houston was 2% of the driving rain. This is being considered as an unintentional leak and is hence twice the value listed in ASHRAE 160 as passing the exterior water shedding layer. And the amount of water was clipped at the maximum water content for the Roxul. This is the moisture content that would occur should all the voids in the insulation be filled with water which is completely unrealistic and much worse than could ever happen, as water initially drains out of ComfortBoard IS quite quickly. This comparison is shown in the Houston analysis section of the report, but the results show that in Houston, there was virtually no predicted impact of the rain leakage, likely due to the energy available for drying the water quickly.

Figure 15 : Moisture source information for driving rain leakage from WUFI

These same criteria resulted in calculation errors when they were applied to St. Louis. This was likely because there was less energy available for drying, and the unrealistic parameters of wetting actually caused increases in moisture content. For St. Louis, 1% rain water leakage was used (recommended in ASHRAE 160) and the source term clipping was set to the free water saturation, which is the moisture content that corresponds with 100% RH on the sorption isotherm. According to the WUFI data, the free water saturation is 0.5 kg of water per m^3 of rockwool insulation. This means that if the free water saturation of 0.5 kg/m^3 is achieved, the rest is assumed to be drained away as it cannot be held by the insulation.

Wall Analysis

Climate Zone 1 – Miami

Residential Assembly – 2x4 Wood Framed Wall

CZ 1	Miami (cold-year)
Installed Insulation	R-13 + R-3.8 ci
Orientation	South-East
Sheathing	OSB
Interior Humidity Conditions	Sinusoidal - max 60%RH July 1, min 45%RH Jan 1
Interior Vapor Control	Latex paint on interior of GWB ~5 perms (Class III)

The exterior conditions used in the simulations for Miami are shown in **Figure 16** and **Figure 17**.

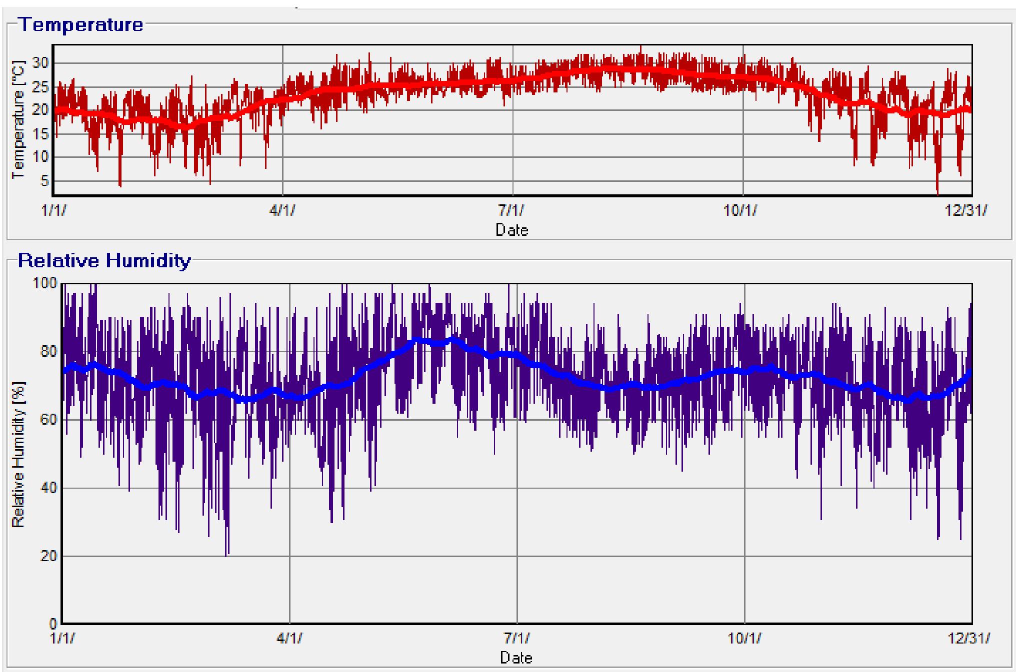

Figure 16 : Exterior temperature and humidity provided by WUFI for Miami (cold year)

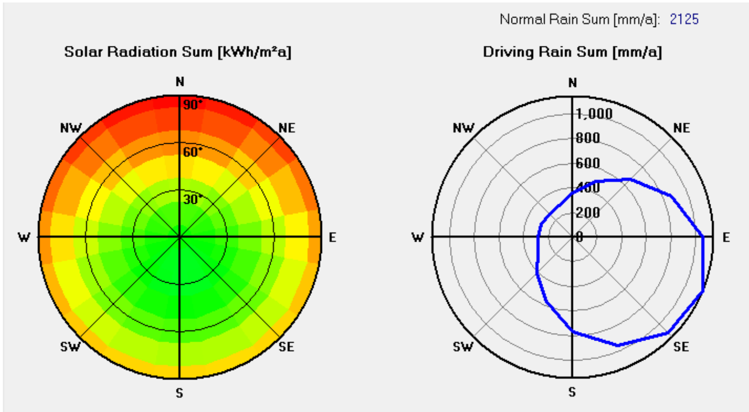

Figure 17 : Solar Radiation and Driving rain provided by WUFI for Miami (cold year)

Analysis for Miami was conducted on four different cases;

- Unventilated Solid Brick Masonry cladding
- Ventilated (10 ACH) Solid Brick Masonry cladding
- Red Matt Clay Brick
- Vinyl Siding

The highest sheathing moisture contents were experienced with the Solid Brick Masonry cladding, but these predicted moisture contents did not exceed 16%. The moisture content of the exterior surface of the OSB experienced some drying as a result of the ventilation (purple line Figure 18). Because the Red Matt Clay Brick and the vinyl siding have minimal absorptivity, there are no predicted effects of solar inward vapor drives.

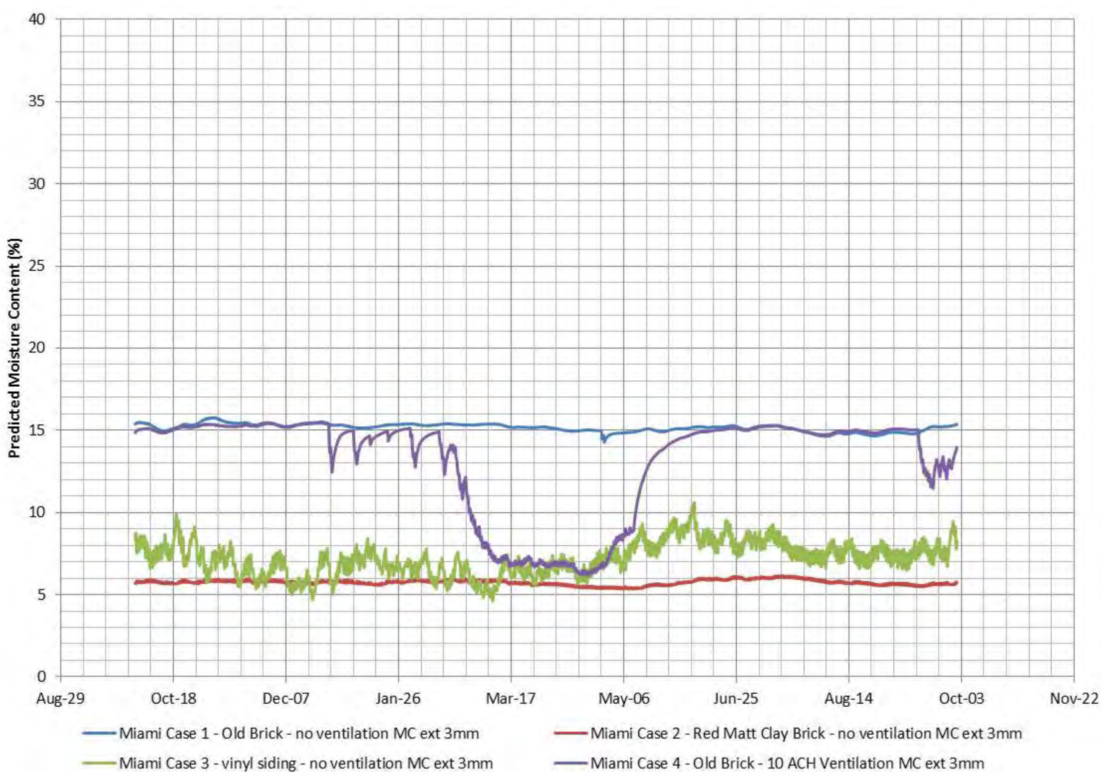

Figure 18 : CZ1 Miami – OSB Sheathing Moisture Content – ext. 3mm – South-East Orientation

The predicted relative humidities at the exterior surface of the interior gypsum wall board are shown in **Figure 19**. The relative humidity of the assemblies with absorptive Solid Brick Masonry experience predicted relative humidity of 90%. There is a drying effect of the brick ventilation shown in the RH graph which also corresponds to the lower sheathing moisture content. By changing the sheathing membrane permeance to 6.5 perms, the RH at the gypsum board is kept below 80%.

The predicted moisture content of the gypsum is shown in **Figure 20**. The two wall assemblies with Solid Brick Masonry with elevated relative humidity show gypsum moisture content greater than 3% which could be problematic. These two assemblies were analyzed with a 5 perm interior vapor control layer on the surface of the gypsum board. If the permeance is increased to 7.5 perms, the moisture content of the gypsum does not exceed 2% as shown by the green line in **Figure 20**. When the vapor permeance of the sheathing membrane is changed to 6.5 perms, the predicted peak moisture content drops from 5% (blue line) to 1.2% (purple line).

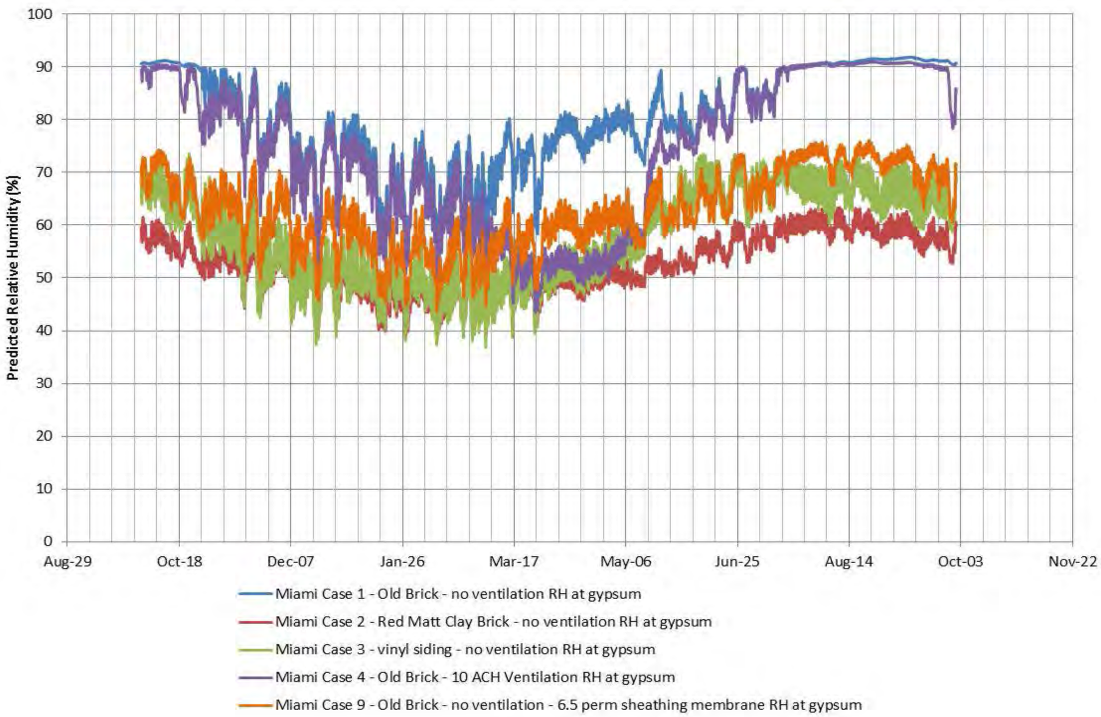

Figure 19 : CZ1 Miami – Relative Humidity at the Exterior Surface of the Interior Drywall – South-East Orientation

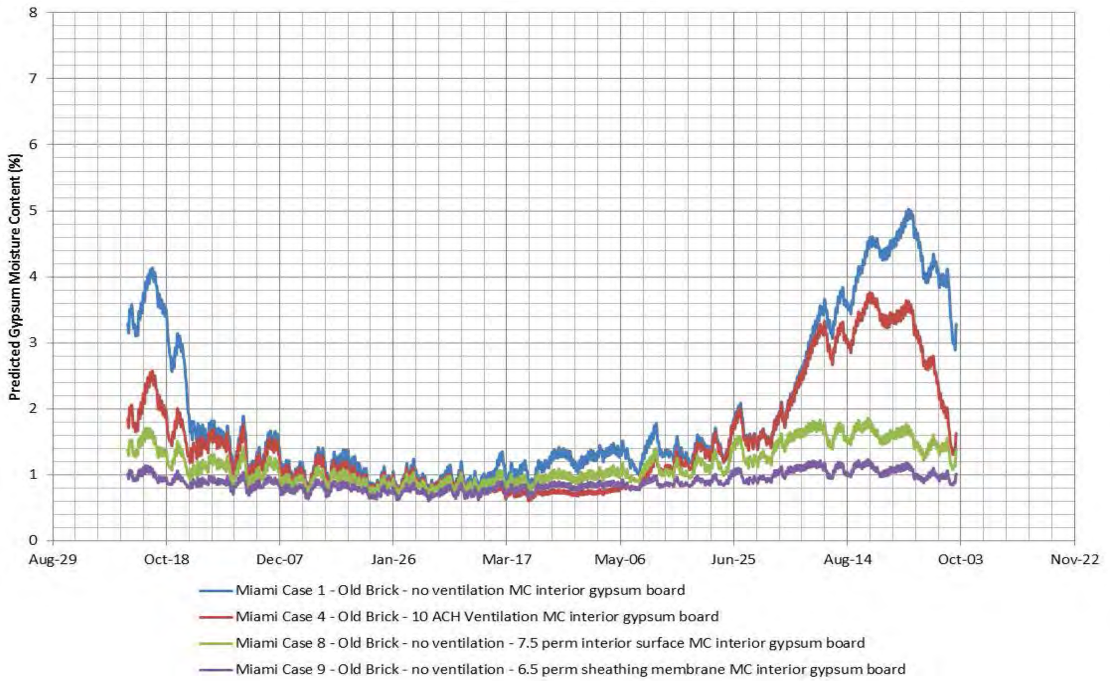

Figure 20 : CZ1 – Miami - Predicted interior gypsum board moisture content

Climate Zone 1 (Miami) Summary

- There are no predicted moisture related durability failures related to the OSB sheathing
- The relative humidity at the exterior surface of the gypsum is elevated above 90% under these analysis criteria for the entire summer. According the sorption isotherm for interior gypsum board, the moisture content of gypsum increases quickly starting at approximately 90%. This means that the predicted relative humidity at the surface of the gypsum may result in moisture related durability issues.
- The moisture content of the gypsum for the cases with elevated relative humidity exceeded 3.5% which is not recommended. If the vapor permeance of the interior surface was increased, the moisture content of the gypsum board did not exceed 2% which is considerably safer.
- The most risky wall is the unventilated Solid Masonry Brick because of its relatively high absorptivity of incidence rain. This wall experiences a predicted relative humidity of 90% against the exterior surface of the sheathing. Some ventilation of the masonry cladding is shown to have an effect on both the sheathing moisture content and relative humidity in the stud space.

Climate Zone 2 – Houston

Residential Assembly – 2x4 Wood Framed Wall

CZ 2	Houston (warm year)
Installed Insulation	R-13 + R-3.8 ci
Orientation	South-East
Sheathing	OSB
Interior Humidity Conditions	Sinusoidal - max 60%RH July 1, min 45%RH Jan 1
Interior Vapor Control	Latex paint on interior of GWB ~5 perms (Class III)

The exterior conditions used in simulations for Houston are shown in **Figure 21** and **Figure 22**.

