Modeling Enclosure Design in Above Grade Walls Technical Report

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Joseph Lstiburek, Kohta Ueno, Sravanthi Musunuru

Abstract:

This Technical Report describes the modeling of typical wall assemblies that have performed well historically in various climate zones. The provided information can be generalized for application to a broad population of houses, within the limits of existing experience. WUFI software model was calibrated or "tuned" using wall assemblies with historically successful performance. Running the rainwater and airflow "tuned" WUFI software model generated the library of input data and results presented. The results agree with historical experience of these assemblies constructed in the climate zones modeled. The files present various custom settings that will help avoid results that will require overly conservative enclosure assemblies.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Modeling Enclosure Design in Above Grade Walls

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Building Science Corporation

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Contents

List of Figures

Unless otherwise noted, all figures were created by Building Science Corporation.

List of Tables

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Definitions

ACH	Air changes per hour
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
DOE	U.S. Department of Energy
IECC	International Energy Conservation Code
MC	Moisture content (wood % by weight)
NREL	National Renewable Energy Laboratory
OSB	Oriented strand board
RH	Relative humidity
WUFI	*Wärme und Feuchte instationär*

Executive Summary

The Technical Report describes the modeling of typical wall assemblies that have performed well historically in various climate zones. The WUFI (*Wärme und Feuchte instationär*) software (Version 5.3) model was used. A library of input data and results are provided. The provided information can be generalized for application to a broad population of houses, within the limits of existing experience.

The WUFI software model was calibrated or "tuned" using wall assemblies with historically successful performance. The primary performance criteria or failure criteria establishing historic performance was moisture content of the exterior sheathing - More specifically, historic reports of decay, based on observation of large numbers of wall assemblies ("buildings") over a decade or longer. The primary "tuning" parameters (simulation inputs) were airflow and specifying appropriate material properties. "Rational" hygric loads were established based on experience – specifically rain wetting and interior moisture (RH levels). The "tuning" parameters were limited or bounded by published data or experience.

The WUFI software model is a one-dimensional combined heat and moisture flow model. Typical building assemblies are multi-layer systems with complex three-dimensional airflow pathways. One-dimensional combined heat and moisture flow models have proven difficult to use for analysis in these types of assemblies due to the complexity added by the airflow and rain components.

Rain is a significant moisture load: modeling the rain transport mechanism—a three dimensional phenomena in a multi-layer system—adds more complexity. The WUFI rain modeling inputs assumed a fraction (1%) of the incident water penetrating past the cladding, and a smaller fraction (0.01%) past the water control layer and into the sheathing.

WUFI software is capable of modeling cladding ventilation, by introducing interior or exterior condition air into an airspace within the assembly. This allows for explicit (and correct) modeling of ventilated rainscreen behaviors. This airflow model within WUFI also allows the analysis of "through the assembly airflow" (i.e., air leakage through typical imperfect assemblies). This flow was approximated by adding air spaces between the insulation and sheathing, where interior and exterior-sourced air was introduced.

Running the rainwater and airflow "tuned" WUFI software model generated the library of input data and results presented. The results agree with historical experience of these assemblies constructed in the climate zones modeled.

The WUFI templates provided with this report supply useful information resources to new or less-experienced users. The files present various custom settings that will help avoid results that will require overly conservative enclosure assemblies. Overall, better material data, consistent initial assumptions, and consistent inputs among practitioners will improve the quality of WUFI modeling, and improve the level of sophistication in the field.

1 Problem Statement

1.1 Introduction

Hygrothermal simulations such as WUFI (Künzel 2002) are coming into increasingly common use among building science researchers and practitioners, architects and designers, and energy analysts. Such simulations have been shown to be powerful and validated tools that predict hygrothermal behavior of enclosure assemblies. Simulation developers have continued to expand the capabilities of such tools over time.

However, with increasing dissemination of these modeling tools – most notably WUFI - less-experienced or less-informed practitioners have run models that provide unrealistic results—typically overly conservative. In some cases, these results clearly contradict extensive field experience and known history of assemblies, showing failure when they do not occur in reality. In other more worrisome cases, models run on assemblies that clearly have not performed historically show successful performance. This has resulted in confusion in the building industry—specifically, problems with advancing knowledge of moisture-safe building enclosure/shell assemblies. Development of moisture-safe enclosure assemblies is a component that will contribute to the Building America target of reducing residential carbon emissions 20% by 2020 and 80% by 2050.

NREL and the Standing Technical Committee on Enclosures presented top priorities for research in their document, "Building America Technical Innovations Leading to 50% Savings – A Critical Path" (NREL 2013). Critical Milestone E4, under Enclosures states:

> *Develop guidance on design methods for enclosure design with a focus on above-grade walls; guidance to be provided for both new construction and retrofits in all U.S. climate zones.*

The Technical Report addresses this priority by modeling typical wall assemblies that have performed well historically, and demonstrating that these models agree with historic experience when modeled correctly. A library of input data and results are provided.

1.2 Background

Hygrothermal analysis is a relatively new field. The fundamentals date back to the 1950s. Analysis was observation and experience based. The major focus was rain and groundwater control. As insulation was introduced into assemblies, energy flows were altered, resulting in materials remaining wetter for longer periods of time. Simultaneously, new building materials were introduced that were inherently more water sensitive. The focus shifted from rain and groundwater to vapor movement in the form of air transport and molecular diffusion. Calculation methods of predicting performance and assessing risk were primitive and typically fundamentally flawed. Analysis remained rooted in observation and experience–i.e., a "build it, wet it, watch what happens" methodology.

In the 1980s with the advent of numerical analysis and computer availability, it was believed that a shift from observation and experience to numerical methods based on physics was possible. Numerous models were developed but none with reasonable predictive capability. In the 1990s this changed based on work done in Canada (Kumaran, M., Mitalas, G. and Bomberg, M.; 1994) and Sweden (Viitanen, H., and A. Ritschkoff; 1991). These models were principally research tools rather than design tools. Work done in Germany in 2000 changed the modeling status quo (Künzel, H.; 2002). However, such design models were limited to mass assemblies typical to Europe. North American assemblies are hollow, multi layered, and dominated by three dimensional air flow networks that have proven problematic to modeling efforts.

The dominant European model has proven to be attractive to North American practitioners. WUFI is popular despite its inability to provide reasonable predictive outcomes unless used by an experienced sophisticated user who already "knows" the correct outcome. In fact, despite the sophistication of the numerical analysis, available research is still dominated by experiment. We still must "build it, wet it and watch it." Then, the observed outcomes are used to "tune" available models. The field remains phenomenologically based, as there is yet no widely accepted theory of combined heat and moisture flow.

1.3 Relevance to Building America's Goals

Given the Building America goals of reducing home energy use by 30%-50% (compared to 2009 energy codes for new homes and pre-retrofit energy use for existing homes), this research is an effort to reduce the first cost of wall assemblies. Many low-cost high-performance wall assemblies are not being used due to inappropriate failure criteria (*ASHRAE Standard 160*; ASHRAE 2009) linked with inappropriate hygrothermal modeling.

This work also falls under the category of "2.0 Risk Reduction and Minimization," from the document FY 2014 Residential Energy System Research Needs (NREL 2013).

1.4 Cost-Effectiveness

The goal of this research is to encourage the use of lower cost moisture safe assemblies that are known to work based on field experience and first principles, which are currently being avoided due to inappropriate failure criteria caused by inappropriate hygrothermal modeling.

1.5 Tradeoffs and Other Benefits

Higher cost moisture safe assemblies will be replaced with lower cost moisture safe assemblies. As the modeling becomes more predictive, a reduction in the reliance on field experimentation is likely to occur, reducing the time between innovation and deployment.

2 Simulation Background and Approach

2.1 Model Calibration, Failure Criteria, and Wall Selection

Existing literature and engineering judgment based on experience provided the necessary information to calibrate the WUFI software models (*ASHRAE Handbook of Fundamentals*, ASHRAE 2013; Shi, X., Schumacher, C., Burnett, E., 2004; Straube, J.F., Burnett, E., VanStraaten, R., Schumacher, C., 2004; Straube, J.; J. Smegal, 2009). Similarly, existing literature and engineering judgment based on experience was used to analyze and report on the failure thresholds and criteria for above grade walls (Hutcheon & Handegord, 1983; Kumaran, M., Mitalas, G. and Bomberg, M. 1994; Straube, J. and Burnett, E.; 2005; Timusk, C., 2005; Viitanen, H., and A. Ritschkoff, 1991).

The (a) calibration of the software models and (b) analysis of the failure thresholds/criteria was accomplished by first understanding above-grade walls with historically successful performance (Karagiozis, 2004; Künzel, H. 2002; Ojanen, T., Kohonen, R. and Kumaran, M., 1994). Walls with historically successful performance were identified by the participants of a Building America Expert Meeting (Ueno and Lstiburek 2014) and by Building Science Corporation dialog with the home building industry and code authorities.

A round of WUFI files was generated based on these identified common wall assemblies. The behavior of these assemblies was examined, to determine appropriate failure criteria based on this historic record. The intent was to counter much of the common, existing modeling that shows that walls known to perform well (historically) do not meet various failure criteria (*ASHRAE Standard 160*, ASHRAE, 2009). Each of these wall assemblies is accompanied by a short case study, that explains the history of the wall, how it works (hygrothermally), the function of each component (air barrier vs. vapor retarder vs. water control), and the thought process behind the design.

All simulations were run using WUFI (Wärme und Feuchte instationär) 1-D software, version 5.3. Simulations were run for a period of three years, in order to reduce the effect of initial conditions (moisture stored in building materials), and to show longer-term trends of moisture accumulation or drying.

2.2 Simulated Wall Assemblies

Three rounds of simulation work were conducted (Round One, Two and Three); each successive round of simulations was used to “tune” successive rounds. Wall assembly variables included standard framing (2x4) vs. advanced framing (2x6) (i.e., R-13 vs. R-19 insulation), plywood sheathing vs. OSB sheathing, vapor retarders (Class II) vs. vapor barriers (Class I), and unvented and drained claddings vs. vented and drained claddings.