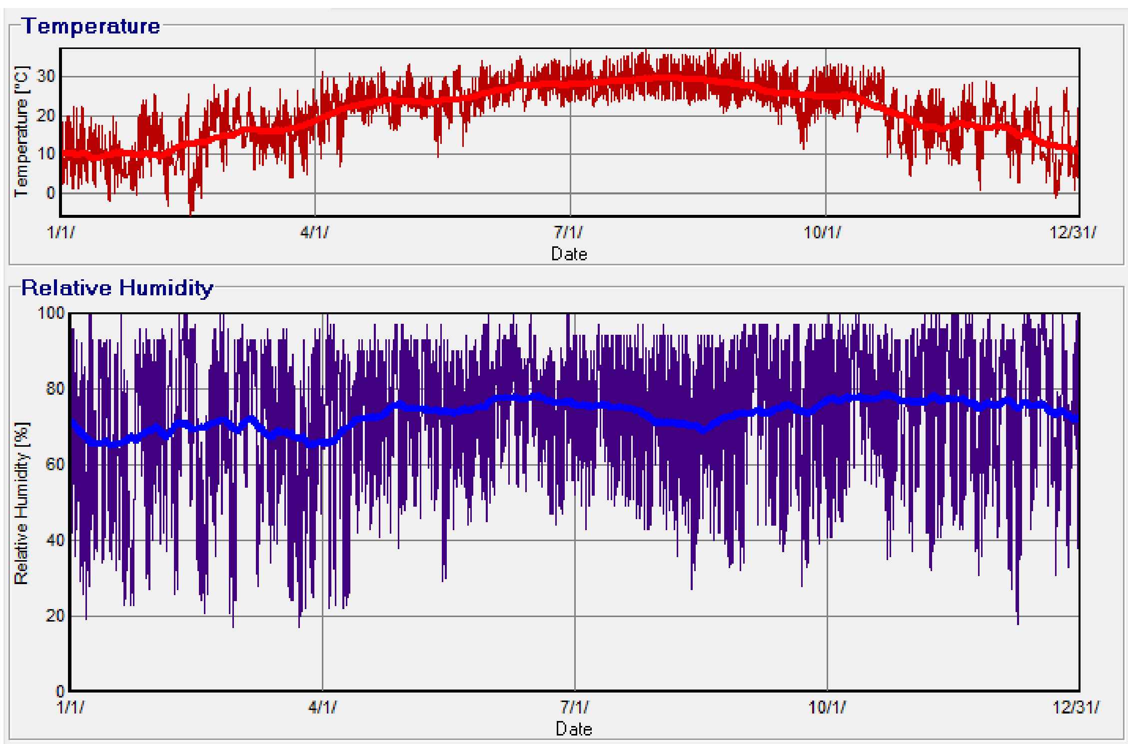

Figure 21 : Exterior temperature and humidity provided by WUFI for Houston (warm year)

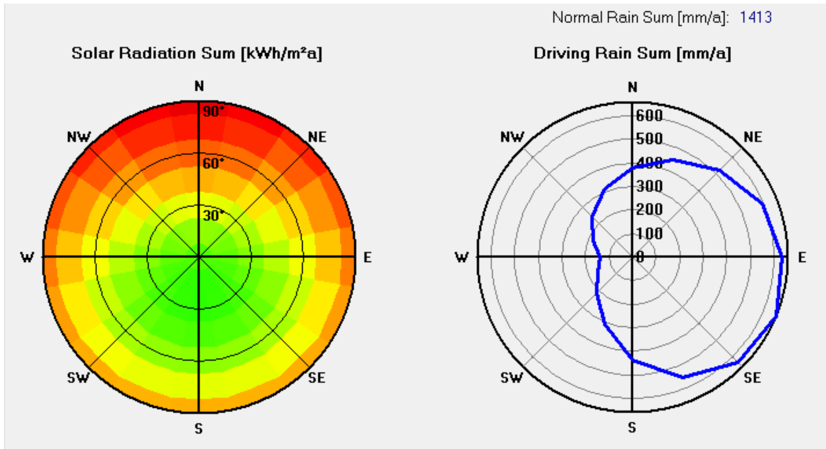

Figure 22 : Solar Radiation and Driving rain provided by WUFI for Houston (warm year)

Analysis for Houston was conducted on five different cases;

- Unventilated Solid Brick Masonry cladding
- Ventilated (10 ACH) Solid Brick Masonry cladding
- Red Matt Clay Brick
- Vinyl Siding
- Unventilated Solid Brick Masonry cladding with a rain leak

The highest sheathing moisture contents were experienced with the Solid Brick Masonry cladding, but these predicted moisture contents did not exceed 19%. The moisture content of the exterior surface of the OSB experienced some drying as a result of the ventilation (purple line Figure 18). Because the Red Matt Clay Brick and the vinyl siding have minimal absorptivity, there are no predicted effects of solar inward vapor drives.

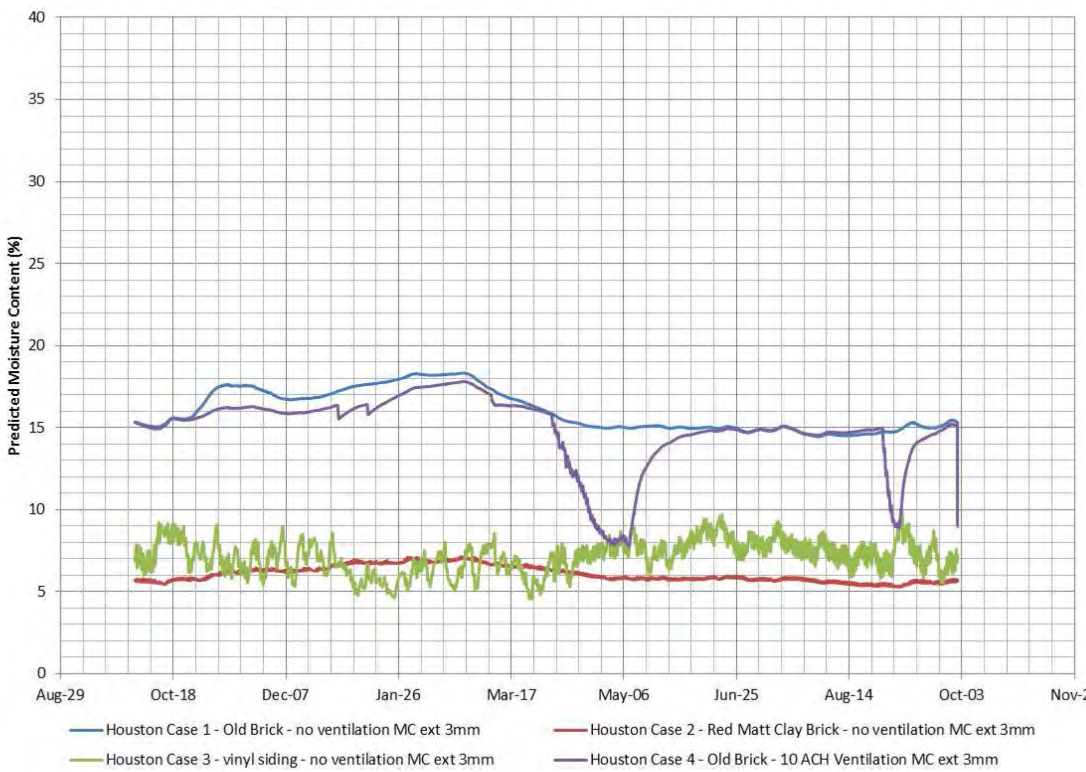

Figure 23 : CZ2 Houston – OSB Sheathing Moisture Content – South-East Orientation

The predicted relative humidity at the exterior surface of the interior gypsum wall board are shown in **Figure 24**. The relative humidity of the assemblies with absorptive Solid Brick Masonry peaks at 92%, slightly higher than Houston. There is less of a predicted improvement with ventilation because the ambient relative humidity in Houston is so high. Decreasing the vapor permeance of the sheathing membrane to 6.5 perms from 50 perms, reduces the RH at the gypsum from 92% (blue line to 76% (orange line).

Houston was chosen for a sensitivity analysis of rain leakage because it experienced the highest predicted sheathing moisture content under analysis conditions. The rain leakage was added to the interior 10 cm (~1/2") of the ComfortBoard IS against the sheathing membrane. The amount of water added was 2% of the driving rain. Minimal increases were predicted as a result of the rain water leakage to the area between sheathing membrane and exterior rockwool insulation as shown in **Figure 25**. The minimal increase may have been a result of high temperatures and sufficient energy for drying to the interior and exterior of the enclosure.

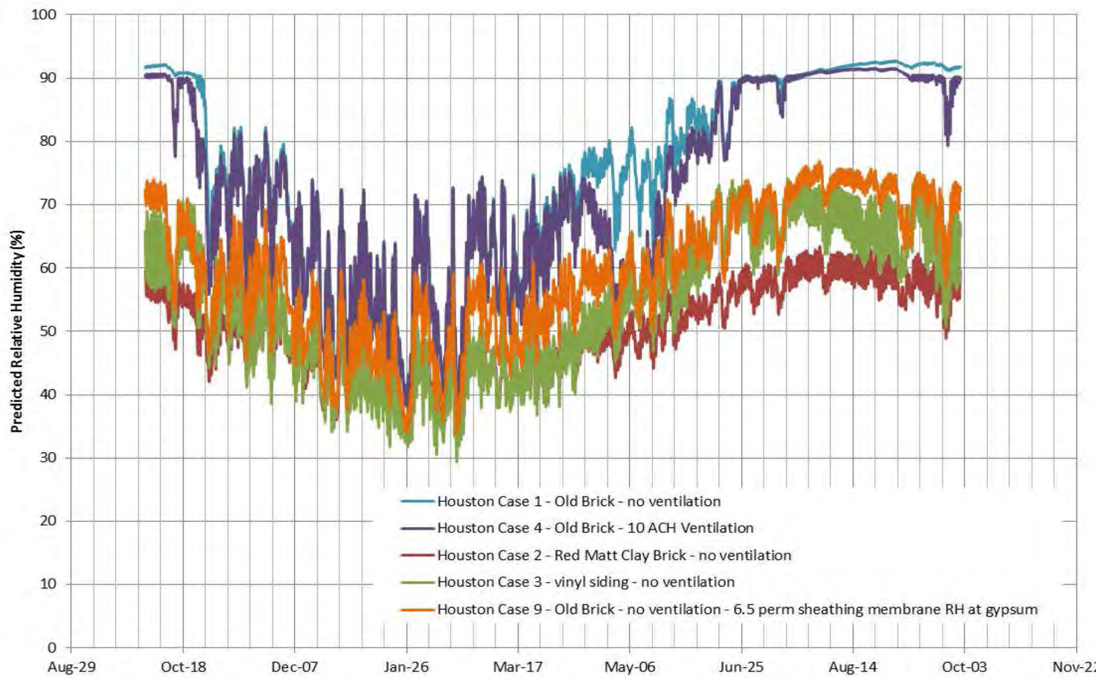

Figure 24 : CZ2 Houston – Relative Humidity at the Exterior Surface of the Interior Drywall – South-East Orientation

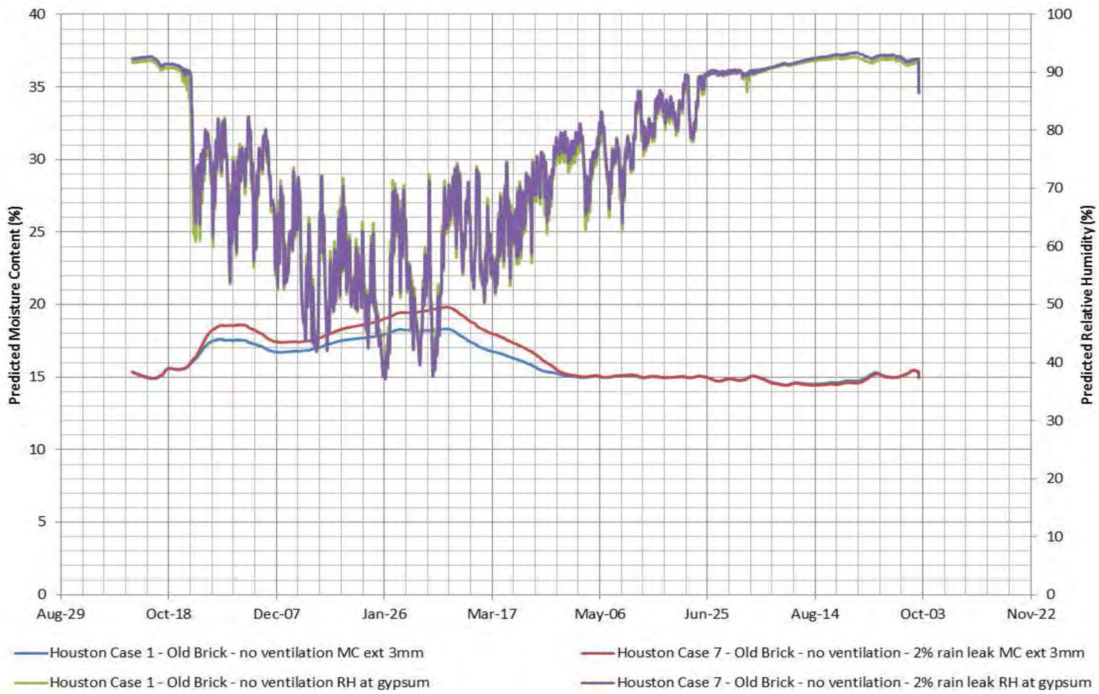

Figure 25 : Comparison of predicted moisture content and relative humidity with and without 2% rain leakage

The predicted moisture content of the gypsum for Houston is shown in **Figure 26**. The two wall assemblies with Solid Brick Masonry with elevated relative humidity show gypsum moisture content greater than 4% which will be problematic. These two assemblies were analyzed with a 5 perm interior vapor control layer on the surface of the gypsum board. If the permeance is increased to 7.5 perms, the moisture content of the gypsum does not exceed 2% as shown by the green line in **Figure 26** which is much safer. When the vapor permeance of the sheathing membrane is changed to 6.5 perms, the predicted peak moisture content drops from 6.2% (blue line) to 1.2% (purple line).

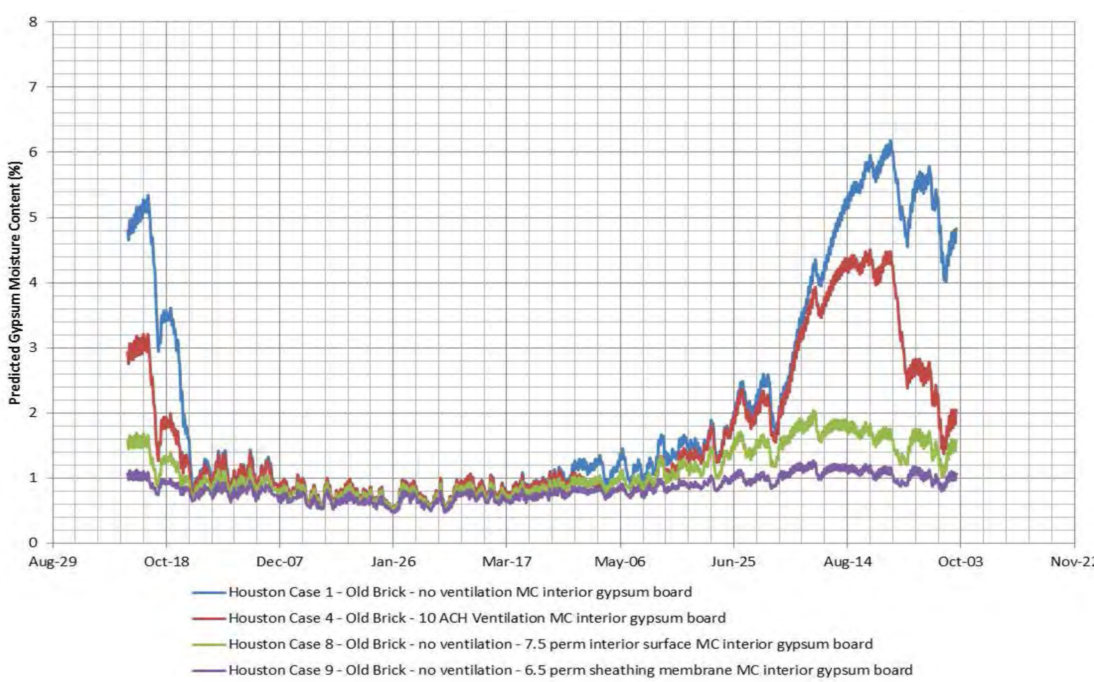

Figure 26 : CZ2 – Houston - Predicted interior gypsum board moisture content

Climate Zone 2 (Houston) Summary

- There are no predicted moisture related durability failures related to the OSB sheathing
- The relative humidity at the exterior surface of the gypsum is elevated above 90% under these analysis criteria for the entire summer. According the sorption isotherm for interior gypsum board, the moisture content of gypsum increases quickly starting at approximately 90%. This means that the predicted relative humidity at the surface of the gypsum may result in moisture related durability issues.
- The most risky wall is the unventilated Solid Masonry Brick because of its relatively high absorptivity of incidence rain. This wall experiences a predicted relative humidity of 90% against the exterior surface of the sheathing. Some ventilation of the masonry cladding is shown to have an effect on both the sheathing moisture content and relative humidity in the stud space.

Climate Zone 2 – Orlando

Residential Assembly – 2x4 Wood Framed Wall

CZ 2	Orlando
Installed Insulation	R-13 + R-3.8 ci
Orientation	South-East
Sheathing	OSB
Interior Humidity Conditions	Sinusoidal - max 60%RH July 1, min 45%RH Jan 1
Interior Vapor Control	Latex paint on interior of GWB ~5 perms (Class III)

The exterior conditions used in the simulations for Orlando are shown in **Figure 27** and **Figure 28**.

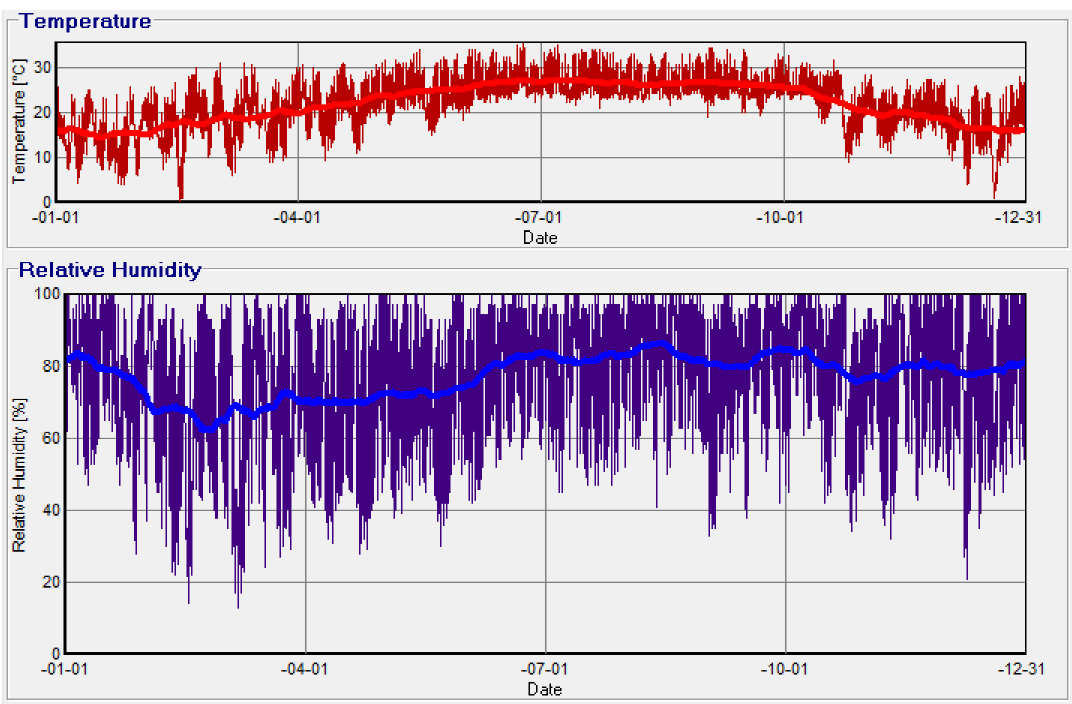

Figure 27 : Exterior temperature and humidity based on TMY3 data for Orlando

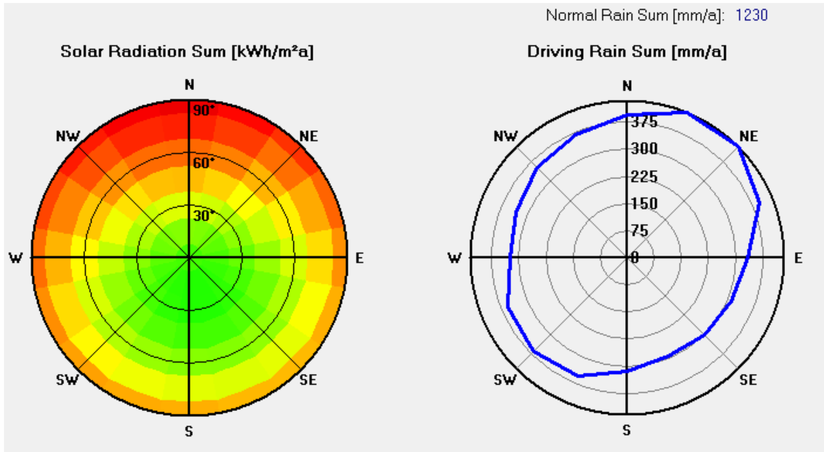

Figure 28 : Solar Radiation and Driving rain based on TMY3 data for Orlando

Analysis for Orlando was conducted on four different cases;

- Unventilated Solid Brick Masonry cladding
- Ventilated (10 ACH) Solid Brick Masonry cladding
- Unventilated Solid Brick Masonry cladding with a 1 perm interior finish
- Unventilated Solid Brick Masonry cladding with increased driving rain coefficients

The highest sheathing moisture content (over 40%) was experienced with the Solid Brick Masonry cladding and the addition of the 1 perm interior surface layer. Moisture related durability issues will occur very quickly in that assembly.

The other three assemblies had very similar predicted performance, with no predicted wood moisture contents in excess of 17%. There was a minimal increase in the wood moisture content during the rainy season with increased driving rain coefficients (purple line **Figure 29**), and some decreased moisture contents as a result of the 10 ACH ventilation behind the masonry (red line **Figure 29**).

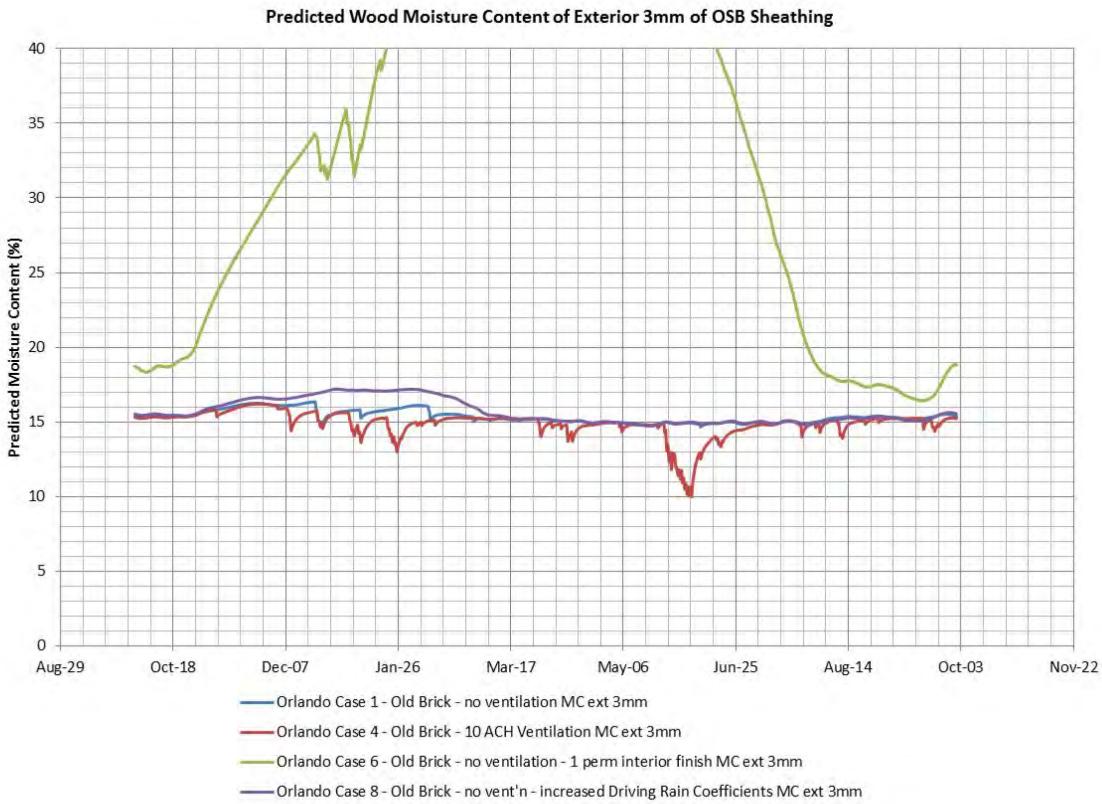

Figure 29 : CZ2 Orlando – OSB Sheathing Moisture Content – South-East Orientation

The predicted relative humidities at the exterior surface of the interior gypsum wall board are shown in **Figure 24**. The analysis with the 1 perm interior coating has a predicted RH of approximately 100% for the entire year. The other three assemblies performed similarly, with the increased driving rain coefficient analysis (red line **Figure 30**) having the highest sustained relative humidity of the three, because of the increased moisture load. Analysis of the gypsum board moisture content (**Figure 31**) shows peak moisture contents that exceed 2%, but are considerably lower than Houston. The relative humidity of these two assemblies fluctuates between 80% and 90% for much of the summer, instead of exceeding 90% as is the case for Houston.

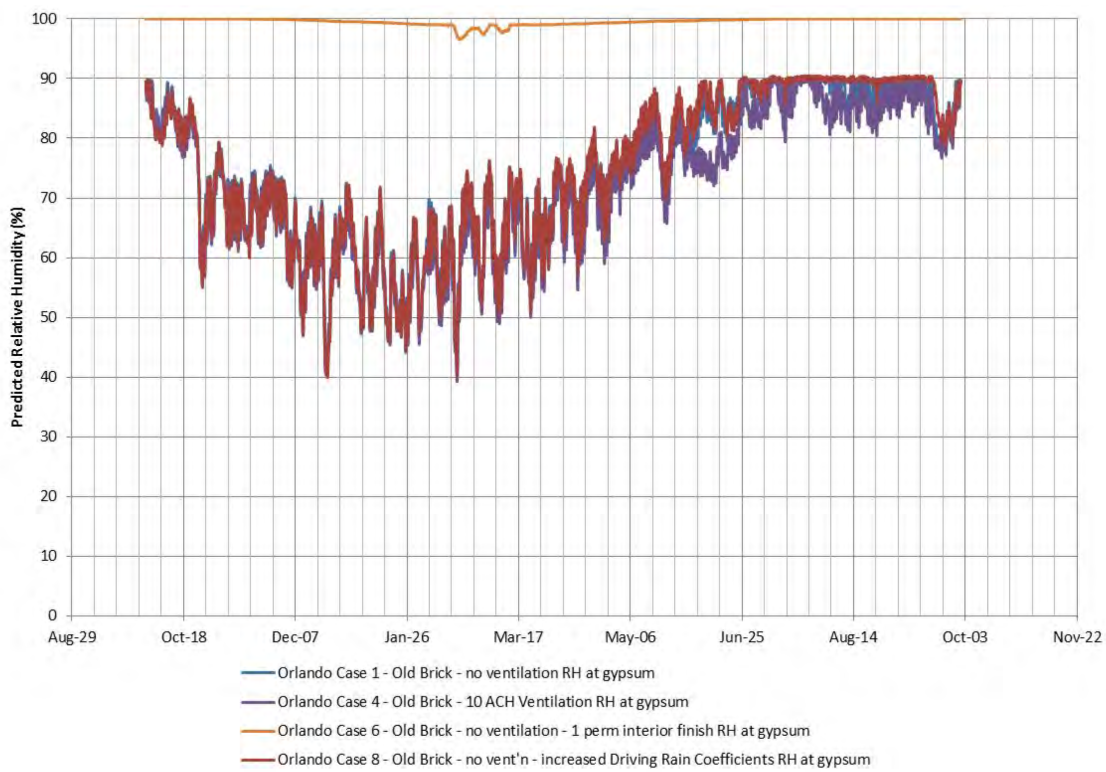

Figure 30 : CZ2 Houston – Relative Humidity at the Exterior Surface of the Interior Drywall – South-East Orientation

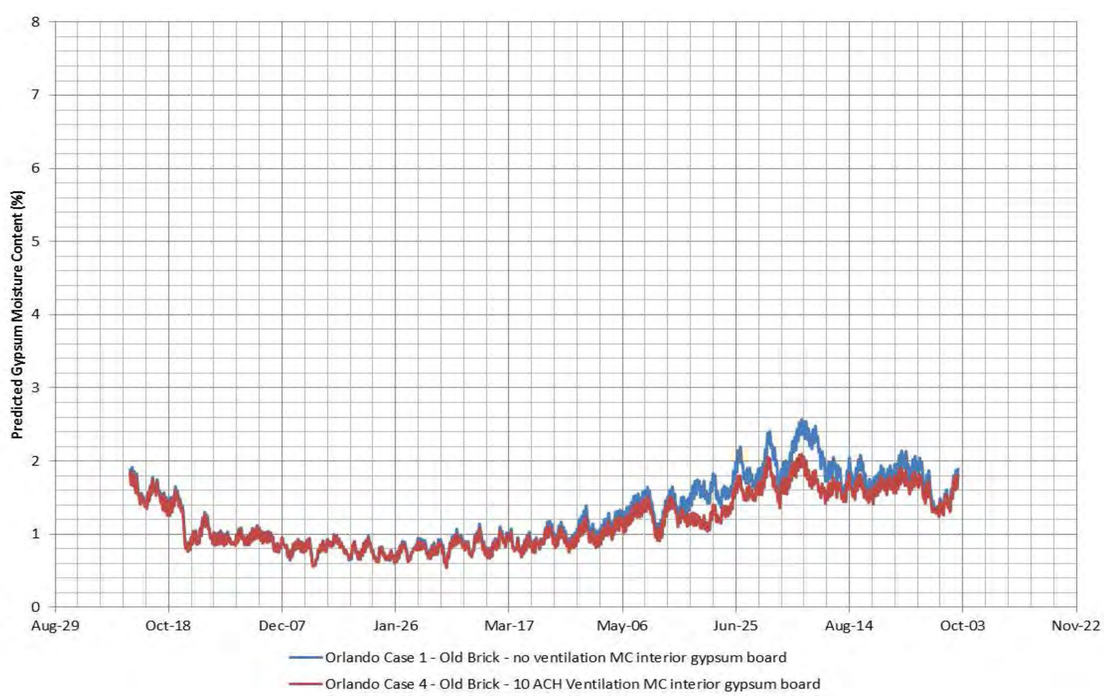

Figure 31 : CZ2 – Orlando - Predicted interior gypsum board moisture content

Climate Zone 2 (Orlando) Summary

- If a 1 perm interior layer is used in Orlando, the wall will fail both in terms of OSB sheathing wetting, and gypsum board wetting.
- There are no predicted moisture related durability failures related to the OSB sheathing in the remaining three assemblies with a 5 perm interior surface layer.
- The relative humidity at the exterior surface of the gypsum is elevated at 90% under when using a 1 perm interior finish for the entire summer. According the sorption isotherm for interior gypsum board, the moisture content of gypsum increases quickly starting at approximately 90%. This means that the predicted relative humidity at the surface of the gypsum may result in moisture related durability issues.

Climate Zone 3 – Atlanta

Residential Assembly – 2x4 Wood Framed Wall

CZ 3	Atlanta (warm year)
Installed Insulation	R-13 + R-3.8 ci
Orientation	East
Sheathing	OSB
Interior Humidity Conditions	Sinusoidal - max 60%RH July 1, min 35%RH Jan 1
Interior Vapor Control	Latex paint on interior of GWB ~5 perms (Class III)

The exterior conditions used in the simulations for Orlando are shown in **Figure 32** and **Figure 33**.

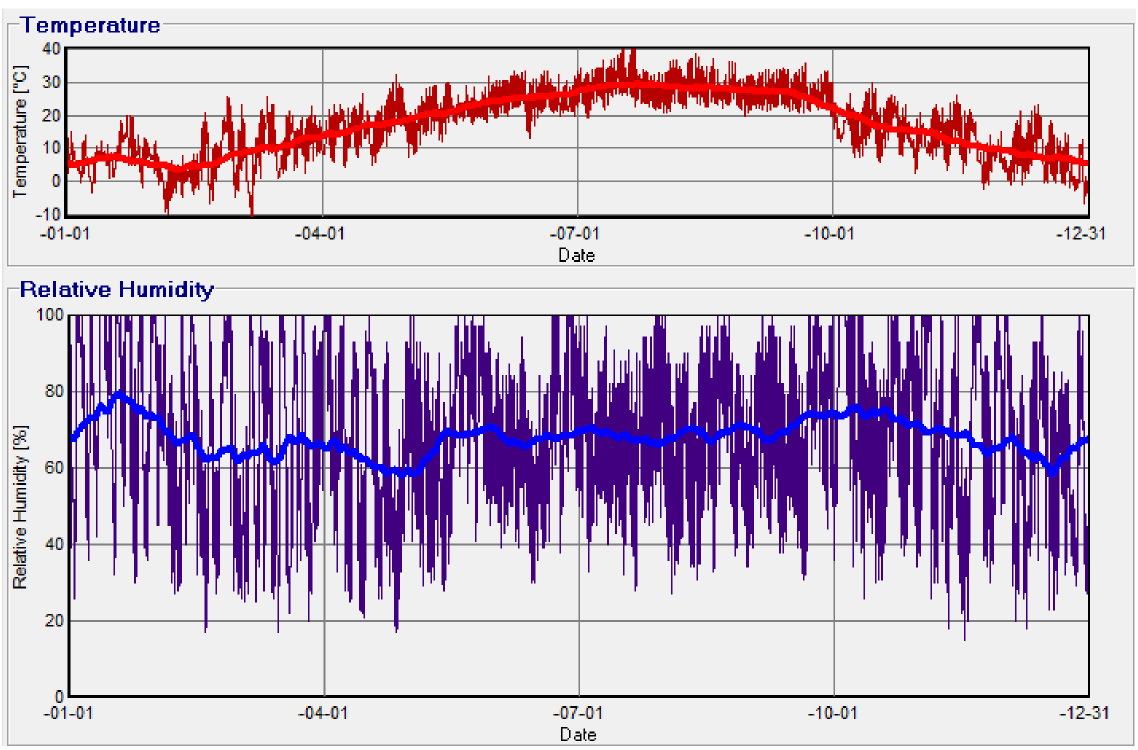

Figure 32 : Exterior temperature and humidity provided by WUFI for Atlanta (warm year)

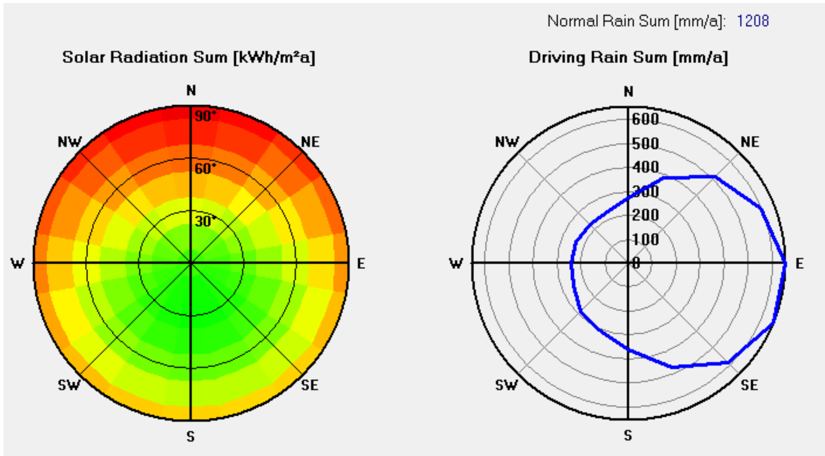

Figure 33 : Solar Radiation and Driving rain provided by WUFI for Atlanta (warm year)

Analysis for Orlando was conducted on three different cases:

- Unventilated Solid Brick Masonry cladding
- Ventilated (10 ACH) Solid Brick Masonry cladding
- Unventilated Solid Brick Masonry cladding with a 1 perm interior finish

The highest sheathing moisture content (over 40%) was experienced with the Solid Brick Masonry cladding and the addition of the 1 perm interior surface layer. Moisture related durability issues will occur in that assembly.

The other three assemblies had very similar predicted performance, with no predicted wood moisture contents in excess of 18%. There was predicted decreased moisture content as a result of the 10 ACH ventilation behind the masonry (red line **Figure 34**).