The three Rounds change the “base wall” (cavity insulation level and interior vapor control):

- Round One is based on a 2x4 (R-13 fiberglass batt insulation) wall, with interior vapor control provided by an interior Kraft facer on the fiberglass batt insulation.
- Round Two substitutes 2x6 framing (R-19 fiberglass batt insulation) for the 2x4 framing of Round One.

- Round Three changes Round Two by replacing the Kraft facer with 6 mil polyethylene.

Within each round, a series of changes are made to the cladding types and exterior structural sheathing, for six wall combinations per round, as discussed below:

- Wall 1 (Wood Siding-Ply): latex-painted wood siding, over plywood sheathing
- Wall 2 (Vinyl Siding-Ply): changes Wall 1 by substituting vinyl siding for wood siding; highlighted in red in Table 1, Table 2, and Table 3.
- Wall 3 (Vinyl-OSB): changes Wall 2 by substituting OSB sheathing for plywood; highlighted in green in Table 1, Table 2, and Table 3.
- Wall 4 (Brick-OSB): changes Wall 3 by replacing vinyl siding with a drained and ventilated brick cladding; highlighted in blue in Table 1, Table 2, and Table 3.
- Wall 5 (Stucco-OSB): changes Wall 4 by replacing brick with hard-coat stucco, applied over two layers of #15 felt; highlighted in blue in Table 1, Table 2, and Table 3.
- Wall 6 (Vented Stucco-OSB): changes Wall 5 by replacing stucco with stucco applied over a spacer or "breather" mesh between two layers of #15 felt; highlighted in blue in Table 1, Table 2, and Table 3. The reasoning behind this spacer mesh in promoting ventilation drying is discussed by Lstiburek (2008).

All walls use #15 asphalt saturated kraft paper (building paper) as a water control layer/drainage plane, fiberglass stud bay insulation, and interior gypsum board with latex paint.

All simulations were performed in six climate zones (see 2.3 Climate Locations), resulting in 36 simulations (6 walls × 6 climates) per Round.

The full listing of the wall assembly components are shown in Table 1 (Round One), Table 2 (Round Two) and Table 3 (Round Three).

Table 1: Round One (2x4 Framing, R-13 Fiberglass) wall assemblies

	Wall 1 (Wood Siding-Ply)	Wall 2 (Vinyl Siding-Ply)	Wall 3 (Vinyl-OSB)	Wall 4 (Brick-OSB)	Wall 5 (Stucco-OSB)	Wall 6 (Vented Stucco-OSB)
Cladding	latex painted wood siding	vinyl siding	vinyl siding	brick veneer	stucco	stucco #15 asphalt paper polypropylene drainage mat (½ in)
Water Control Layer	#15 asphalt paper	#15 asphalt paper	#15 asphalt paper	#15 asphalt paper	#15 asphalt paper (2 layers)	#15 asphalt paper
Structural Sheathing	plywood sheathing	plywood sheathing	OSB sheathing	OSB sheathing	OSB sheathing	OSB sheathing
Framing	2x4 framing	2x4 framing	2x4 framing	2x4 framing	2x4 framing	2x4 framing
Cavity Insulation	R-13 fiberglass batt	R-13 fiberglass batt	R-13 fiberglass batt	R-13 fiberglass batt	R-13 fiberglass batt	R-13 fiberglass batt
Vapor Control	Kraft facer on fiberglass batt	Kraft facer on fiberglass batt	Kraft facer on fiberglass batt	Kraft facer on fiberglass batt	Kraft facer on fiberglass batt	Kraft facer on fiberglass batt
Interior Finish	gypsum wall board	gypsum wall board	gypsum wall board	gypsum wall board	gypsum wall board	gypsum wall board
Interior Finish	latex paint	latex paint	latex paint	latex paint	latex paint	latex paint

Table 2: Round Two (2x6 Framing, R-19 Fiberglass) wall assemblies

	Wall 1 (Wood Siding-Ply)	Wall 2 (Vinyl Siding-Ply)	Wall 3 (Vinyl-OSB)	Wall 4 (Brick-OSB)	Wall 5 (Stucco-OSB)	Wall 6 (Vented Stucco-OSB)
Cladding	latex painted wood siding	vinyl siding	vinyl siding	brick veneer	stucco	stucco #15 asphalt paper polypropylene drainage mat (½ in)
Water Control Layer	#15 asphalt paper	#15 asphalt paper	#15 asphalt paper	#15 asphalt paper	#15 asphalt paper (2 layers)	#15 asphalt paper
Structural Sheathing	plywood sheathing	plywood sheathing	OSB sheathing	OSB sheathing	OSB sheathing	OSB sheathing
Framing	2x6 framing	2x6 framing	2x6 framing	2x6 framing	2x6 framing	2x6 framing
Cavity Insulation	R-19 fiberglass batt	R-19 fiberglass batt	R-19 fiberglass batt	R-19 fiberglass batt	R-19 fiberglass batt	R-19 fiberglass batt
Vapor Control	Kraft facer on fiberglass batt	Kraft facer on fiberglass batt	Kraft facer on fiberglass batt	Kraft facer on fiberglass batt	Kraft facer on fiberglass batt	Kraft facer on fiberglass batt
Interior Finish	gypsum wall board	gypsum wall board	gypsum wall board	gypsum wall board	gypsum wall board	gypsum wall board
Interior Finish	latex paint	latex paint	latex paint	latex paint	latex paint	latex paint

Table 3: Round Three (2x6 Framing, R-19 Fiberglass, Kraft Facing→Polyethylene) wall assemblies

	Wall 1 (Wood Siding-Ply)	Wall 2 (Vinyl Siding-Ply)	Wall 3 (Vinyl-OSB)	Wall 4 (Brick-OSB)	Wall 5 (Stucco-OSB)	Wall 6 (Vented Stucco-OSB)
Cladding	latex painted wood siding	vinyl siding	vinyl siding	brick veneer	stucco	stucco #15 asphalt paper polypropylene drainage mat (½ in)
Water Control Layer	#15 asphalt paper	#15 asphalt paper	#15 asphalt paper	#15 asphalt paper	#15 asphalt paper (2 layers)	#15 asphalt paper
Structural Sheathing	plywood sheathing	plywood sheathing	OSB sheathing	OSB sheathing	OSB sheathing	OSB sheathing
Framing	2x6 framing	2x6 framing	2x6 framing	2x6 framing	2x6 framing	2x6 framing
Cavity Insulation	R-19 fiberglass batt	R-19 fiberglass batt	R-19 fiberglass batt	R-19 fiberglass batt	R-19 fiberglass batt	R-19 fiberglass batt
Vapor Control	Polyethylene	Polyethylene	Polyethylene	Polyethylene	Polyethylene	Polyethylene
Interior Finish	gypsum wall board	gypsum wall board	gypsum wall board	gypsum wall board	gypsum wall board	gypsum wall board
Interior Finish	latex paint	latex paint	latex paint	latex paint	latex paint	latex paint

2.3 Climate Locations

All of the wall assemblies were simulated in the climate locations shown in Table 4 and Figure 1, to understand the climate sensitivity of these assemblies.

WUFI database weather files were used for each climate, selecting the cold year data, which is the worst case for interior-sourced interstitial condensation.

Table 4: Simulation geographic locations with climate zones

City, State	IECC Climate Zone	Climate Description
Minneapolis, MN	6A	Very Cold
Chicago, IL	5A	Cold
Kansas City, MO	4A	Mixed-Humid
Seattle, WA	4C	Marine
Atlanta, GA	3A	Mixed-Humid
Houston, TX	2A	Hot-Humid

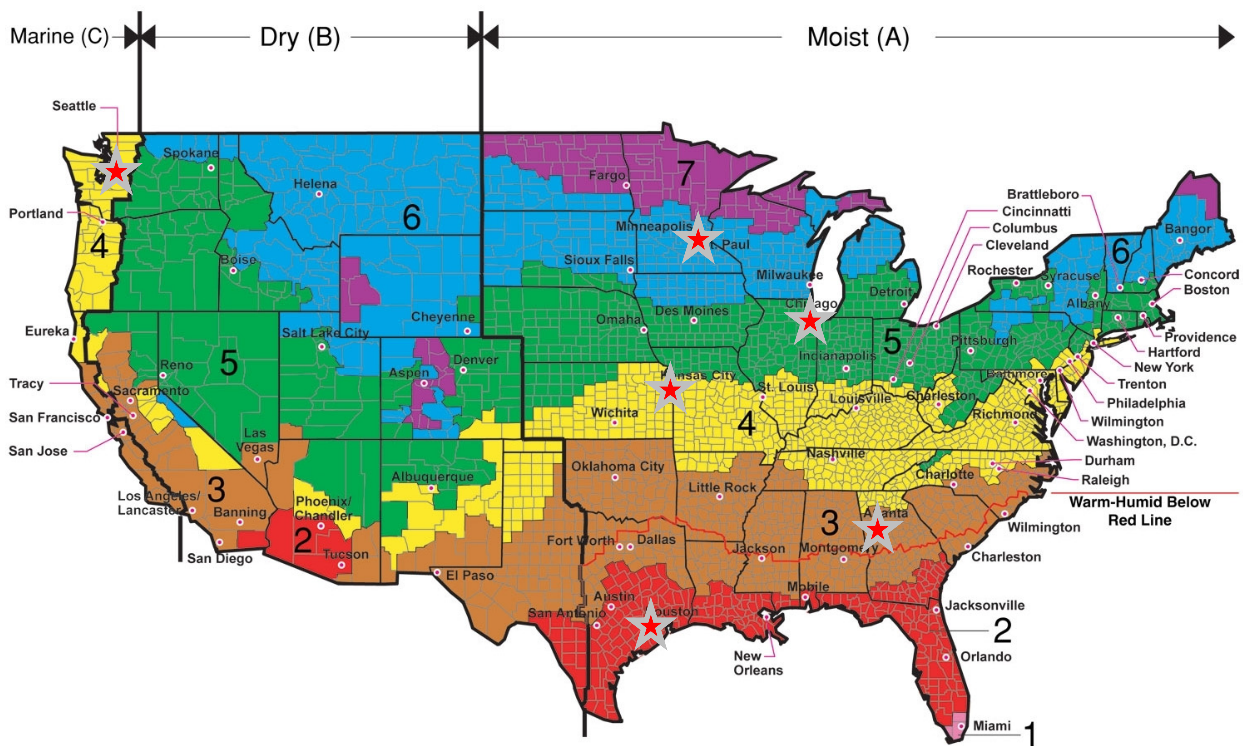

Figure 1: DOE climate zone map with simulated cities highlighted

2.4 Interior Boundary Conditions

Interior conditions have a significant effect on hygrothermal simulations, especially when air leakage from the interior is simulated (see 2.5 Drainage Cavity and Stud Bay Cavity Ventilation). Interior temperature was varied as a sine wave in all climates, set at 75°F ±2°F (73° to 77°F), with the peak in early August (Figure 2).

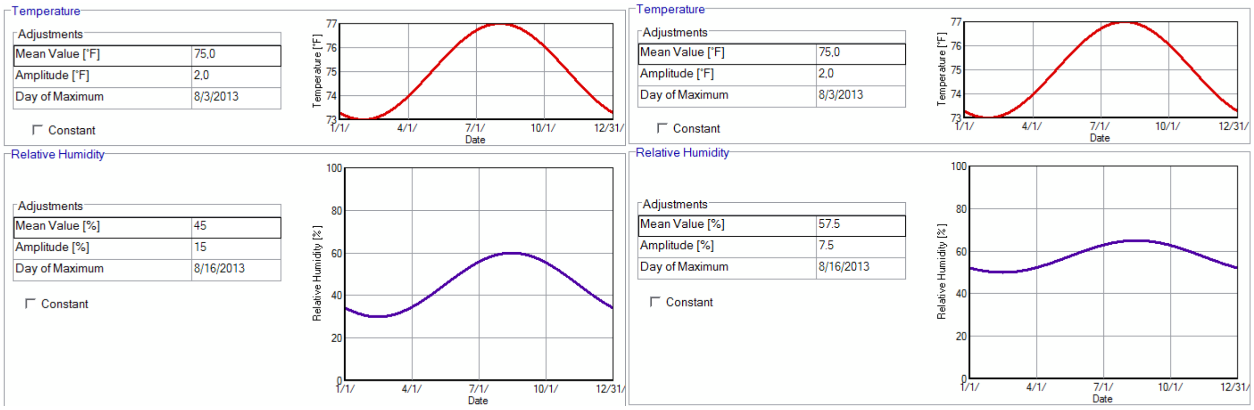

Figure 2: Interior temperature and RH boundary conditions for Chicago (left) and Seattle (right)

Interior RH levels were also set as a seasonal sine wave (Figure 2). However, interior climate conditions vary by climate region; mixed- and hot-humid climates have higher interior RHs than cold and very cold climates. The resulting sine wave minimum and maximum values are shown in Table 5; the RH maximum is set for mid-August.

Table 5: Simulation locations with climate zones and interior RH levels

City, State	CZ	Average RH	Minimum	Maximum
Minneapolis, MN	6A	45%	30%	60%
Chicago, IL	5A	45%	30%	60%
Kansas City, MO	4A	45%	30%	60%
Seattle, WA	4C	57%	50%	65%
Atlanta, GA	3A	55%	40%	70%
Houston, TX	2A	55%	40%	70%

2.5 Drainage Cavity and Stud Bay Cavity Ventilation

Most of the claddings are designed as drained and ventilated cavities, which allow outside airflow behind the cladding to provide drying of rain wetting of the cladding. This ventilation airflow also bypasses vapor-impermeable materials (such as vinyl siding), thus allowing outward drying of the backup wall.

This ventilation is represented in the WUFI simulation by using an air space (left-most "Air layer" in Figure 3), and providing air change with exterior air in this air space. Ventilation rates were selected based on Straube and Burnett (2005), and are presented in Table 6 ("Cladding Ventilation") as air changes per hour (ACH, in units of 1/h). Note that vinyl siding is very air leaky, resulting in the high (200) air change; ventilated brick cavities have a much lower (10) rate. The conventional stucco wall (no ventilation) has no cladding ventilation (which contributes to moisture issues associated with this cladding, per Lstiburek 2008). The vented stucco was modeled at 10 ACH.

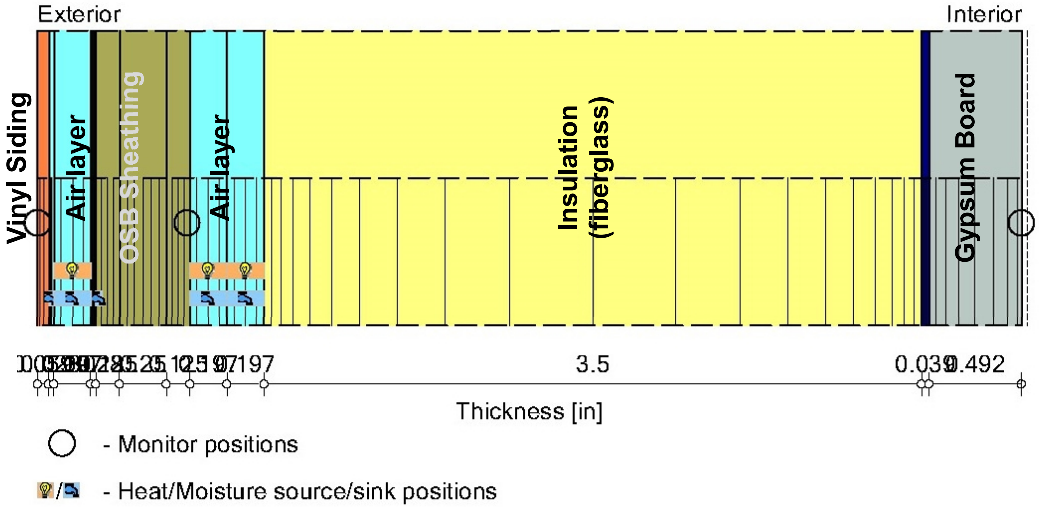

Figure 3: WUFI cross-section (Round 1 - Wall 3) showing ventilation air spaces

In addition, stud wall cavities are seldom built in a completely airtight manner. This leakage connects the stud bay cavity with both exterior and interior environments. To simulate the effect of this air leakage, small amounts of both exterior air and interior air (10 ACH respectively) were added in a layer inboard of the sheathing, as shown in Figure 3 and Table 6.

Table 6: Cladding and stud bay ventilation rates, in air changes per hour

	Cladding Ventilation (1/h)	Sheathing Ventilation (Exterior) (1/h)	Sheathing Ventilation (Interior) (1/h)
Wall 1 (Wood Siding-Ply)	20	10	10
Wall 2 Vinyl Siding-Ply)	200	10	10
Wall 3 (Vinyl-OSB)	200	10	10
Wall 4 (Brick-OSB)	10	10	10
Wall 5 (Stucco-OSB)	none	10	10
Wall 6 (Vented Stucco-OSB)	10	10	10

The ventilation rates are also provided in Appendix D: WUFI Source, Sinks.

2.6 Bulk Water Leakage

In all cases, bulk water was introduced within the assembly, to simulate the effect of rainwater exposure and penetration. First, in the exterior-side boundary conditions (Figure 4); 70% of the incident rain adheres to the vertical wall surface and 30% runs off.

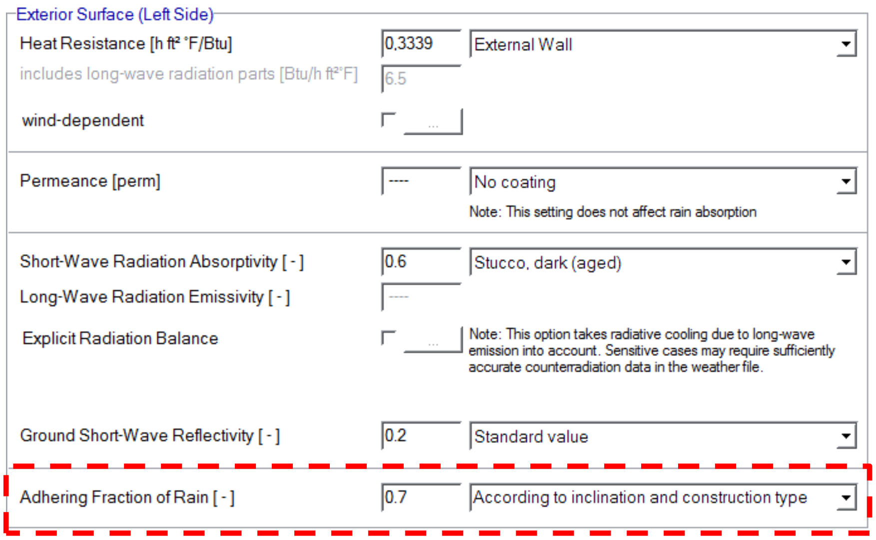

Figure 4: WUFI exterior surface boundary conditions, rain adhesion highlighted

This rainwater was introduced within the assembly using source terms in WUFI, placed as shown in Figure 5. A fraction of the adhering rainfall (1%) was introduced at the inner face of the exterior surface (cladding), per the green circle in Figure 5. This reflects the fact that all claddings leak some fraction of the incident water. In addition, a smaller fraction (0.01%) of the incident rainfall was introduced behind the water control layer (drainage plane), per the orange circle in Figure 5. This is intended to simulate water management failures that commonly occur in construction.

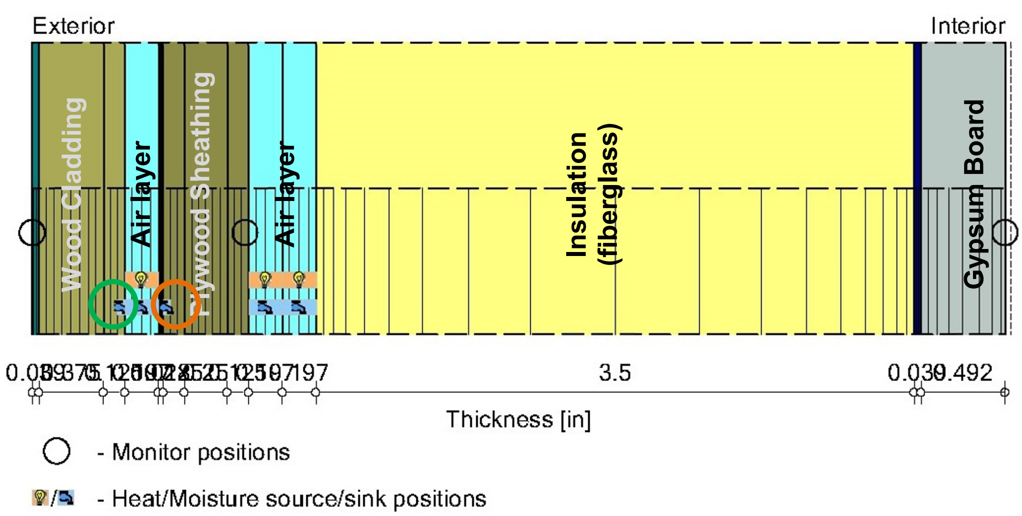

Figure 5: WUFI cross-section (Round 1 - Wall 1) showing moisture source/sink terms

More specifics on bulk water sources are provided in Appendix D: WUFI Source, Sinks.