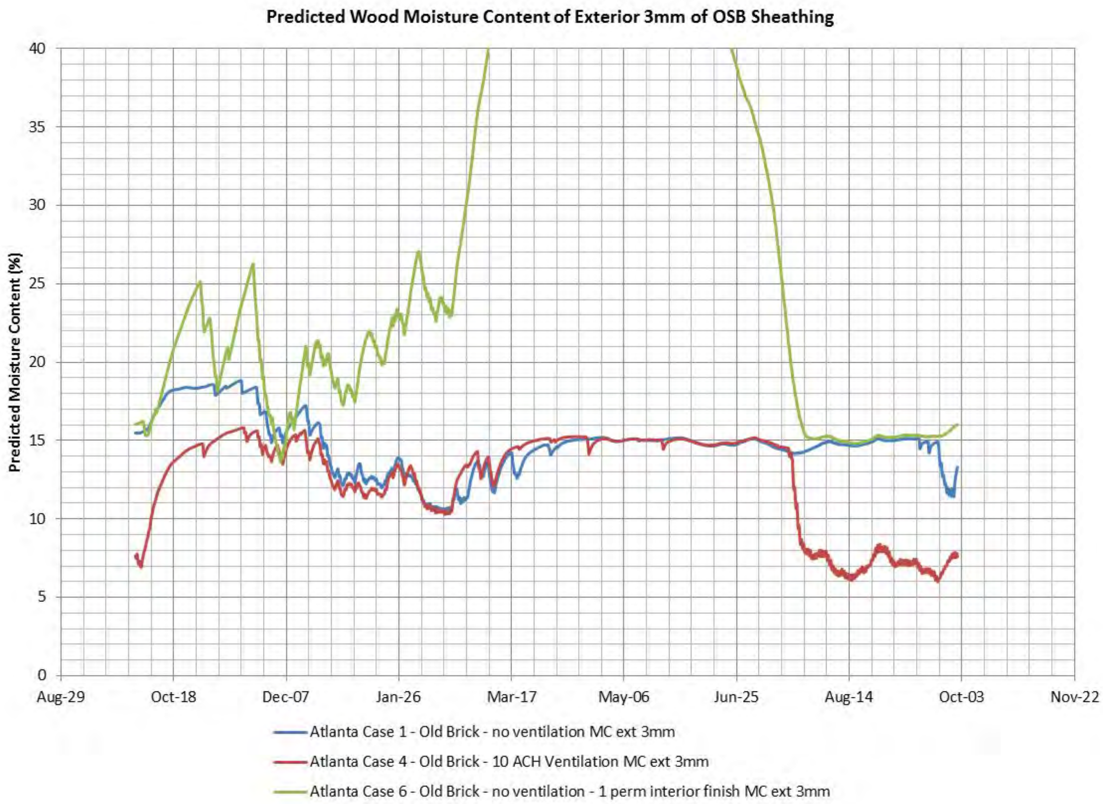

Figure 34 : CZ3 Atlanta – OSB Sheathing Moisture Content – South-East Orientation

The predicted relative humidity at the exterior surface of the interior gypsum wall board are shown in **Figure 24**. The analysis with the 1 perm interior coating has a predicted RH of approximately 100% for half of the year. The assembly with the ventilated brick still peaked at approximately 91% RH, but the RH decreased more quickly than in the unventilated case.

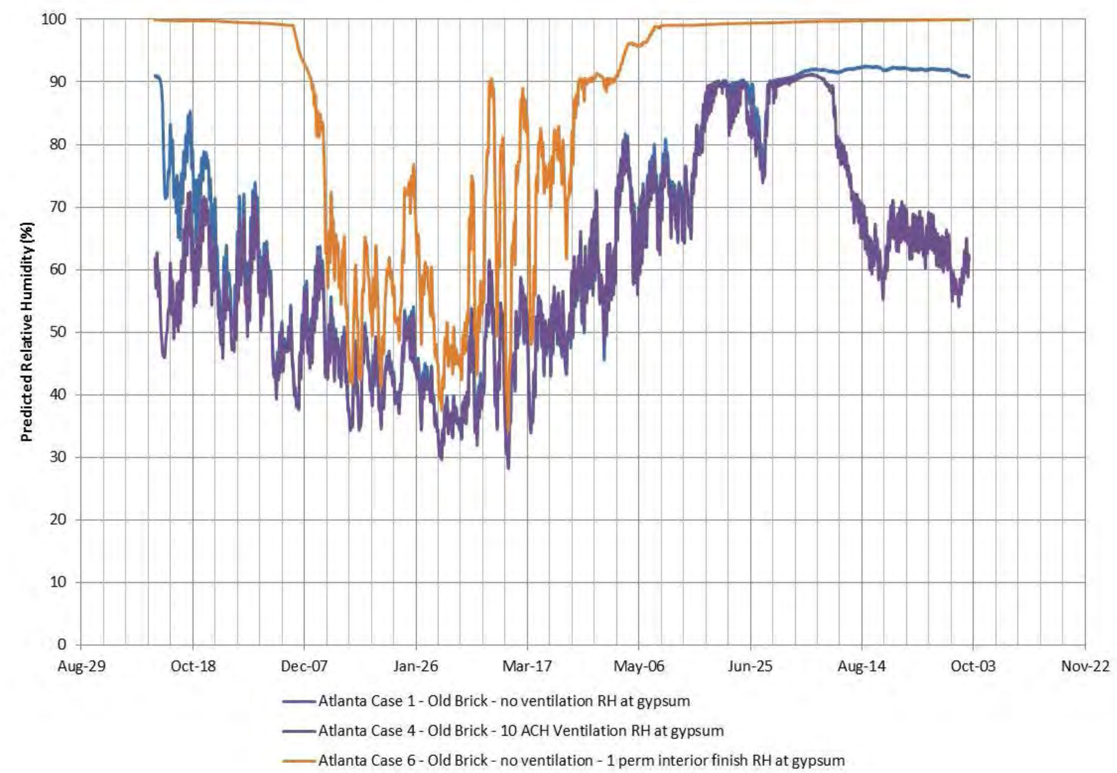

Figure 35 : CZ3 Atlanta – Relative Humidity at the Exterior Surface of the Interior Drywall – South-East Orientation

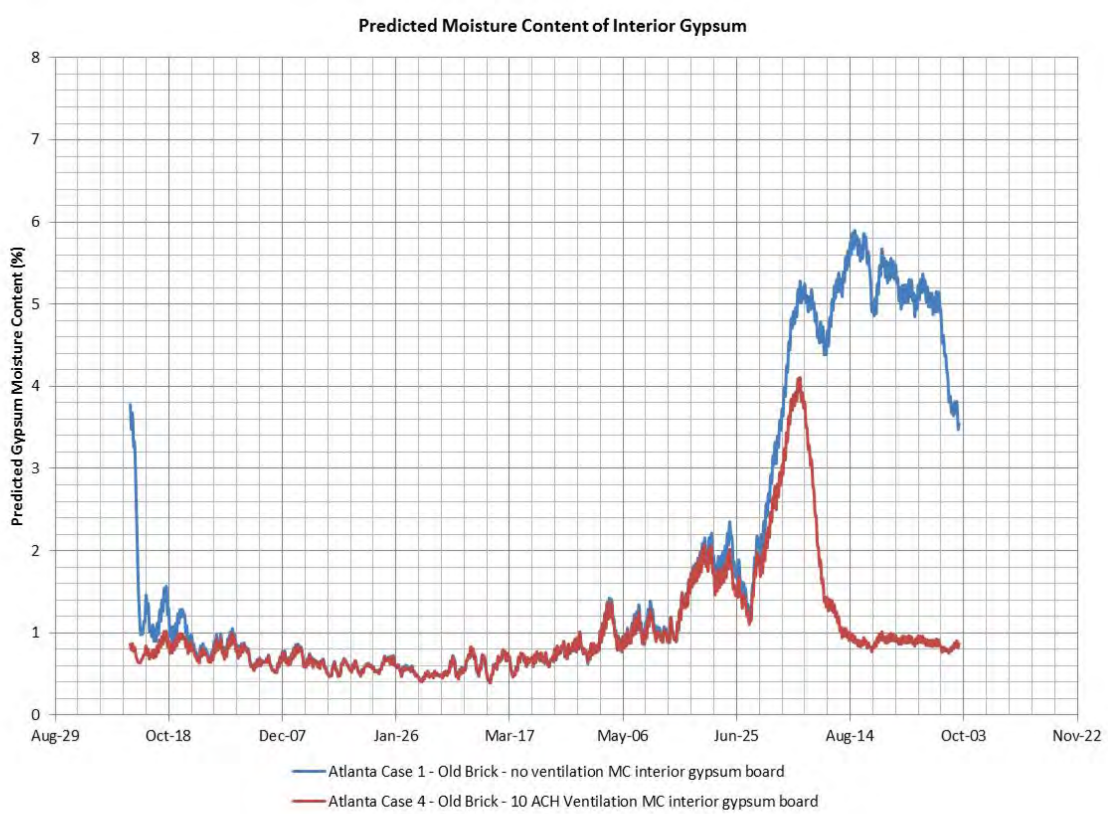

Figure 36 : CZ3 – Atlanta - Predicted interior gypsum board moisture content

Climate Zone 3 (Atlanta) Summary

- If a 1 perm interior layer is used in Atlanta the wall will fail both in terms of OSB sheathing wetting, and gypsum board wetting.
- There are no predicted moisture related durability failures related to the OSB sheathing in the two assemblies with Solid Brick Masonry.
- The relative humidity at the exterior surface of the gypsum is elevated over 90% under these analysis criteria of a 1 perm interior finish for the entire summer. According the sorption isotherm for interior gypsum board, the moisture content of gypsum increases quickly starting at approximately 90%. This means that the predicted relative humidity at the surface of the gypsum may result in moisture related durability issues.

Climate Zone 3 – Charlotte

Residential Assembly – 2x4 Wood Framed Wall

CZ 3	Charlotte
Installed Insulation	R-13 + R-3.8 ci
Orientation	South
Sheathing	OSB
Interior Humidity Conditions	Sinusoidal - max 60%RH July 1, min 35%RH Jan 1
Interior Vapor Control	Latex paint on interior of GWB ~5 perms (Class III)

The exterior conditions used in simulations for Charlotte are shown in **Figure 37** and **Figure 38**.

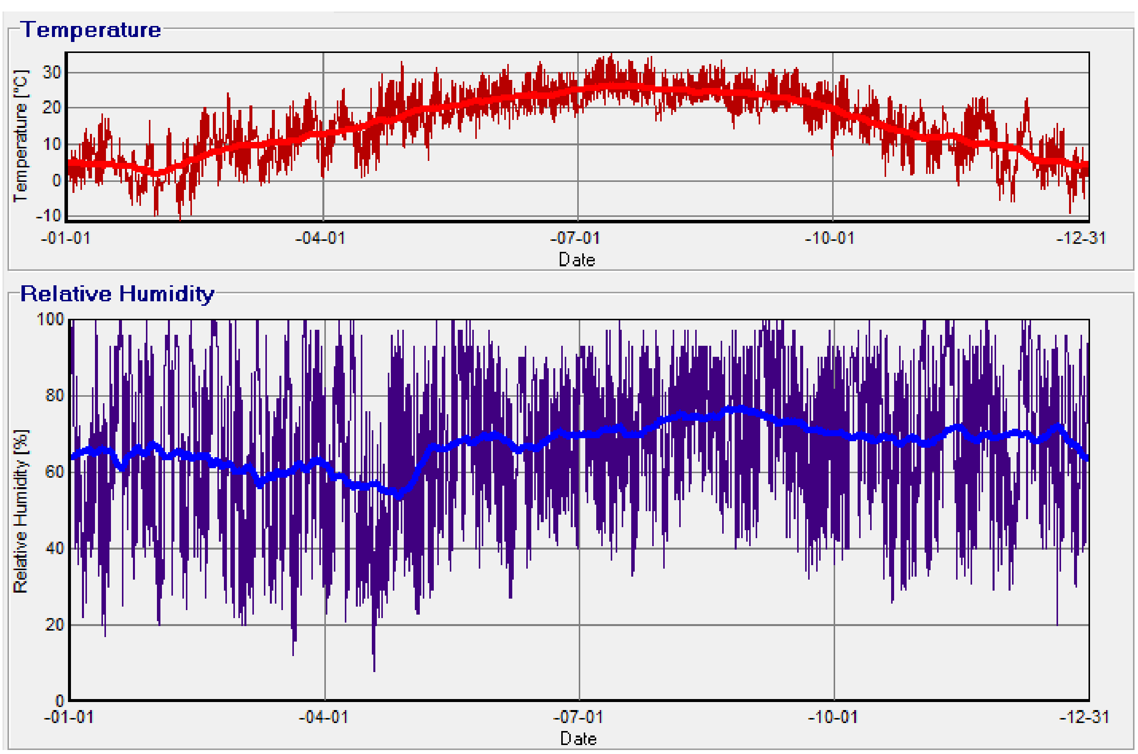

Figure 37 : Exterior temperature and humidity based on TMY3 data for Charlotte

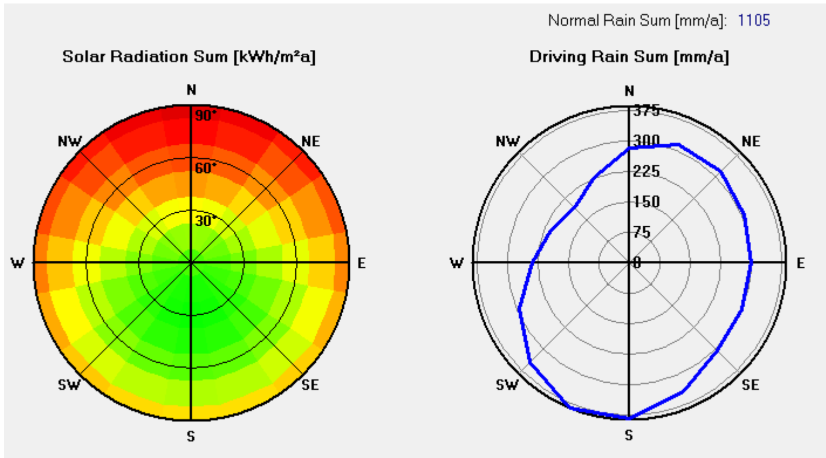

Figure 38 : Solar Radiation and Driving rain based on TMY3 data for Charlotte

Analysis for Charlotte was conducted on three different cases:

- Unventilated Solid Brick Masonry cladding
- Ventilated (10 ACH) Solid Brick Masonry cladding
- Unventilated Solid Brick Masonry cladding with a 1 perm interior finish

There were no predicted moisture related durability issues in the sheathing in any of the analyzed wall assemblies. The highest predicted moisture content was in the winter months, when there was less energy available for drying of the wall system. The peak wood sheathing moisture content in the unventilated masonry wall was 19%.

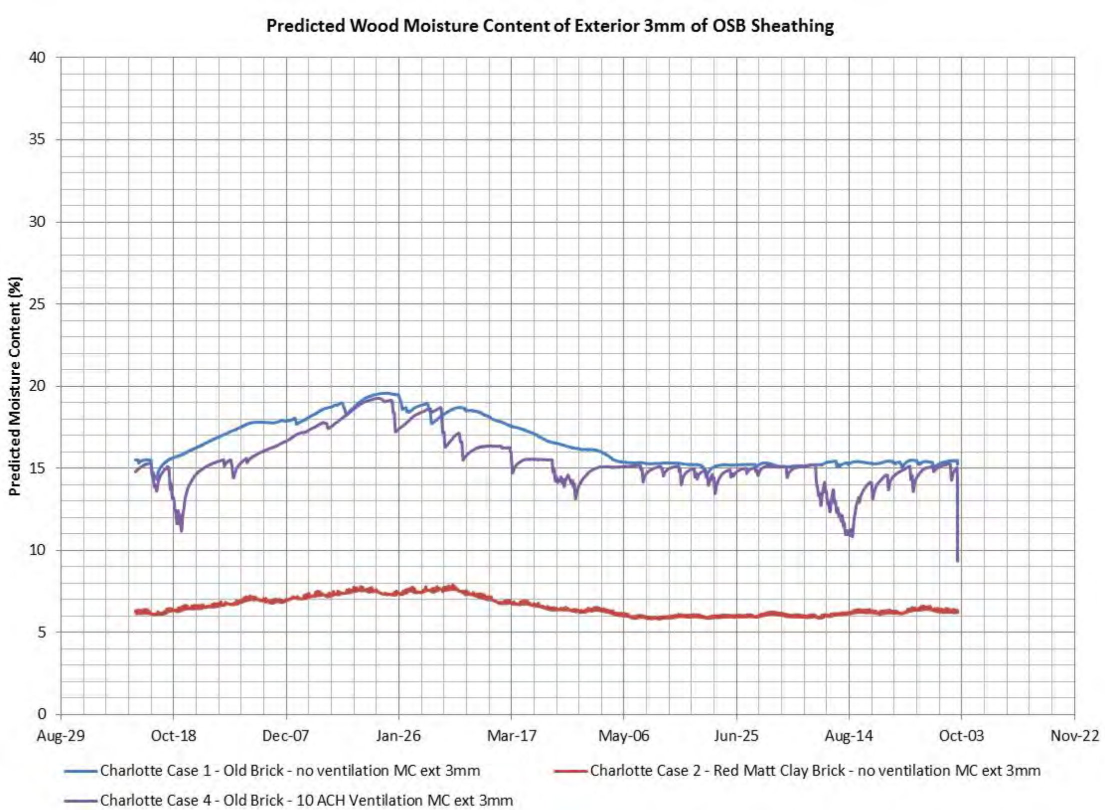

Figure 39 : CZ3 Charlotte – OSB Sheathing Moisture Content – South-East Orientation

The predicted relative humidity at the exterior surface of the interior gypsum wall board is shown in **Figure 40**. The unventilated masonry wall reaches 90% for a few short intervals, and the ventilated masonry wall shows some improvements in the predicted relative humidity. The assembly with the low absorptive brick reaches a maximum RH of approximately 64%.