2.7 Initial Moisture Conditions

In all cases, wood materials were assumed to meet building code required initial moisture contents. For example, all wood based materials used should be below 20% MC by weight.

3 Wall Simulation Results

This section presents the detailed descriptions of each of the six wall systems, with graphs of sheathing moisture content (MC), which is a common metric for evaluating failure. A common practice is to plot the MC of the entire sheathing layer; however, this value is simply the average MC of the sheathing thickness. In reality, sheathing failures are typically associated with high MCs on one face or another—for instance, the interior sheathing face for interior-sourced interstitial condensation, or the exterior face for rain leakage. Therefore, the sheathing was divided into three layers, and the MC of the innermost 1/8 in. (0.125 in.), as shown in red in Figure 6, is plotted.

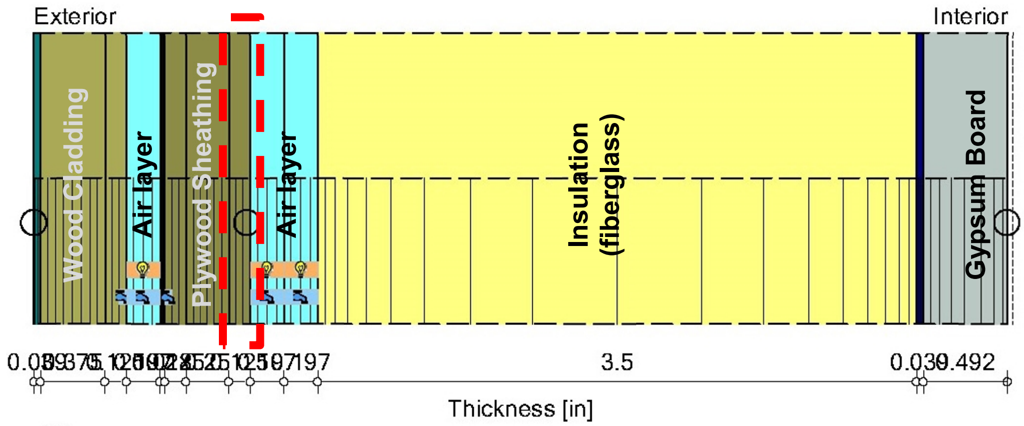

Figure 6: WUFI cross-section (Round 1 - Wall 1) showing sheathing MC interior layer

The original WUFI files will all be available for download for examination and further simulations.

It is important to note that interpreting the results of modeling has been problematic. As noted earlier, wall assemblies that have performed well historically in various climate zones "fail" when standardized moisture failure criteria such as that presented in ASHRAE Standard 160 are applied. As such, the primary performance criteria or failure criteria establishing historic performance is moisture content of the exterior sheathing - More specifically, historic reports of decay, based on observation of large numbers of wall assemblied ("buildings") over a decade or longer.

3.1 Round One (2x4 Framing, R-13 Fiberglass)

The first round of wall systems has 2x4 framing with R-13 fiberglass batt.

3.1.1 Wall 1 (Wood Siding-Ply)

Table 7 shows the layers in the first wall of the Round One (Figure 7) from exterior to interior and their respective functions.

Table 7: Round 1 – Wall 1 (Wood Siding-Ply) layers

Layer	Function
Latex painted wood siding	provides exterior finish for aesthetics
Asphalt saturated Kraft paper (building paper)	functions as air and water control layer

Plywood sheathing	provides structural support
2x4 framing	provides structural support
Kraft-faced R-13 fiberglass batt	functions as thermal and vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

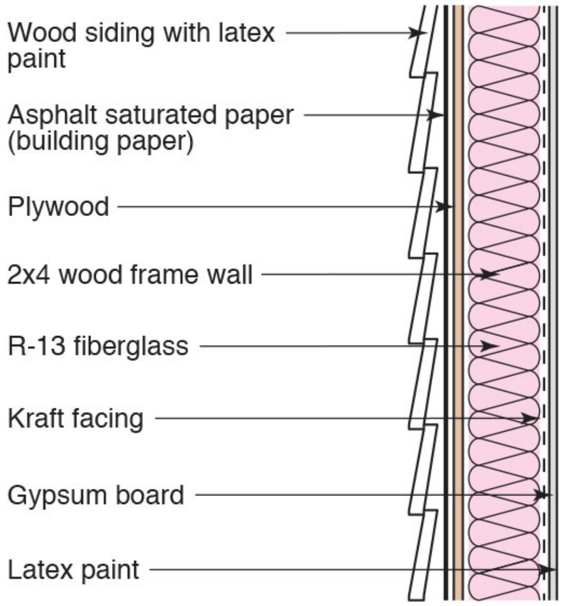

Figure 7: Round 1 - Wall 1 (Wood Siding-Ply) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate locations; Figure 8 to Figure 13 show the moisture content graphs of the interior side of the exterior wall sheathing, over a period of 3 years.

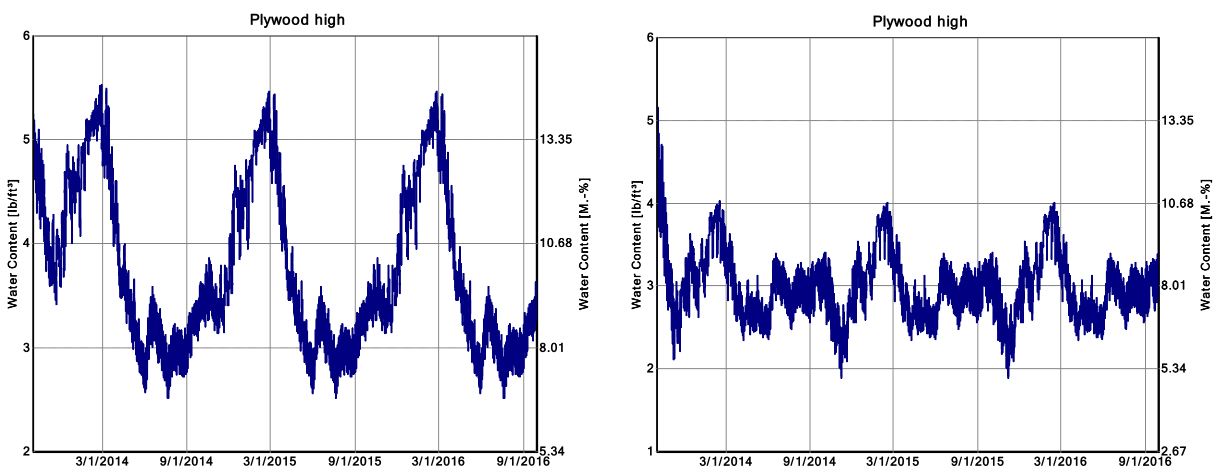

Figure 8: Round 1 - Wall 1 sheathing MC in Houston (Zone 2A), north (left) and south (right)

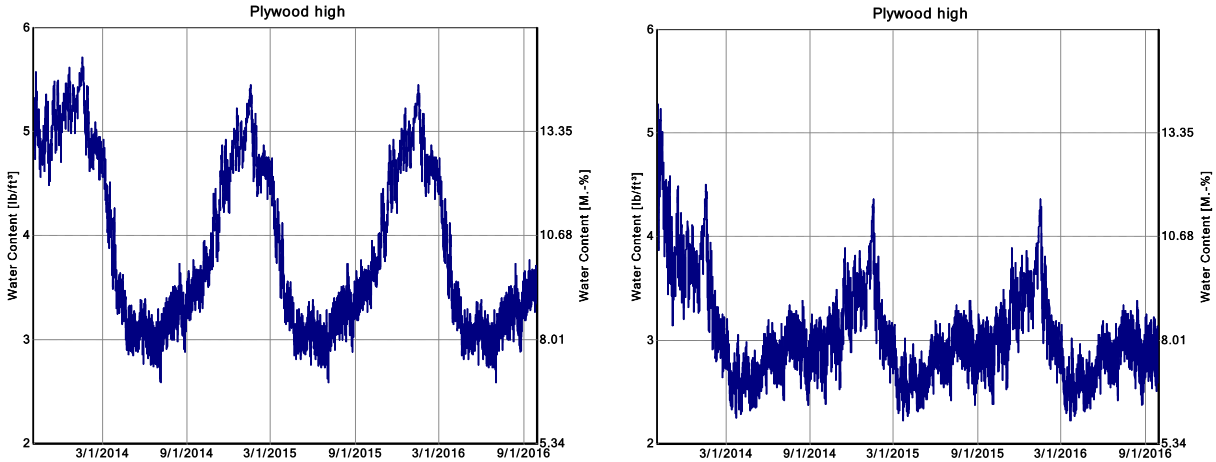

Figure 9: Round 1 - Wall 1 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

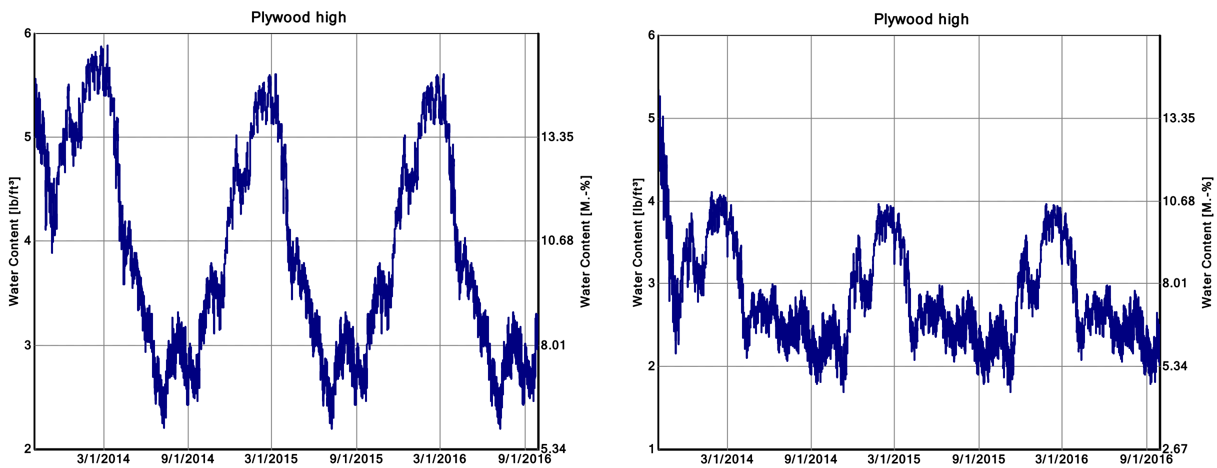

Figure 10: Round 1 - Wall 1 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