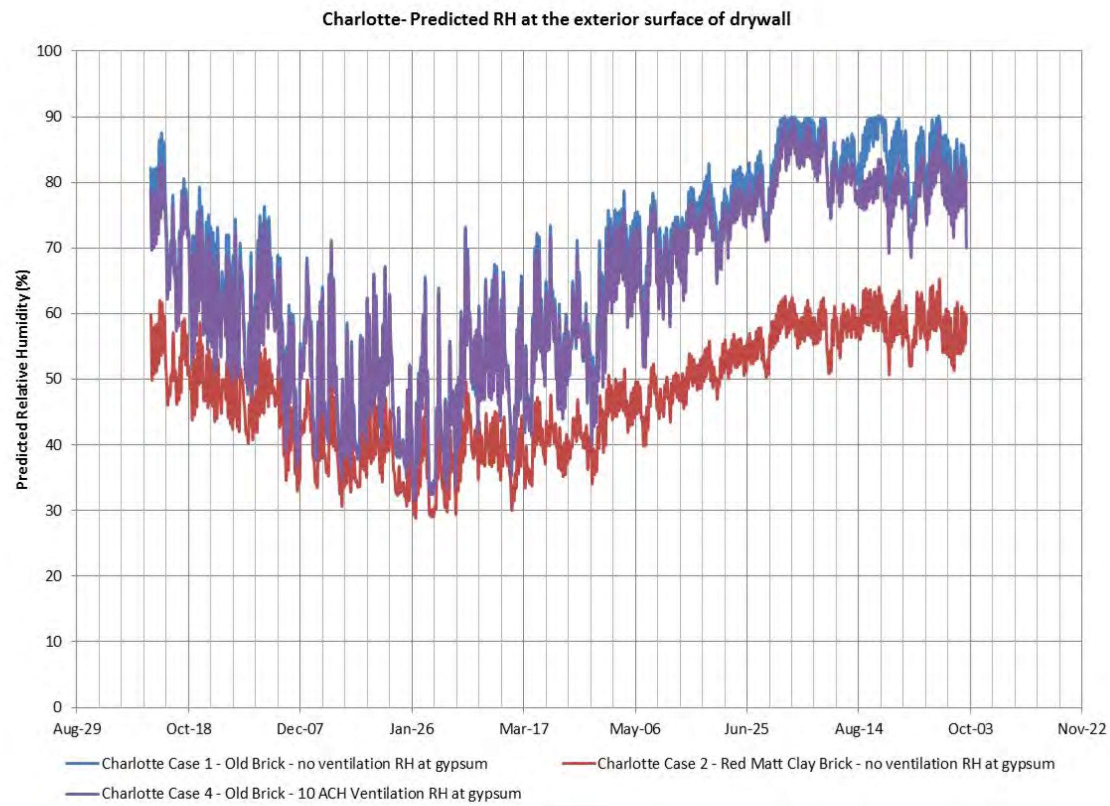

Figure 40 : CZ3 Charlotte – Relative Humidity at the Exterior Surface of the Interior Drywall – South-East Orientation

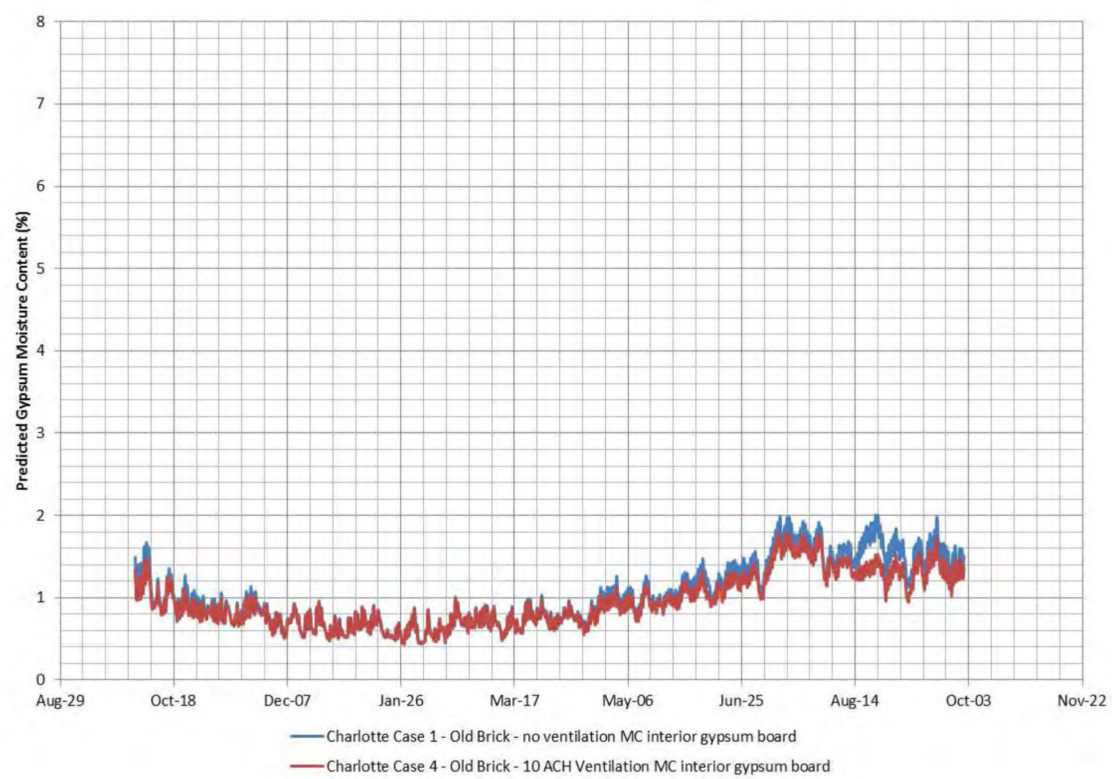

Figure 41 : CZ3 – Charlotte - Predicted interior gypsum board moisture content

Climate Zone 3 (Charlotte) Summary

- There are no predicted moisture related durability failures related to the OSB sheathing in the two assemblies with Solid Brick Masonry in Charlotte.
- The relative humidity at the exterior surface of the gypsum reaches 90% for a few short intervals in the unventilated wall, and less time in the ventilated wall. The ventilation appears to make more of a difference in performance than in Climate zones 1 and 2.

Climate Zone 4 – St. Louis

Residential Assembly – 2x4 Wood Framed Wall

CZ 4	St.Louis (warm year)
Installed Insulation	R-13 + R-3.8 ci
Orientation	South-East
Sheathing	OSB
Interior Humidity Conditions	Sinusoidal - max 60%RH July 1, min 30%RH Jan 1
Interior Vapor Control	Latex paint on interior of GWB ~5 perms (Class III)

The exterior conditions used in simulations for St. Louis are shown in **Figure 42** and **Figure 43**.

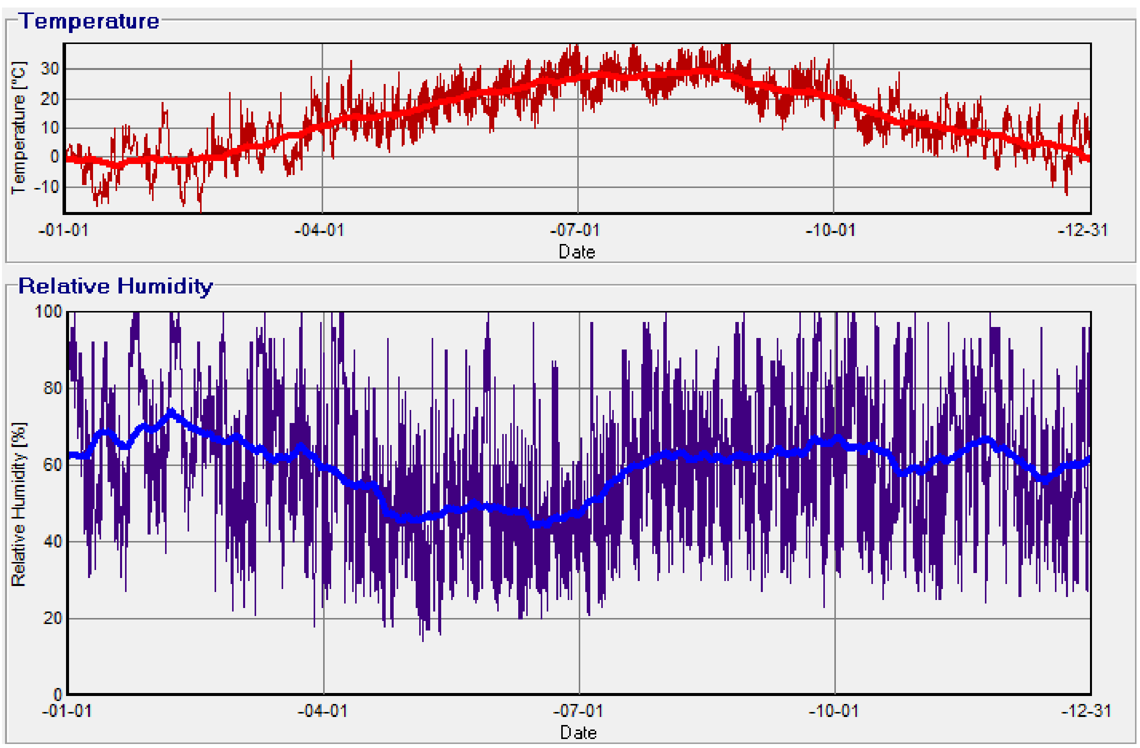

Figure 42 : Exterior temperature and humidity provided by WUFI for St. Louis (warm year)

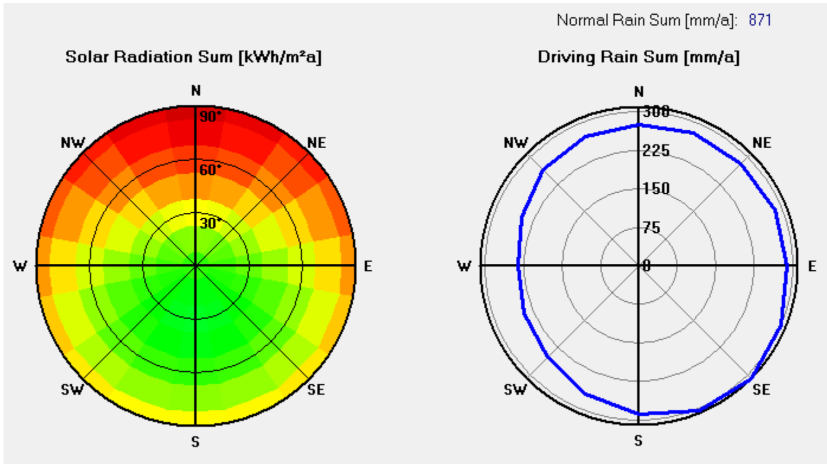

Figure 43 : Solar Radiation and Driving rain provided by WUFI for St. Louis (warm year)

Analysis for St. Louis was conducted on four different cases;

- Unventilated Solid Brick Masonry cladding
- Ventilated (10 ACH) Solid Brick Masonry cladding
- Unventilated Solid Brick Masonry cladding with a 1 perm interior finish
- Unventilated Red Matt Clay Brick

The highest sheathing moisture content was experienced with the Solid Brick Masonry cladding and the addition of the 1 perm interior surface layer. Moisture related durability issues will occur in this assembly.

The unventilated Solid Brick Masonry cladding had a peak OSB moisture content at the exterior surface of 21% in December, when there is a combination of moisture from the interior and exterior, and less energy on the exterior available for drying.

The ventilated Solid Brick Masonry showed significant improvements in moisture content through the summer months when there was increased drying potential from the ambient air.

The assembly with the low absorptive Red Matt Clay Brick did not experience any elevated moisture contents of the sheathing.

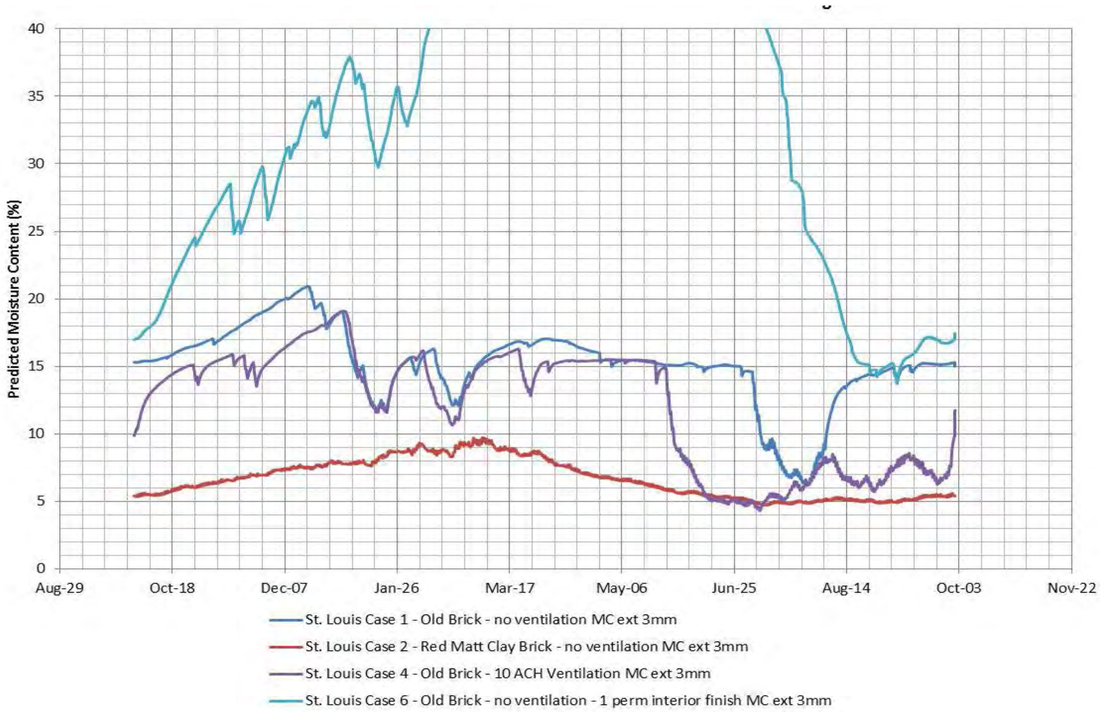

Figure 44 : CZ4 St. Louis – OSB Sheathing Moisture Content – South-East Orientation

The predicted relative humidity at the exterior surface of the interior gypsum wall board for St. Louis is shown in **Figure 45**. The assembly with a 1 perm interior finish has a relative humidity of 100% for approximately half of the year. The unventilated Solid Brick Masonry reaches 90% for short intervals and the ventilated Solid Brick Masonry has a peak relative humidity of approximately 80%.

Analysis of the impact of a driving rain leak to the exterior surface of the ComfortBoard IS directly against the sheathing membrane shows an increase in the predicted sheathing moisture content in the winter months to a maximum of 23%, but no significant change in the solar driven moisture in the OSB moisture content or stud space relative humidity in the summer months.

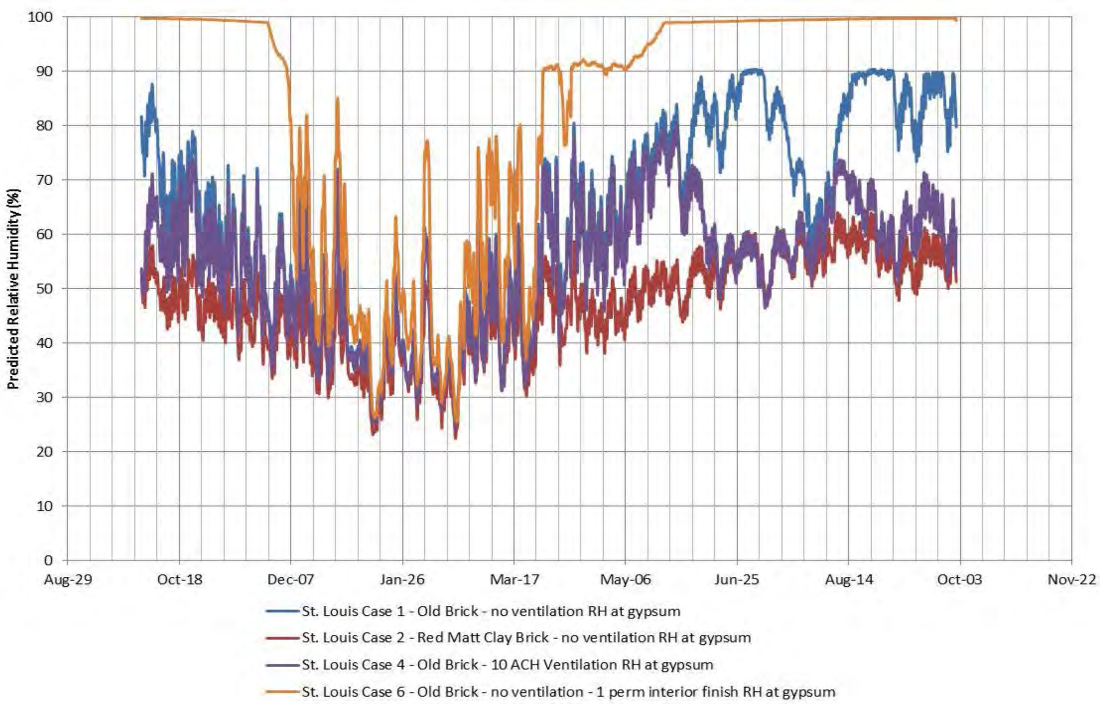

Figure 45 : CZ4 St. Louis – Relative Humidity at the Exterior Surface of the Interior Drywall – South-East Orientation

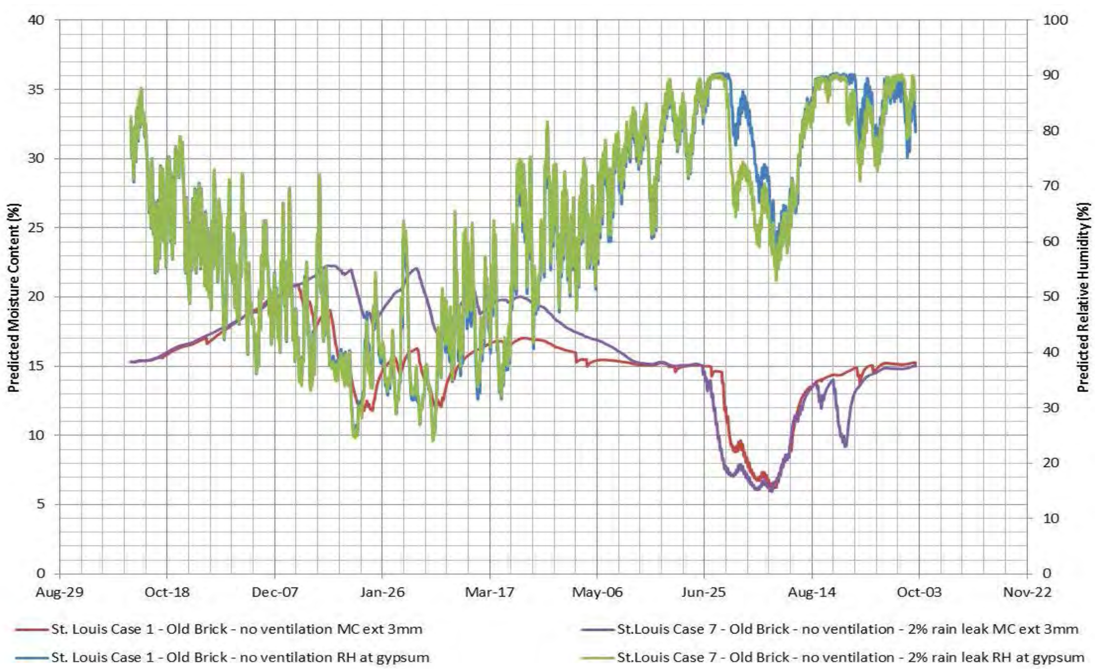

Figure 46 : Comparison of predicted moisture content and relative humidity with and without 1% rain leakage

Analysis of the predicted interior gypsum board moisture content in **Figure 47** shows peaks above 2% in the unventilated masonry cladding, and a reduced summer time moisture content with a 10ACH ventilated cladding.

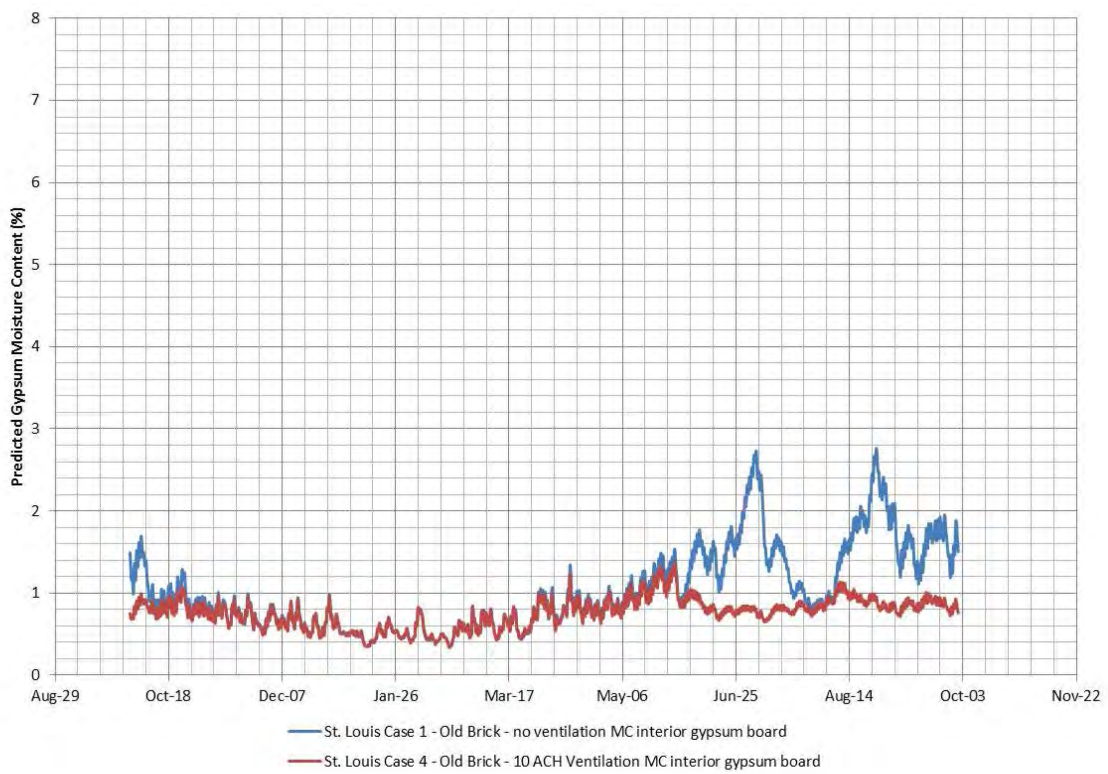

Figure 47 : CZ4 – St. Louis - Predicted interior gypsum board moisture content

Climate Zone 4 (St. Louis) Summary

- If a 1 perm interior layer is used in St. Louis, the wall will fail both in terms of OSB sheathing wetting, and gypsum board wetting.
- There are no predicted moisture related durability failures related to the OSB sheathing in the two assemblies with Solid Brick Masonry.
- The relative humidity at the exterior surface of the gypsum is elevated at 90% for several periods with the unventilated Solid Brick Masonry. According the sorption isotherm for interior gypsum board, the moisture content of gypsum increases quickly starting at approximately 90%. This means that the predicted relative humidity at the surface of the gypsum may result in moisture related durability issues.

Conclusions

The assessment of solar inward vapor drive durability risks is dependent on many variables. The most critical of all these test variables appears to be the vapor permeance of interior surface of the gypsum wall board and the vapor permeance of the sheathing membrane. A sensitivity analysis of the interior vapor permeance between 1 perm and 10 perms, showed a large difference in performance ranging from very safe to severe moisture related damage. The analysis was conducted with an interior vapor permeance of 5perms based on the sensitivity analysis of interior vapor permeance control and the OSB sheathing moisture content.

The sensitivity analysis of sheathing membrane vapor permeance indicated that even with a 2.5perm interior finish the moisture durability could be controlled by decreasing the vapor permeance of the sheathing membrane.

Analysis of interior gypsum board moisture content was also conducted, and it was found that increasing the vapor permeance to 7.5 perms decreased the moisture content of the interior gypsum board significantly to under 2% in Miami and Houston. In nearly all of the analysis locations, a 5 perm interior finish resulted in gypsum board moisture content peaks greater than 2%. It is our experience that with latex paint on the drywall, the assemblies in Climate Zones 1 to 4 perform quite well when subjected to solar driven inward vapor, so the sorption isotherm of the interior gypsum might need to be modified, or the vapor permeance of the installed paint may be closer to 10 perms than 5 perms.

The addition of 10ACH of continuous ventilation behind the brick with exterior air did improve the predicted moisture content of the OSB sheathing and the predicted relative humidity in the stud space, although generally the improvement was not significant.

Changing the interior temperature setpoint did have a small effect on the relative humidity at the exterior surface of the interior gypsum board. In some cases, because of the sensitivity of the gypsum board moisture content to relative humidity, this could play a role in affecting the durability of the interior gypsum board.

Exchanging the highly absorptive Solid Brick Masonry with vinyl siding or less absorptive Red Matt Clay Brick eliminated the predicted solar inward vapor drive moisture related issues in many cases.

Increasing the driving rain coefficients only had a minimal predicted effect on the moisture peaks in the OSB and stud space RH.

Adding a rain leak to the interior layer of the ComfortBatt IS minimally increased the moisture content, and stud space RH, but rockwool can redistribute moisture and dry quite quickly which was why the moisture content did not increase to unsafe levels in the OSB in this study.

Based on predicted OSB sheathing moisture contents, none of the walls with a 5 perm interior layer showed evidence of moisture related durability issues, but there were elevated gypsum board moisture contents greater than 2% with a 5 permeance interior layer and 10 ACH ventilated cavity in Miami, Houston and Atlanta.

It is possible to install the wall assemblies simulated in this analysis in Climate Zones 1 to 4 without resulting in moisture related durability issues, but there is some risk based on the analysis and the uncertainties in both construction and occupant behavior.

Recommendations

It is our experience that low permeance interior finishes such as vinyl wall paper are never recommended on the interior of exterior walls in Climate Zones 1 to 4, and all low permeance coverings such as picture frames, mirrors, whiteboards, cabinets would be less risky if installed on strapping or ventilated such that interior air could free flow against the interior surface of the drywall.

The easiest method to ensure there is no risk of moisture related durability in the enclosure, if a moisture absorptive cladding is specified, is to install a low vapor permeance layer on the exterior of the sheathing to greatly reduce or eliminate the movement of vapor into the enclosure. Many products exist to meet this need including self-adhered membranes, fluid applied membranes, and some mechanically fastened sheet applied sheathing membranes. Another potential product may be Huber ZIP wall system, although the material properties for the sheathing are currently publically unknown and therefore cannot be accurately simulated in WUFI.

Vinyl siding eliminates all of the problems of solar driven inward moisture but often that is not the aesthetic that is desired. Using a lower absorbtivity cladding or minimizing the amount of the water on the surface of the cladding with good water management design (ie. Suitable overhangs, etc.) will also minimize solar inward vapor drives by minimizing the water available to be driven into the enclosure. Ensuring the ventilation cavity in the enclosure is as free as possible of obstacles will also help reduce the solar driven inward vapor by removing vapor in the cavity with ventilation.

We recommend conducting some full scale field testing of various assemblies, particularly the ones that are determined as risky in WUFI, and monitoring the moisture content and relative humidity in the assembly. Intentional wetting in the cavity as well as the moisture absorptive cladding would help stress the system to determine the performance under more challenging conditions.

Based on this analysis and our experience with construction in hot humid climates we recommend that assemblies in hot humid climates, with a brick veneer, Roxul exterior continuous insulation, OSB, Roxul cavity batt, and gypsum wall board have a sheathing membrane with a vapor permeance of 6.5 US perms or less, and only use latex paint on the interior of the gypsum wall board.

Conclusions

The assessment of solar inward vapor drive durability risks is dependent on many variables. The most critical of all these test variables appears to be the vapor permeance of interior surface of the gypsum wall board and the vapor permeance of the sheathing membrane. A sensitivity analysis of the interior vapor permeance between 1 perm and 10 perms, showed a large difference in performance ranging from very safe to severe moisture related damage. The analysis was conducted with an interior vapor permeance of 5perms based on the sensitivity analysis of interior vapor permeance control and the OSB sheathing moisture content.

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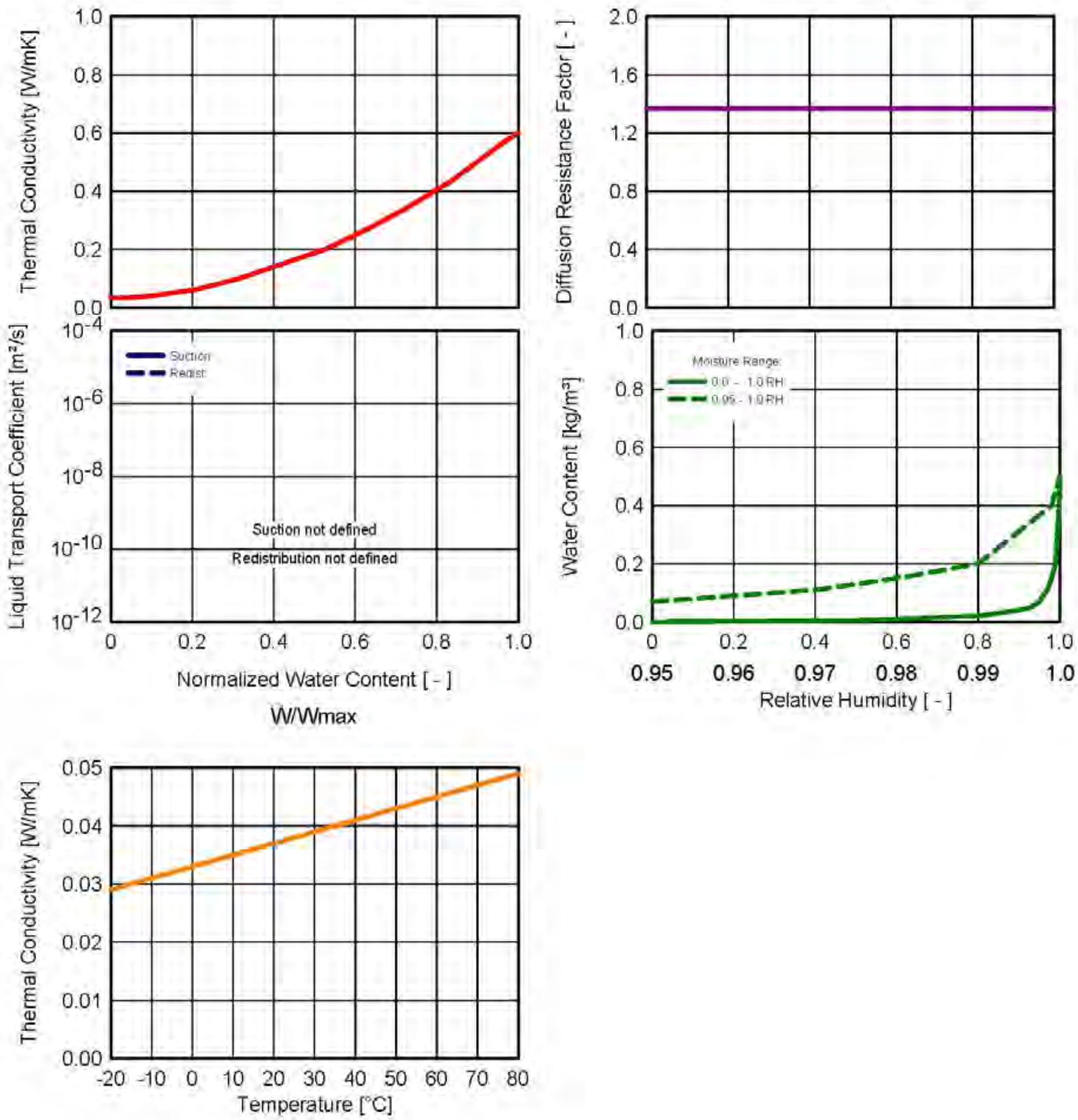
Appendix

WUFI® Pro 5.1

Material : (BSC) Roxul RockBoard 80 - CF IS

Checking Input Data

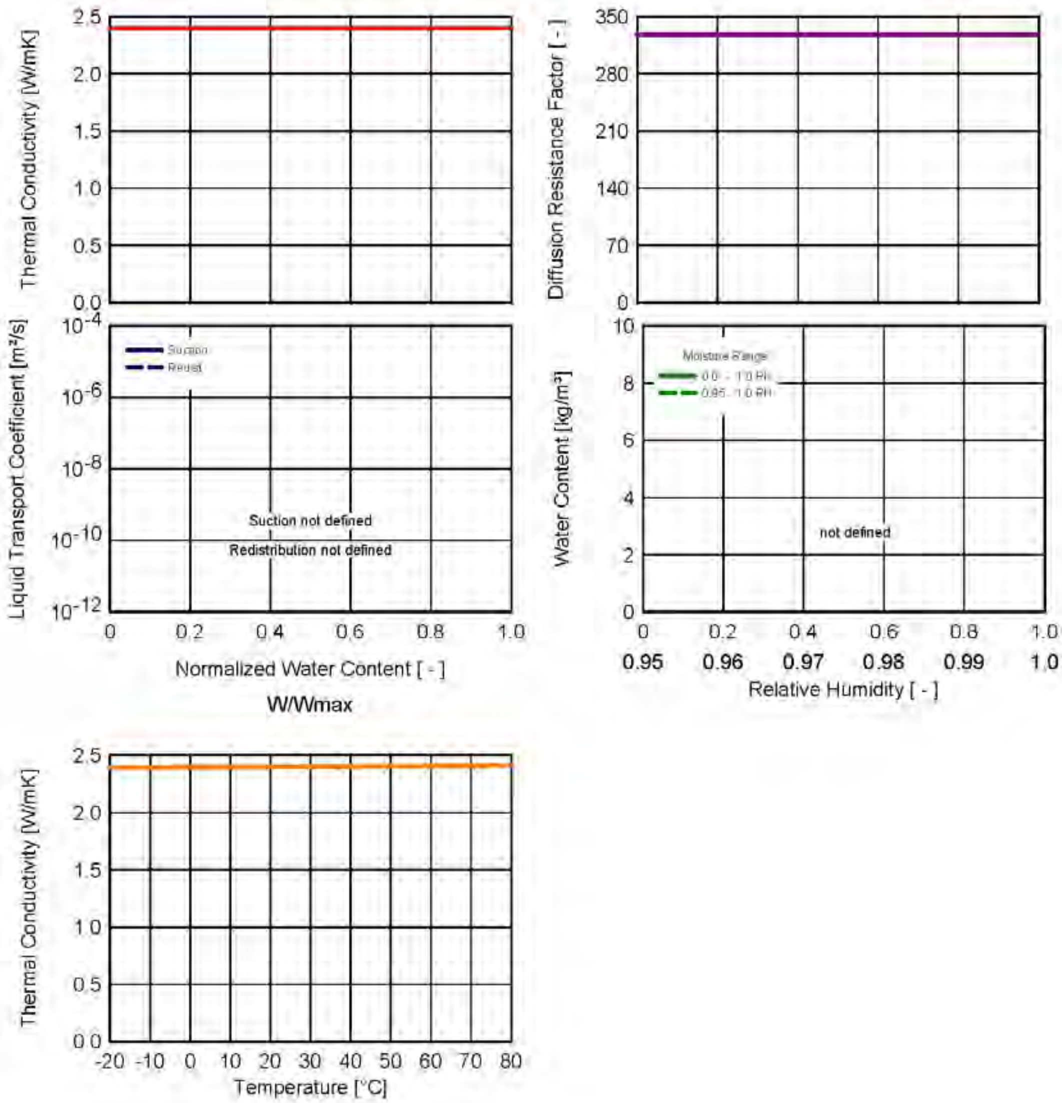
Property	Unit	Value
Bulk density	[kg/m³]	128,0
Porosity	[m³/m³]	0,95
Specific Heat Capacity, Dry	[J/kgK]	850,0
Thermal Conductivity, Dry ,10°C	[W/mK]	0,035
Water Vapour Diffusion Resistance Factor	[-]	1,37
Temp-dep. Thermal Cond. Supplement	[W/mK²]	0,0002