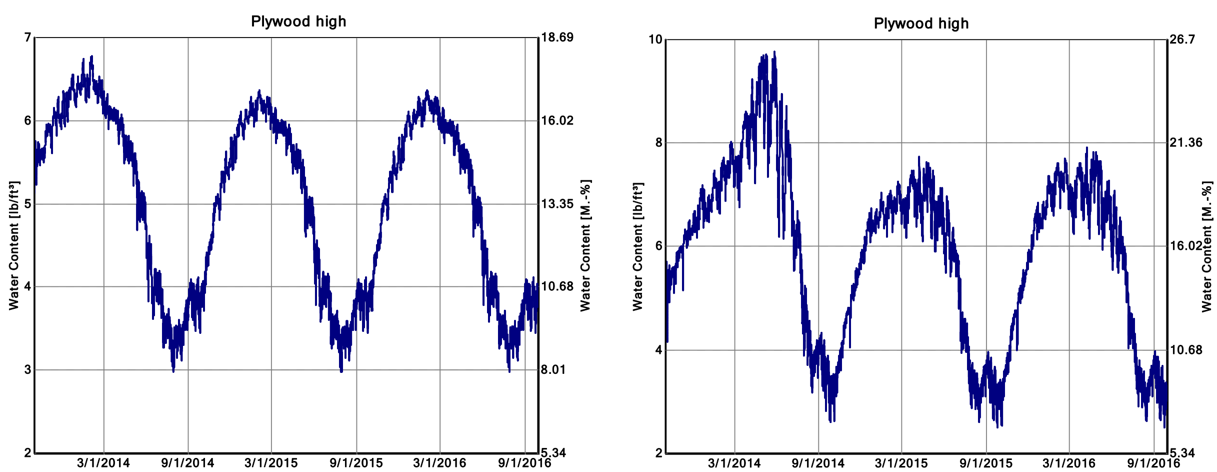

Figure 11: Round 1 - Wall 1 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

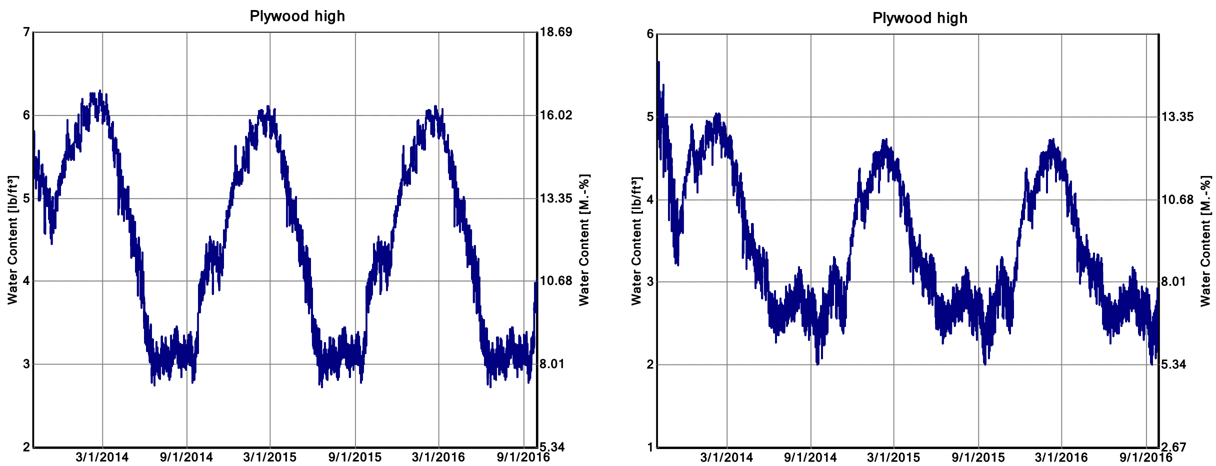

Figure 12: Round 1 - Wall 1 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

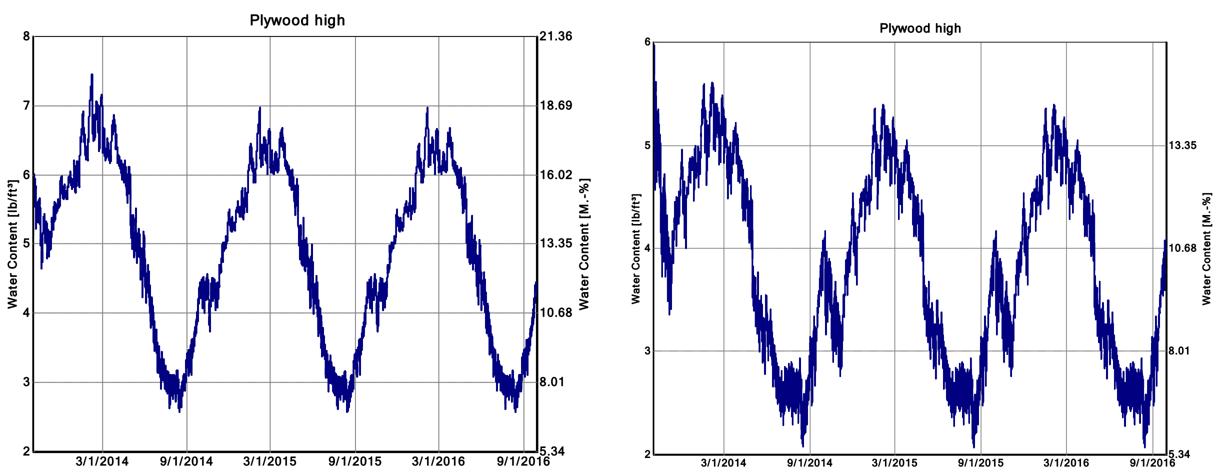

Figure 13: Round 1 - Wall 1 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.1.2 Wall 2 (Vinyl Siding-Ply)

Table 8 shows the layers in the second wall of the Round One (Figure 14) from exterior to interior and their respective functions.

Table 8: Round 1 – Wall 2 (Vinyl Siding-Ply) layers

Layer	Function
Vinyl siding	provides exterior finish for aesthetics
Asphalt saturated Kraft paper (building paper)	functions as air and water control layer
Plywood sheathing	provides structural support
2x4 framing	provides structural support
Kraft-faced R-13 fiberglass batt	functions as thermal and vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

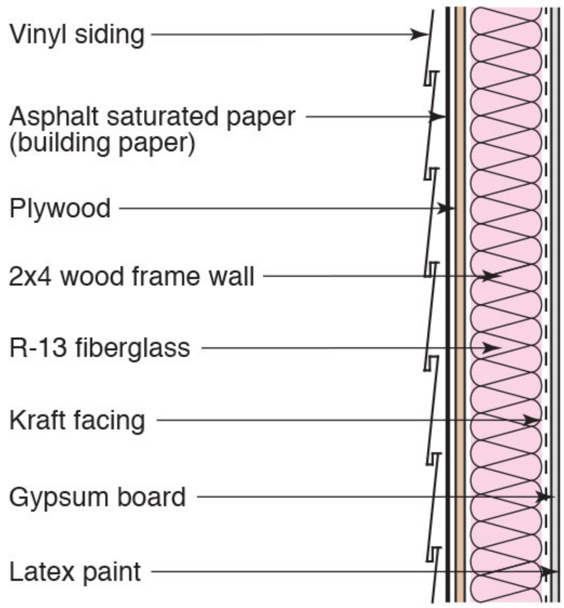

Figure 14: Round 1 - Wall 2 (Vinyl Siding-Ply) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate zones; Figure 15 to Figure 20 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

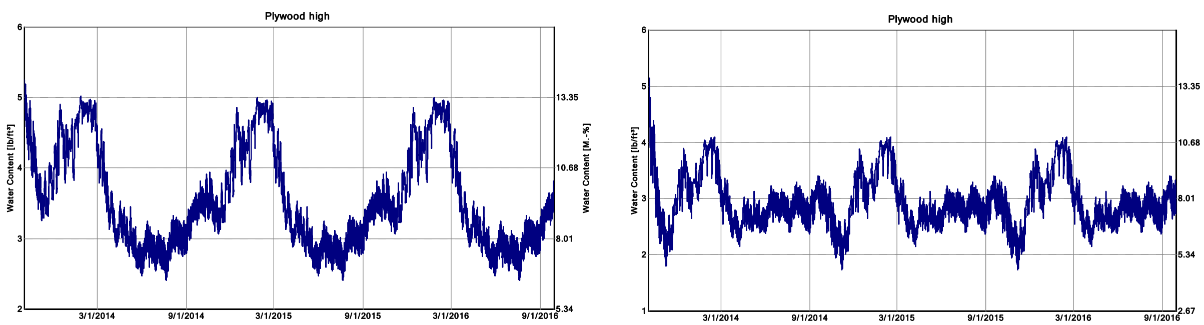

Figure 15: Round 1 - Wall 2 sheathing MC in Houston (Zone 2A), north (left) and south (right)