Material : Spun Bonded Polyolefine Membrane (SBP)

Checking Input Data

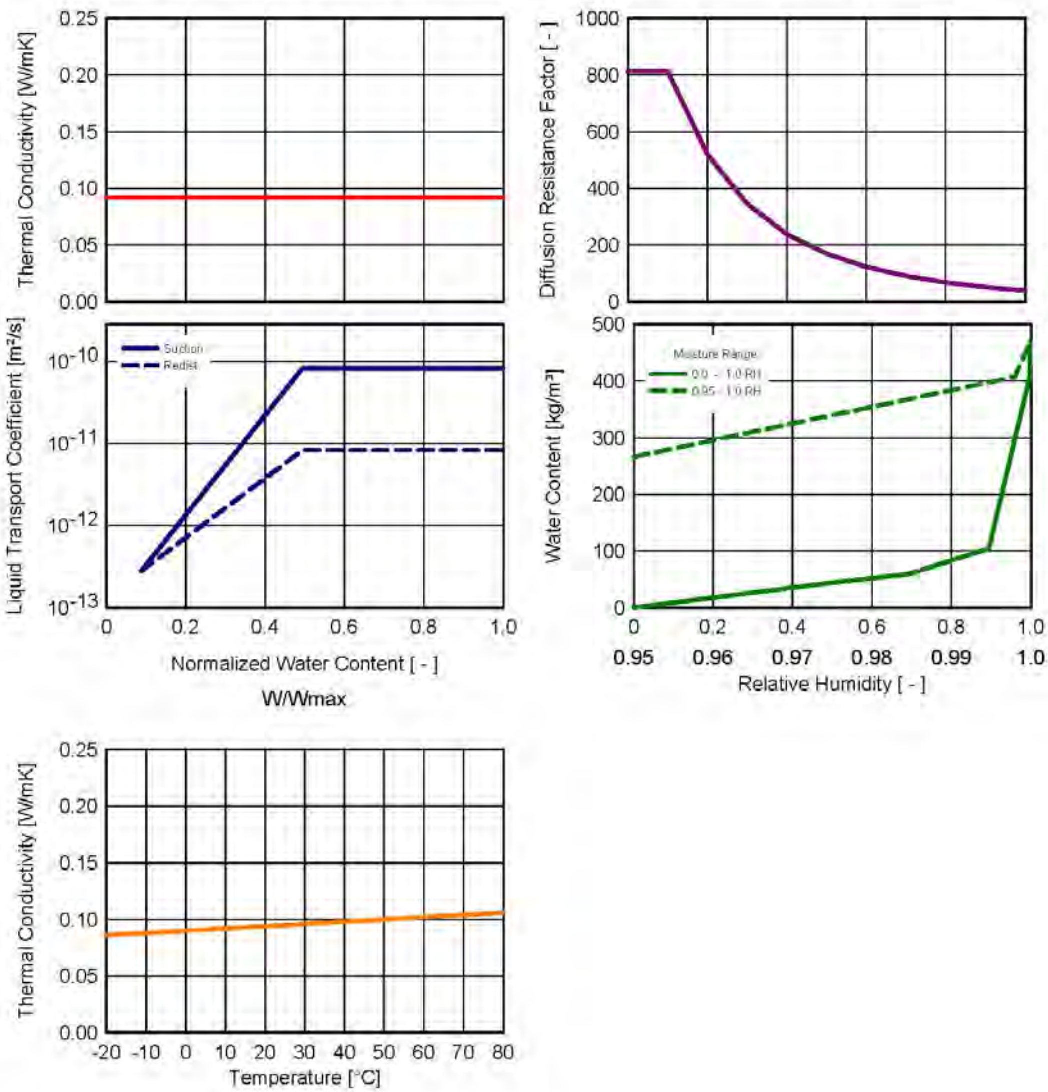
Property	Unit	Value
Bulk density	[kg/m³]	448,0
Porosity	[m³/m³]	0,001
Specific Heat Capacity, Dry	[J/kgK]	1500,0
Thermal Conductivity, Dry ,10°C	[W/mK]	2,4
Water Vapour Diffusion Resistance Factor	[-]	328,4
Temp-dep. Thermal Cond. Supplement	[W/mK²]	0,0002



Material : *Oriented Strand Board (7/16")

Checking Input Data

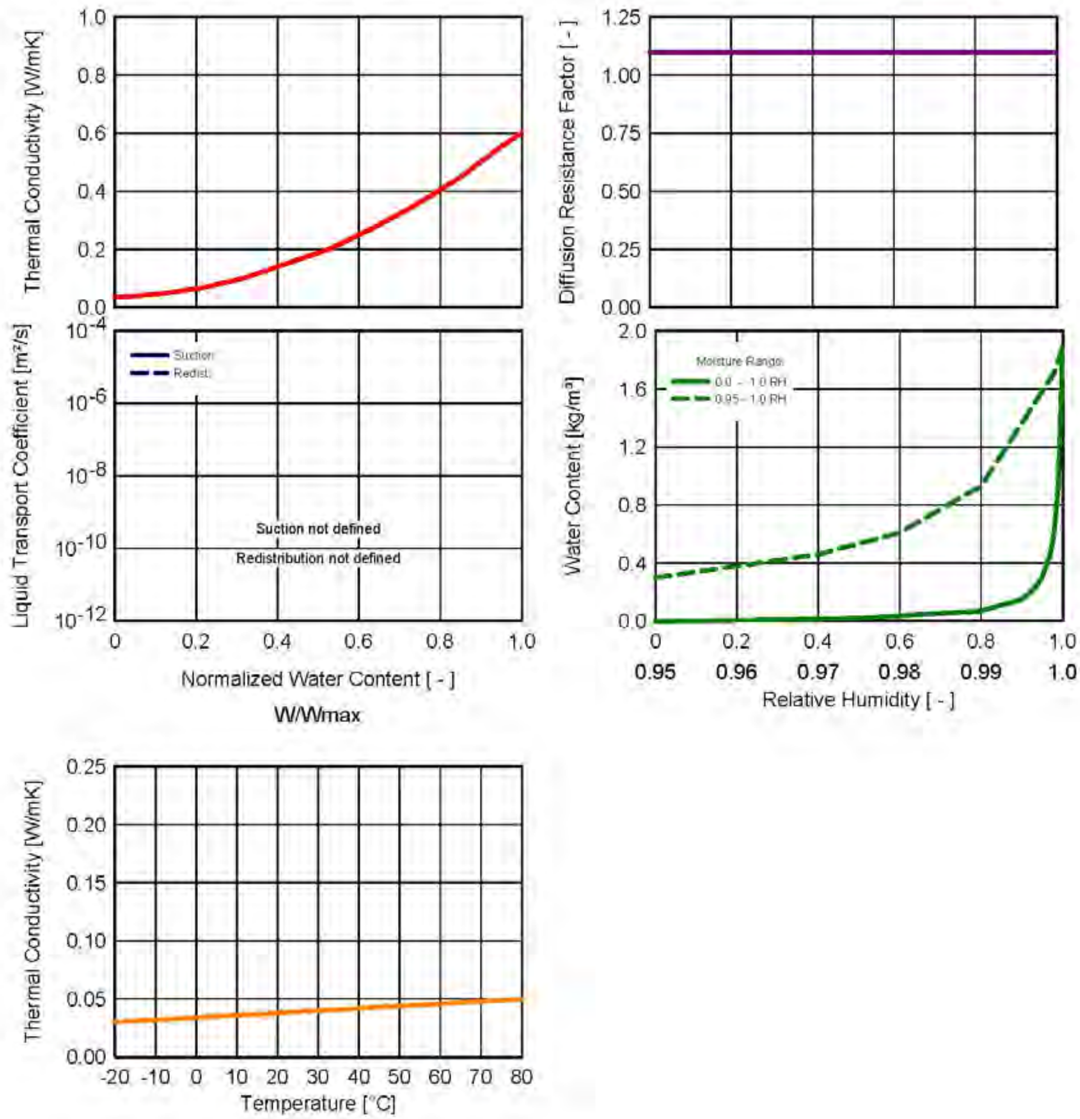
Property	Unit	Value
Bulk density	[kg/m³]	650,0
Porosity	[m³/m³]	0,95
Specific Heat Capacity, Dry	[J/kgK]	1880,0
Thermal Conductivity, Dry ,10°C	[W/mK]	0,092
Water Vapour Diffusion Resistance Factor	[-]	812,8
Reference Water Content	[kg/m³]	83,3
Free Water Saturation	[kg/m³]	470,0
Water Absorption Coefficient	[kg/m²s^0.5]	0,0022
Temp-dep. Thermal Cond. Supplement	[W/mK²]	0,0002



Material : *Roxul ComfortBatt (based on data for Roxul Plus)

Checking Input Data

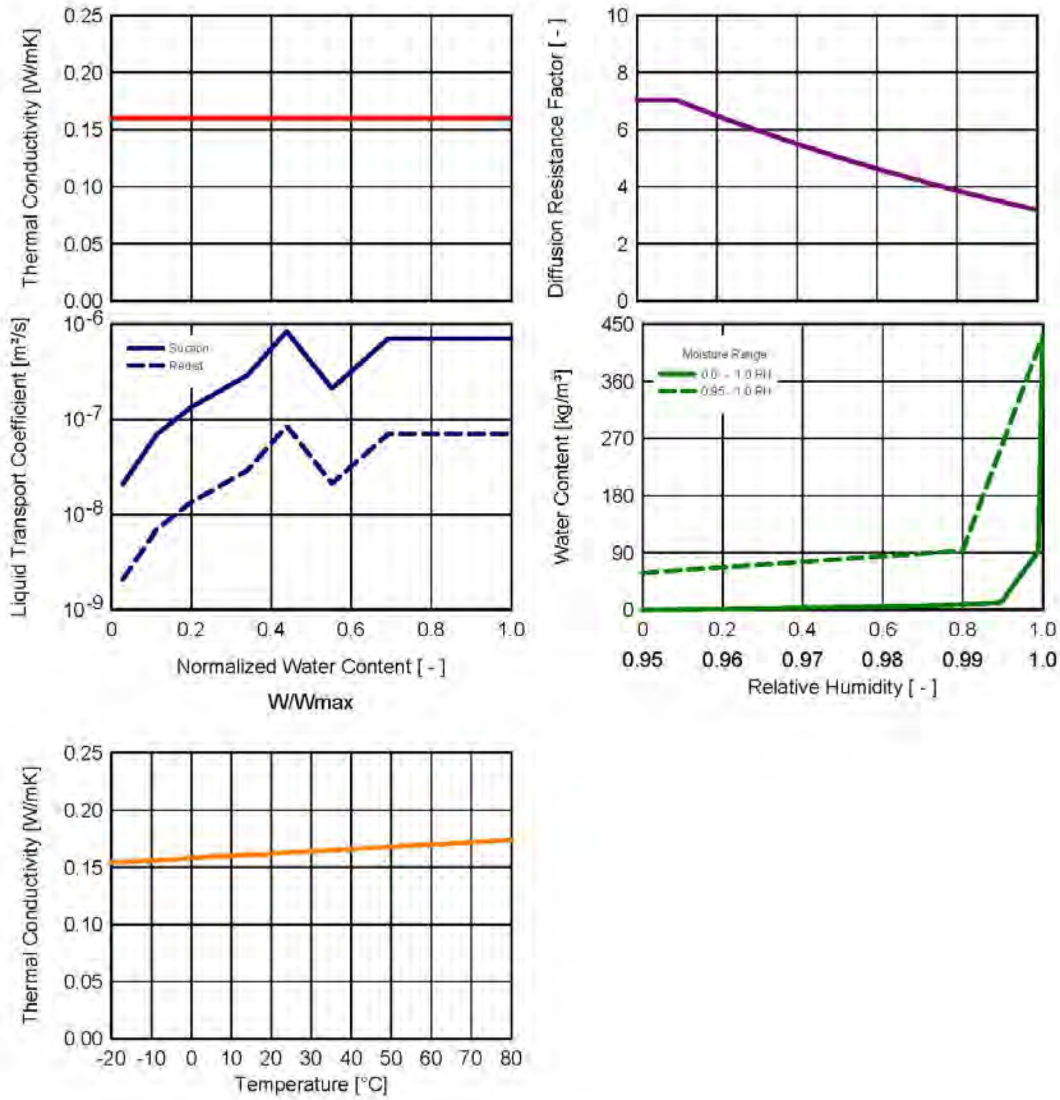
Property	Unit	Value
Bulk density	[kg/m³]	30,0
Porosity	[m³/m³]	0,95
Specific Heat Capacity, Dry	[J/kgK]	850,0
Thermal Conductivity, Dry ,10°C	[W/mK]	0,036
Water Vapour Diffusion Resistance Factor	[-]	1,1
Temp-dep. Thermal Cond. Supplement	[W/mK²]	0,0002



Material : Interior Gypsum Board

Checking Input Data

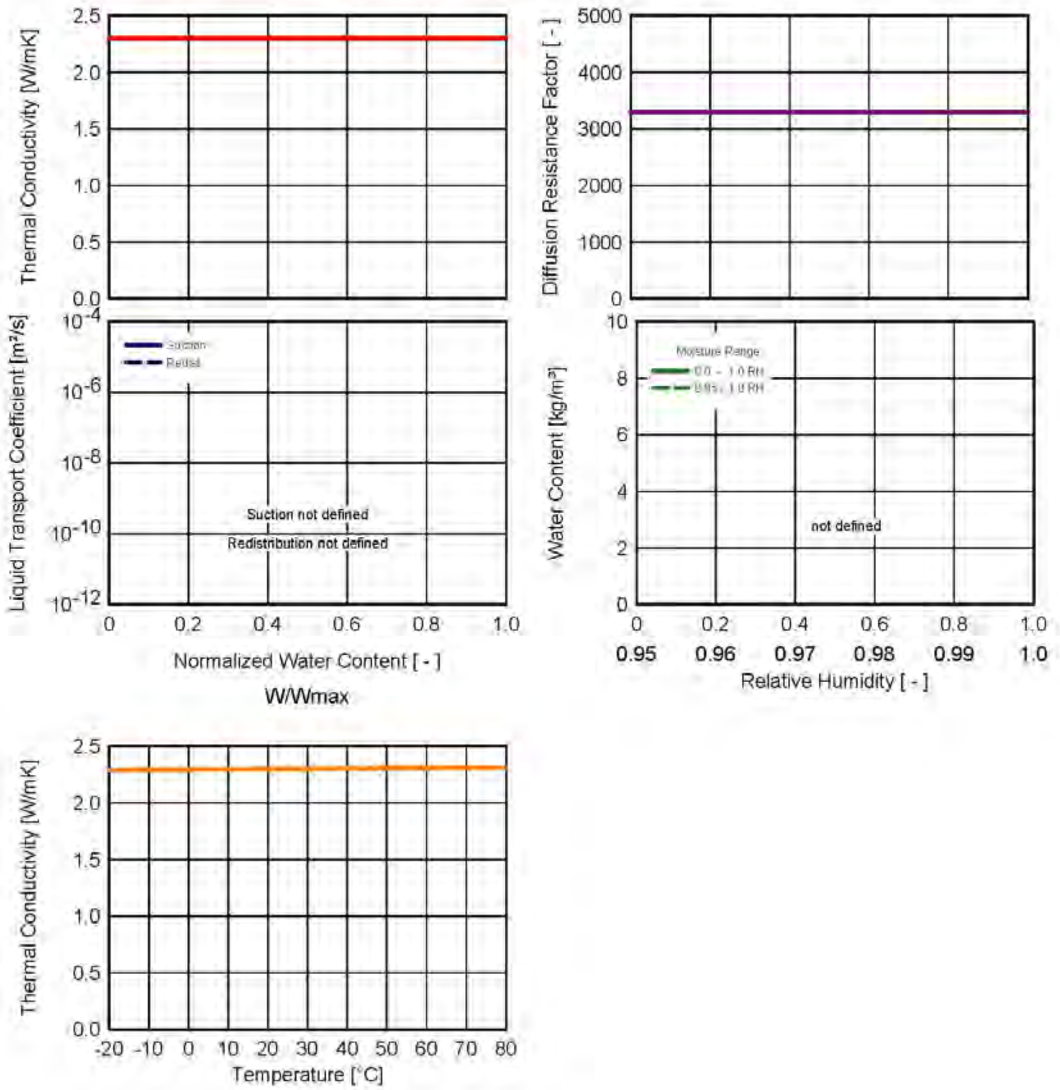
Property	Unit	Value
Bulk density	[kg/m³]	625,0
Porosity	[m³/m³]	0,706
Specific Heat Capacity, Dry	[J/kgK]	870,0
Thermal Conductivity, Dry ,10°C	[W/mK]	0,16
Water Vapour Diffusion Resistance Factor	[-]	7,03
Temp-dep. Thermal Cond. Supplement	[W/mK²]	0,0002