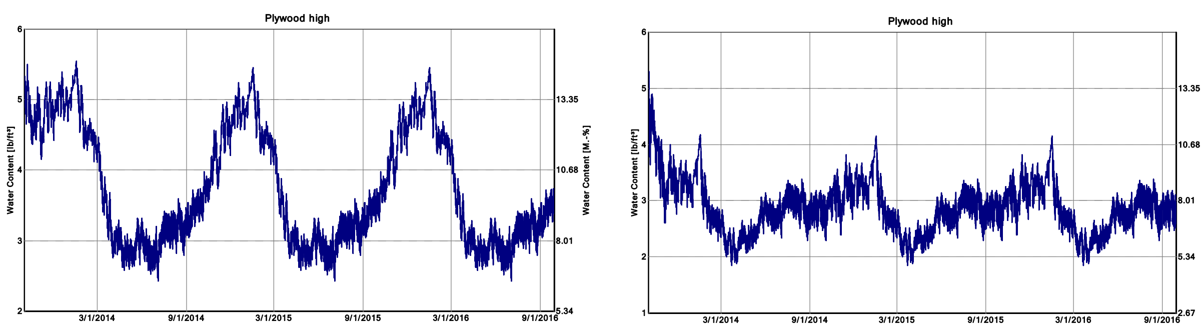

Figure 16: Round 1 - Wall 2 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

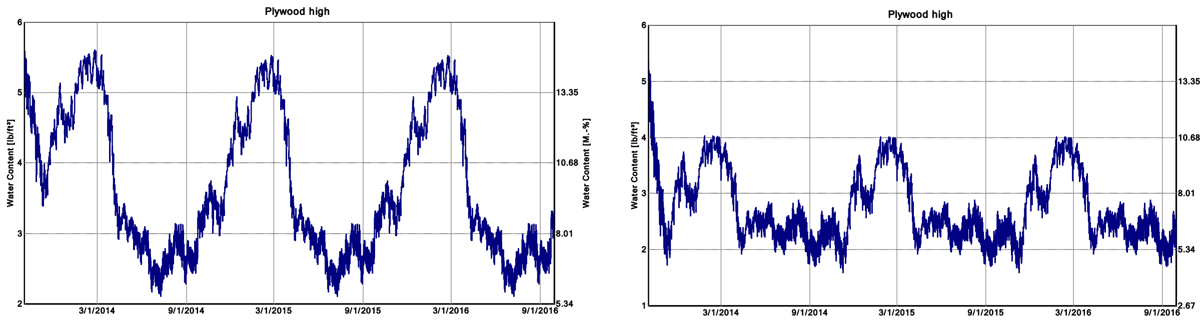

Figure 17: Round 1 - Wall 2 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

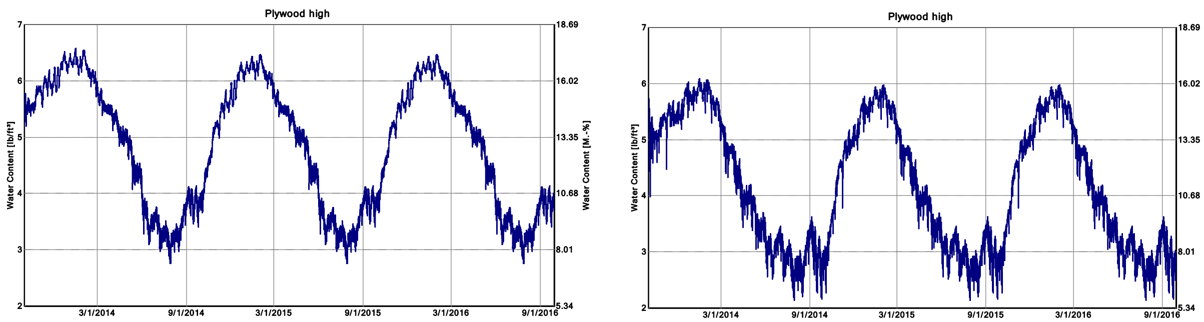

Figure 18: Round 1 - Wall 2 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

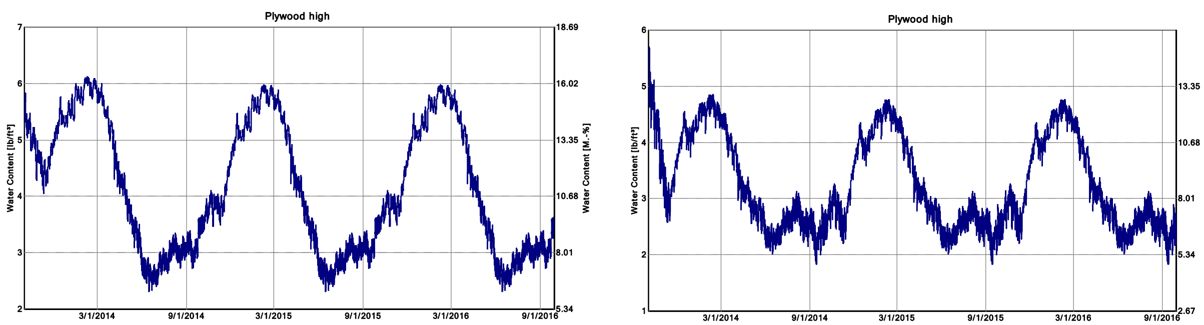

Figure 19: Round 1 - Wall 2 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

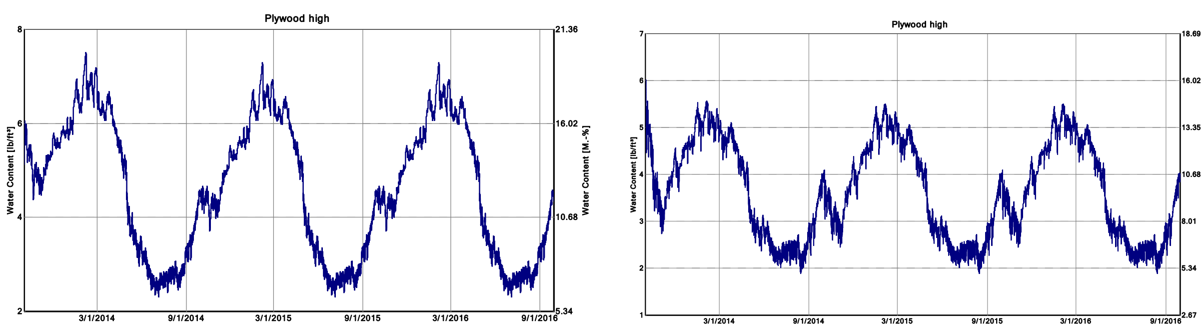

Figure 20: Round 1 - Wall 2 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.1.3 Wall 3 (Vinyl-OSB)

Table 9 shows the layers in the third wall of the Round One (Figure 21) from exterior to interior and their respective functions.

Table 9: Round 1 – Wall 3 (Vinyl-OSB) layers

Layer	Function
Vinyl siding	provides exterior finish for aesthetics
Asphalt saturated Kraft paper (building paper)	functions as air and water control layer
OSB sheathing	provides structural support
2x4 framing	provides structural support
Kraft-faced R-13 fiberglass batt	functions as thermal and vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

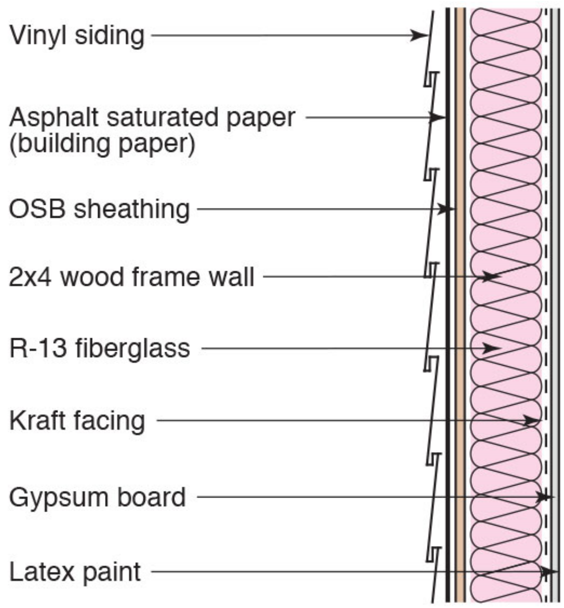

Figure 21: Round 1 - Wall 3 (Vinyl-OSB) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate zones; Figure 22 to Figure 27 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

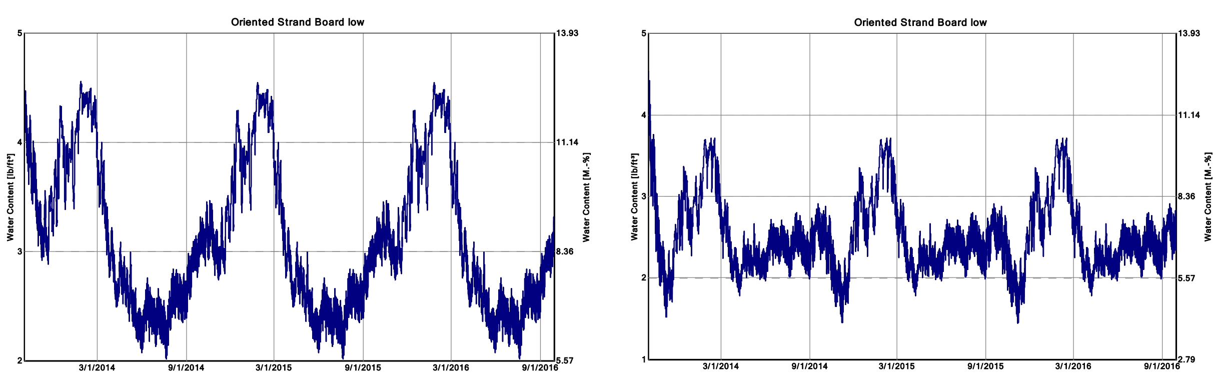

Figure 22: Round 1 - Wall 3 sheathing MC in Houston (Zone 2A), north (left) and south (right)