Material : vapour retarder (1 perm)

Checking Input Data

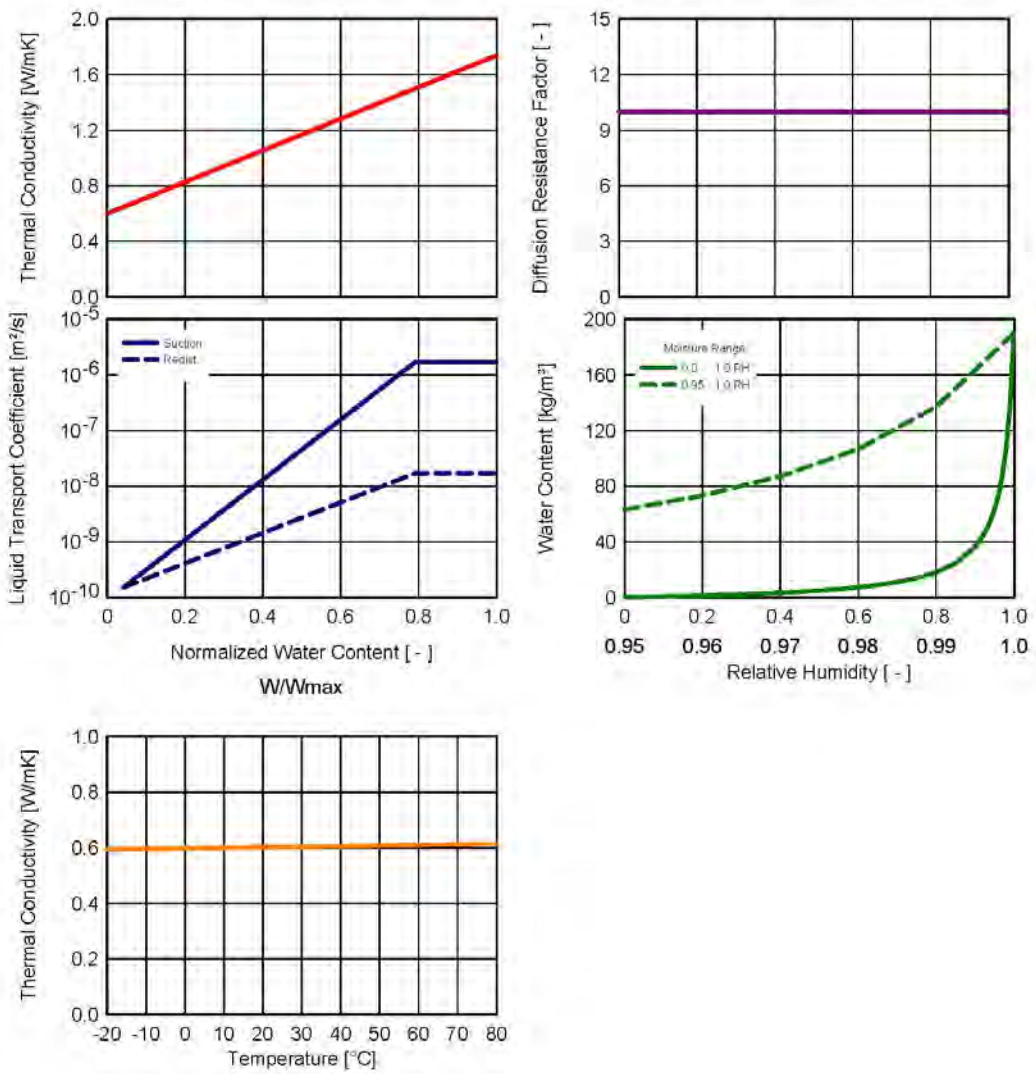
Property	Unit	Value
Bulk density	[kg/m³]	130,0
Porosity	[m³/m³]	0,001
Specific Heat Capacity, Dry	[J/kgK]	2300,0
Thermal Conductivity, Dry ,10°C	[W/mK]	2,3
Water Vapour Diffusion Resistance Factor	[-]	3300,0
Temp-dep. Thermal Cond. Supplement	[W/mK²]	0,0002



Material : Solid Brick Masonry

Checking Input Data

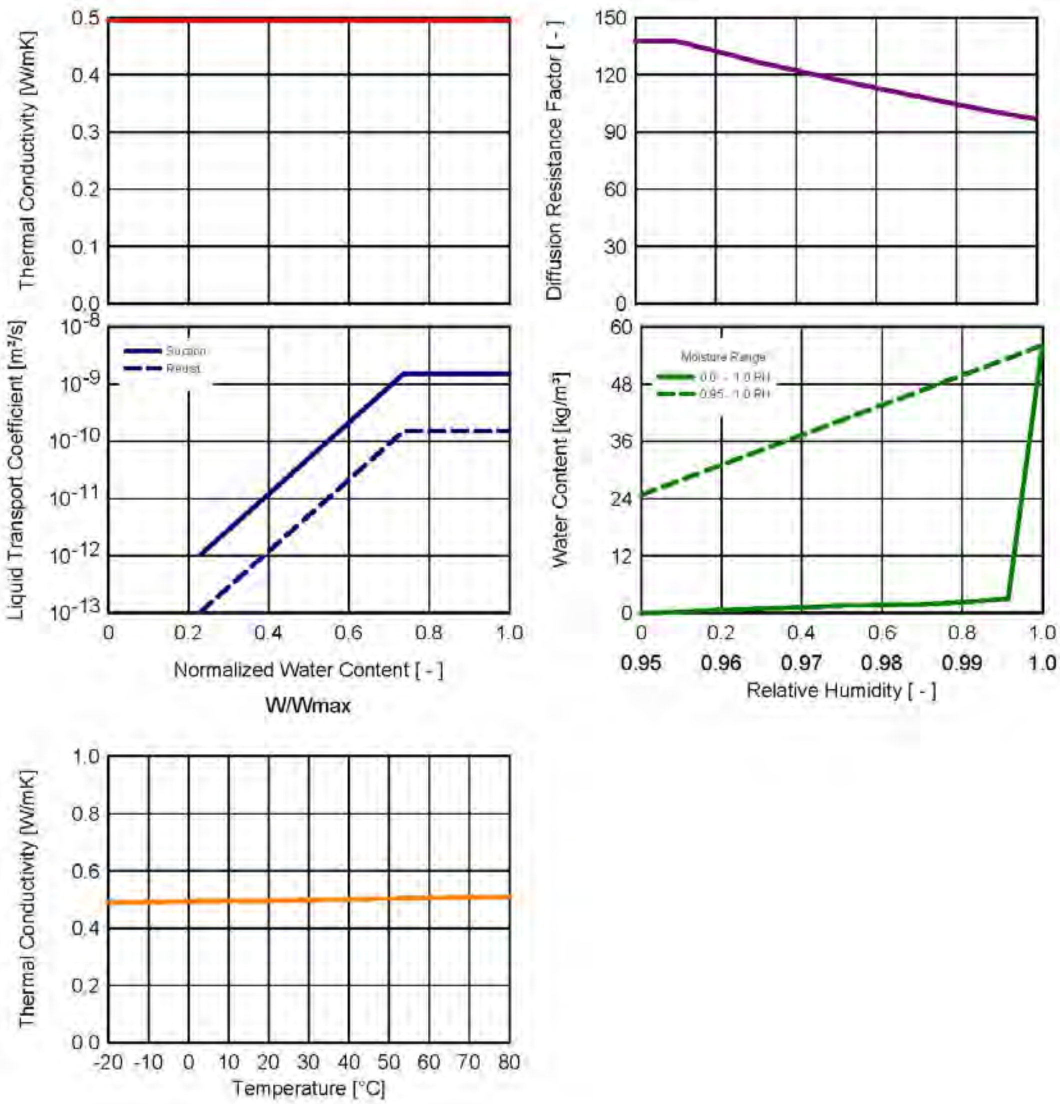
Property	Unit	Value
Bulk density	[kg/m³]	1900,0
Porosity	[m³/m³]	0,24
Specific Heat Capacity, Dry	[J/kgK]	850,0
Thermal Conductivity, Dry ,10°C	[W/mK]	0,6
Water Vapour Diffusion Resistance Factor	[-]	10,0
Reference Water Content	[kg/m³]	18,0
Free Water Saturation	[kg/m³]	190,0
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	15,0
Temp-dep. Thermal Cond. Supplement	[W/mK²]	0,0002



Material : Red Matt Clay Brick

Checking Input Data

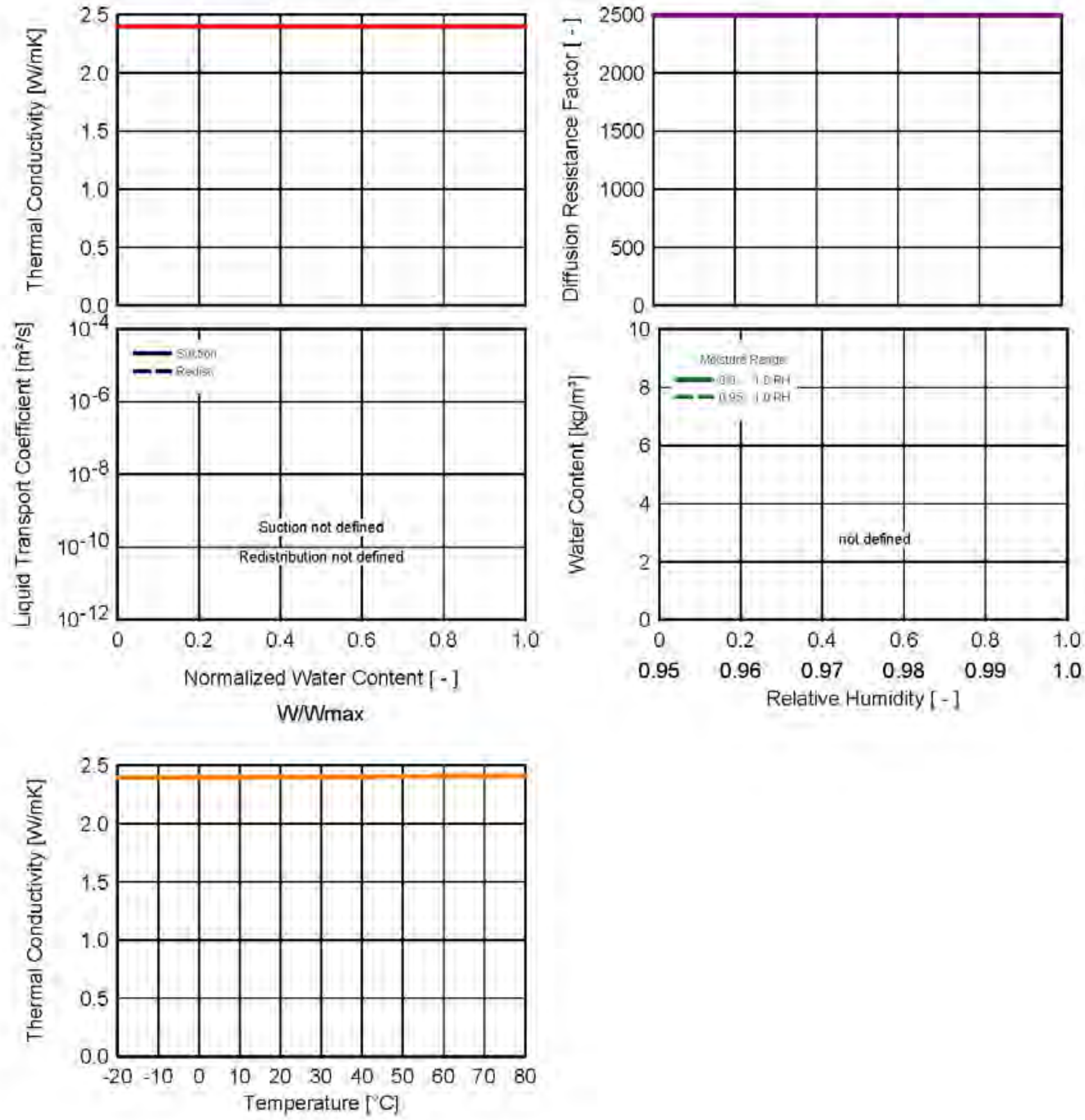
Property	Unit	Value
Bulk density	[kg/m^3]	1935,0
Porosity	[m^3/m^3]	0,217
Specific Heat Capacity, Dry	[J/kgK]	800,0
Thermal Conductivity, Dry ,10°C	[W/mK]	0,495
Water Vapour Diffusion Resistance Factor	[-]	137,8
Temp-dep. Thermal Cond. Supplement	[W/mK^2]	0,0002



Material : *Spun Bonded Polyolefine Membrane (SBP) Dow Weathermate

Checking Input Data

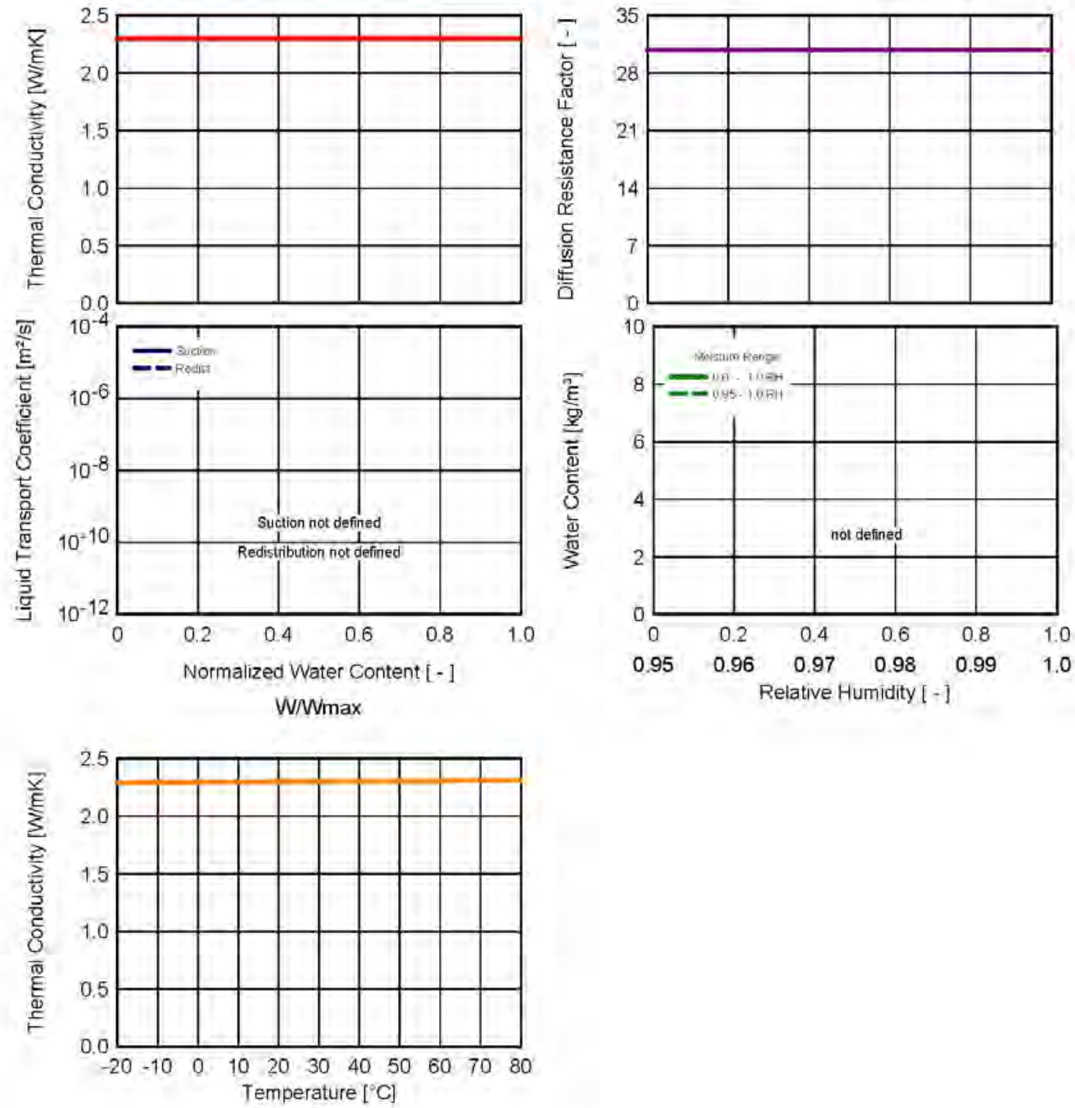
Property	Unit	Value
Bulk density	[kg/m³]	448,0
Porosity	[m³/m³]	0,001
Specific Heat Capacity, Dry	[J/kgK]	1500,0
Thermal Conductivity, Dry ,10°C	[W/mK]	2,4
Water Vapour Diffusion Resistance Factor	[-]	2496,6
Temp-dep. Thermal Cond. Supplement	[W/mK²]	0,0002



Material : BSC Vinyl Siding Equivalence based on PE-Membrane(Poly) 3000 ng/Pa

Checking Input Data

Property	Unit	Value
Bulk density	[kg/m³]	130,0
Porosity	[m³/m³]	0,001
Specific Heat Capacity, Dry	[J/kgK]	2300,0
Thermal Conductivity, Dry ,10°C	[W/mK]	2,3
Water Vapour Diffusion Resistance Factor	[-]	30,83
Temp-dep. Thermal Cond. Supplement	[W/mK²]	0,0002



Material : Air Layer 10 mm; without additional moisture capacity

Checking Input Data

Property	Unit	Value
Bulk density	[kg/m³]	1,3
Porosity	[m³/m³]	0,001
Specific Heat Capacity, Dry	[J/kgK]	1000,0
Thermal Conductivity, Dry ,10°C	[W/mK]	0,071
Water Vapour Diffusion Resistance Factor	[-]	0,73