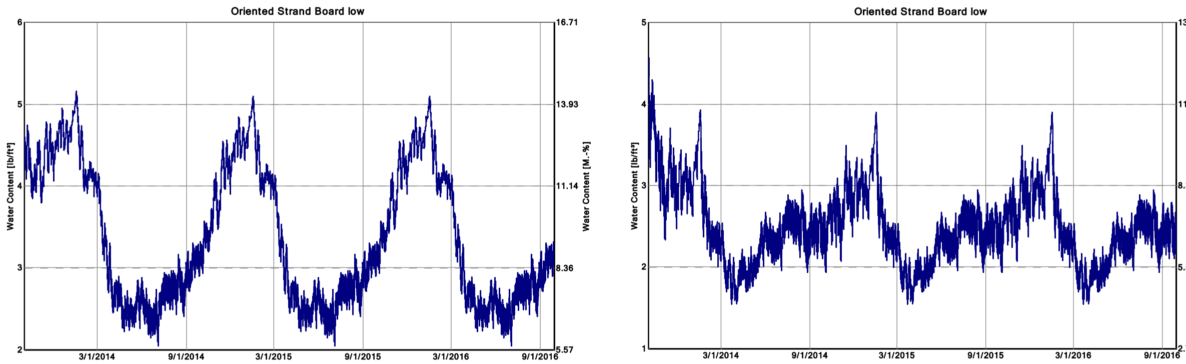

Figure 23: Round 1 - Wall 3 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

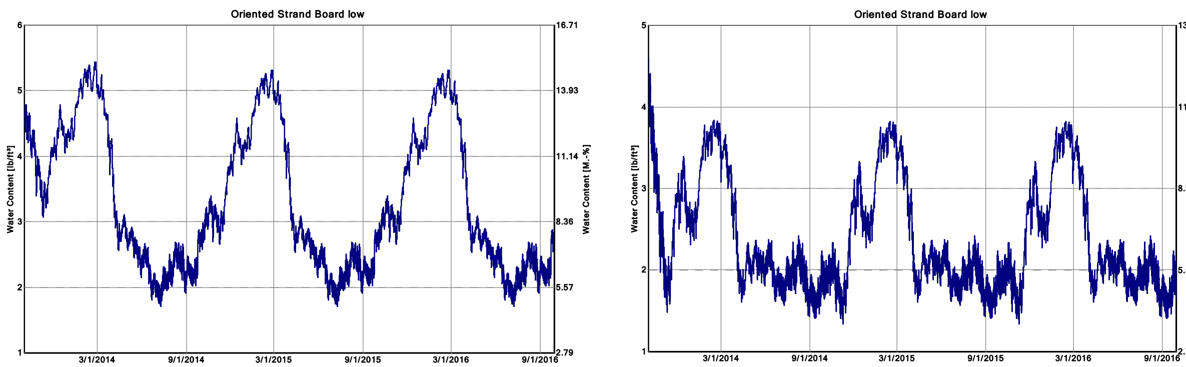

Figure 24: Round 1 - Wall 3 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

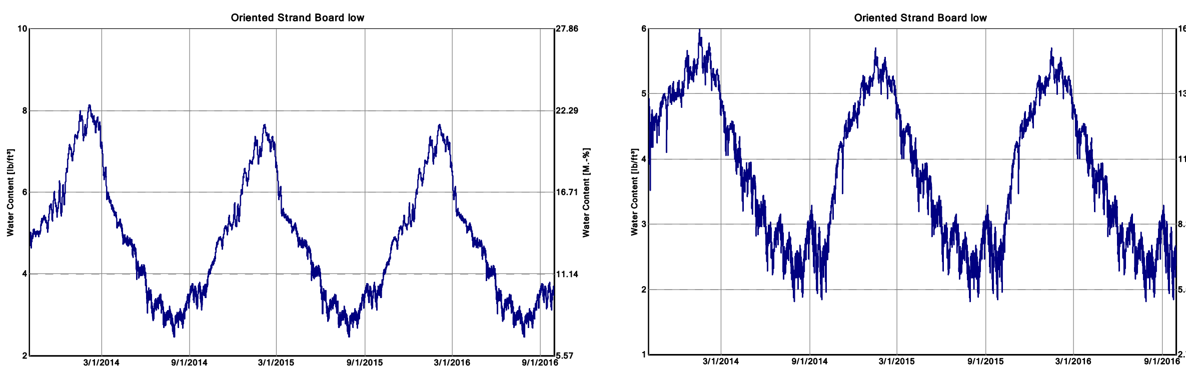

Figure 25: Round 1 - Wall 3 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

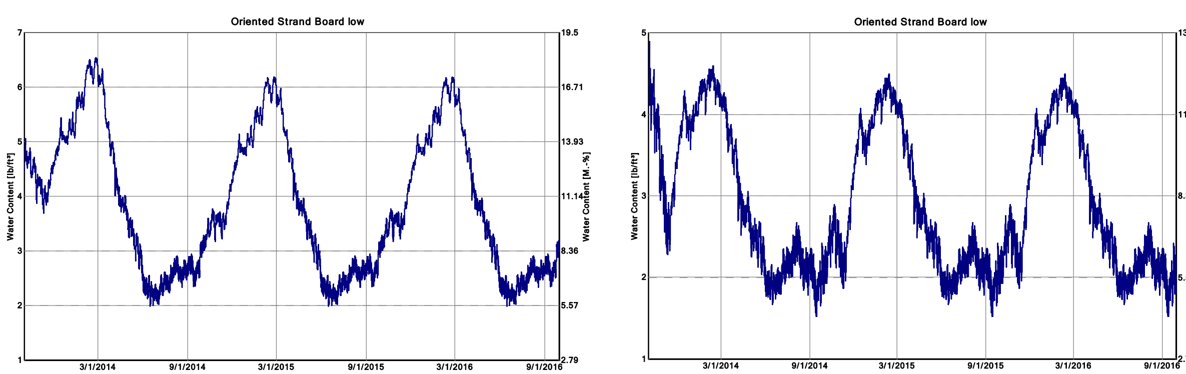

Figure 26: Round 1 - Wall 3 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

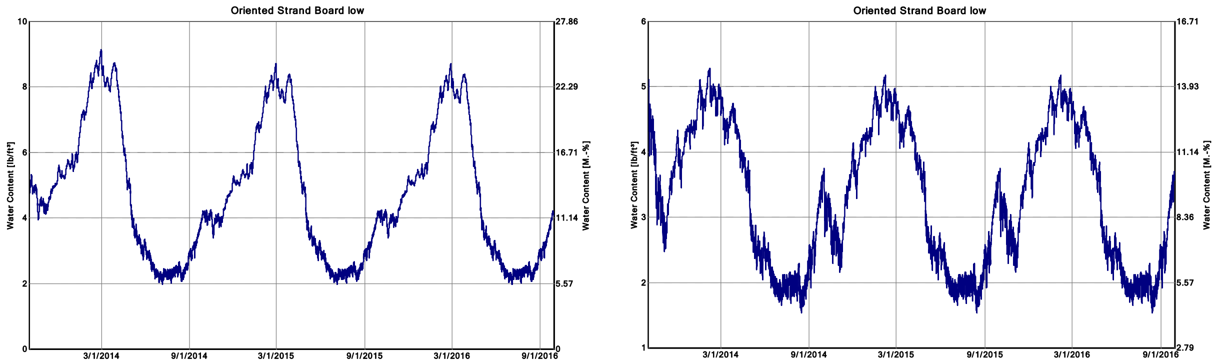

Figure 27: Round 1 - Wall 3 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.1.4 Wall 4 (Brick-OSB)

Table 10 shows the layers in the fourth wall of the Round One (Figure 28) from exterior to interior and their respective functions.

Table 10: Round 1 – Wall 4 (Brick-OSB) layers

Layer	Function
Brick veneer	provides exterior finish for aesthetics
Asphalt saturated Kraft paper (building paper)	functions as air and water control layer
OSB sheathing	provides structural support
2x4 framing	provides structural support
Kraft-faced R-13 fiberglass batt	functions as thermal and vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

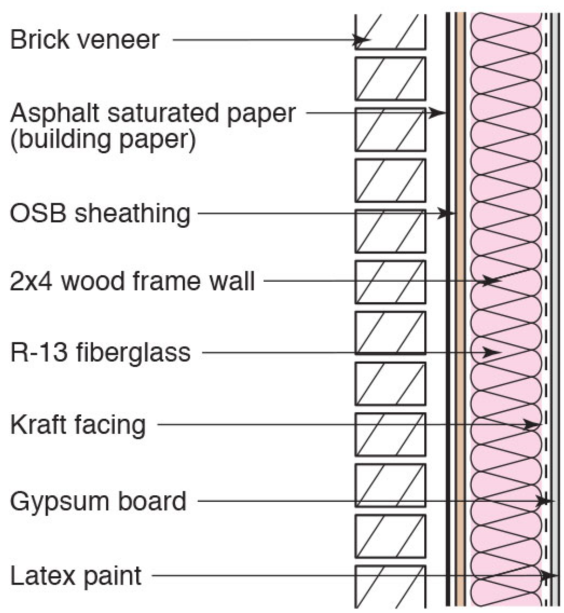

Figure 28: Round 1 - Wall 4 (Brick-OSB) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate zones; Figure 29 to Figure 34 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

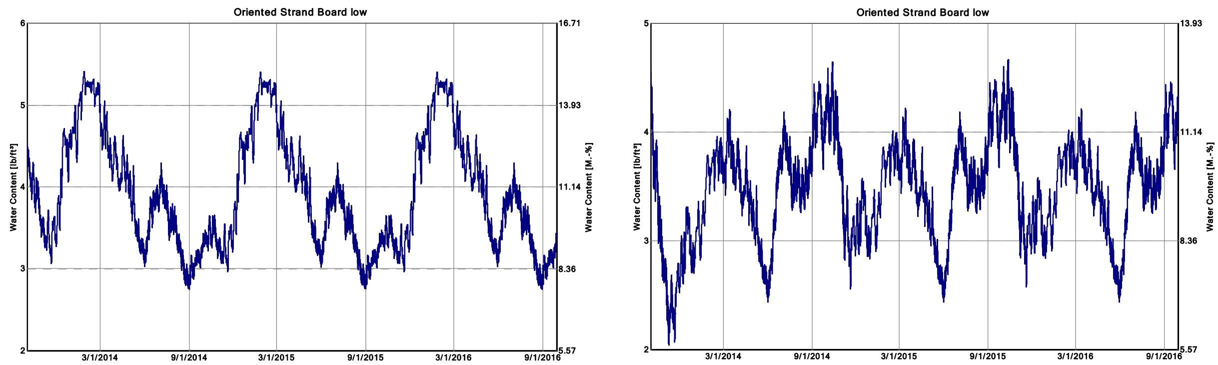

Figure 29: Round 1 - Wall 4 sheathing MC in Houston (Zone 2A), north (left) and south (right)

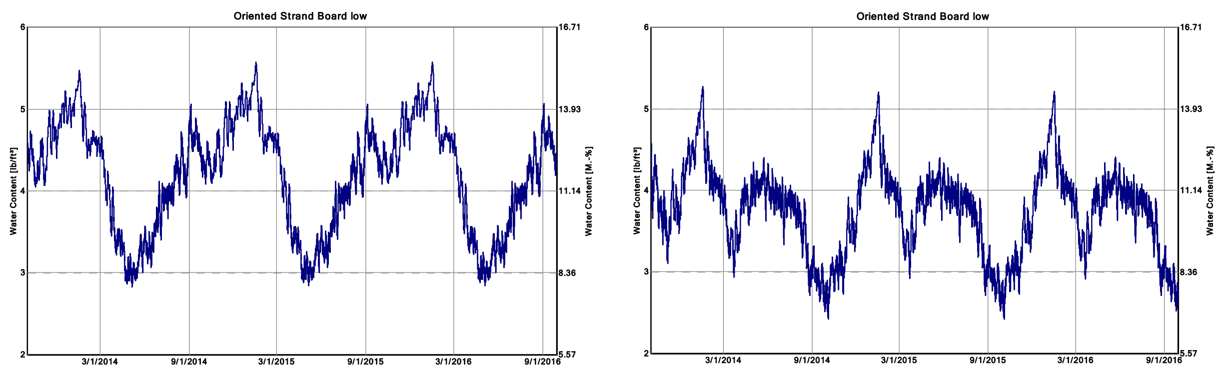

Figure 30: Round 1 - Wall 4 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

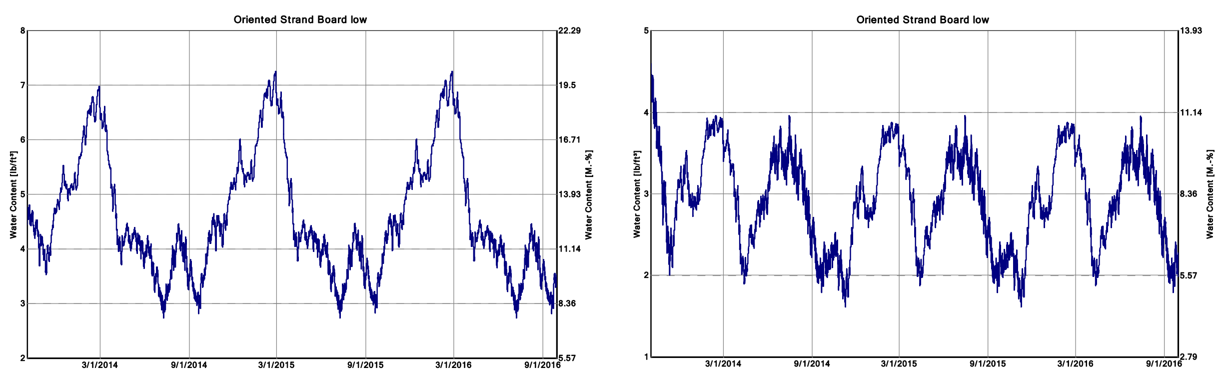

Figure 31: Round 1 - Wall 4 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

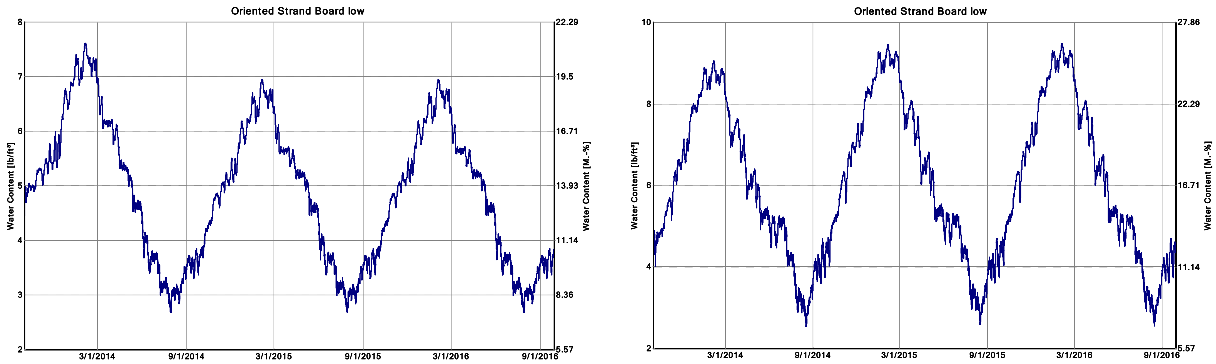

Figure 32: Round 1 - Wall 4 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

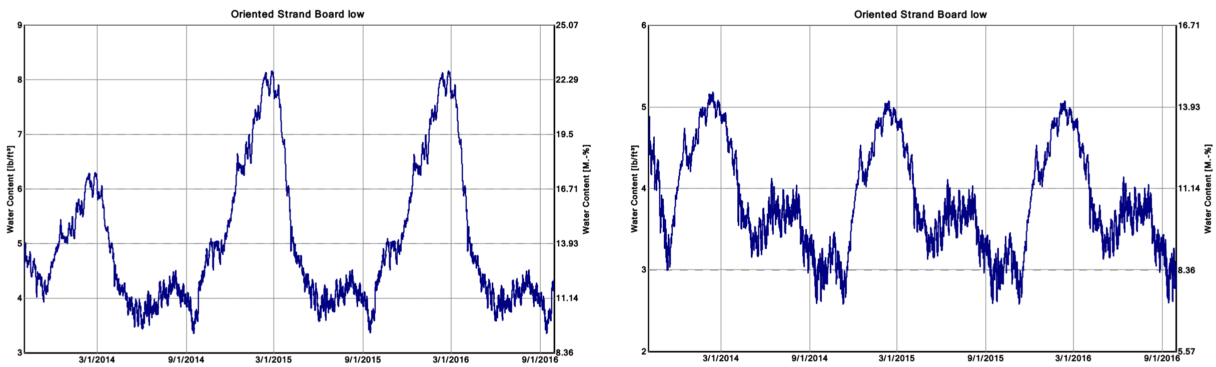

Figure 33: Round 1 - Wall 4 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

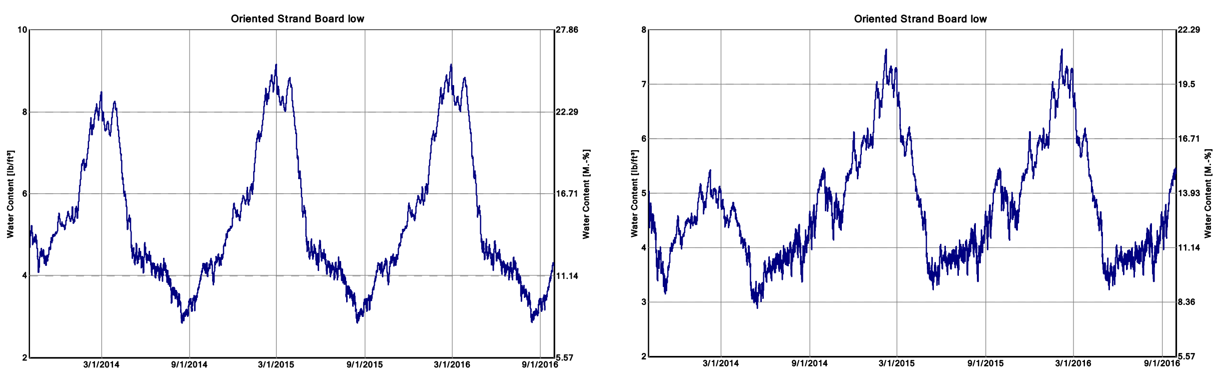

Figure 34: Round 1 - Wall 4 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.1.5 Wall 5 (Stucco-OSB)

Table 11 shows the layers in the fifth wall of the Round One (Figure 35) from exterior to interior and their respective functions.

Table 11: Round 1 – Wall 5 (Stucco-OSB) layers

Layer	Function
Stucco	provides exterior finish for aesthetics
2 layers asphalt saturated Kraft paper (building paper)	functions as air and water control layer
OSB sheathing	provides structural support
2x4 framing	provides structural support
Kraft-faced R-13 fiberglass batt	functions as thermal and vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

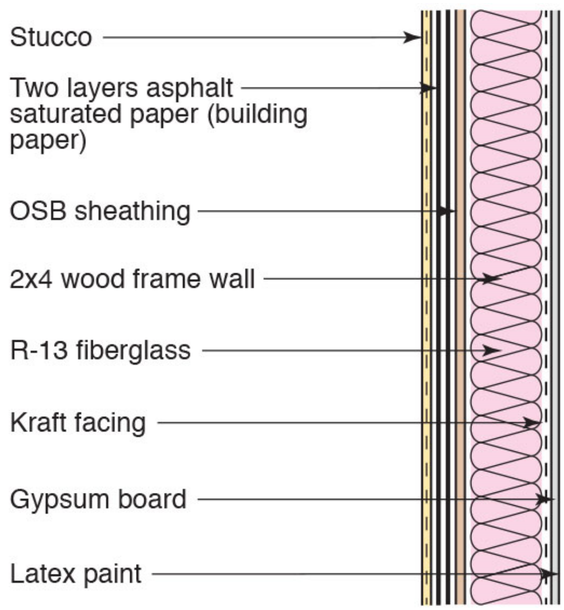

Figure 35: Round 1 - Wall 5 (Stucco-OSB) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate zones; Figure 36 to Figure 41show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

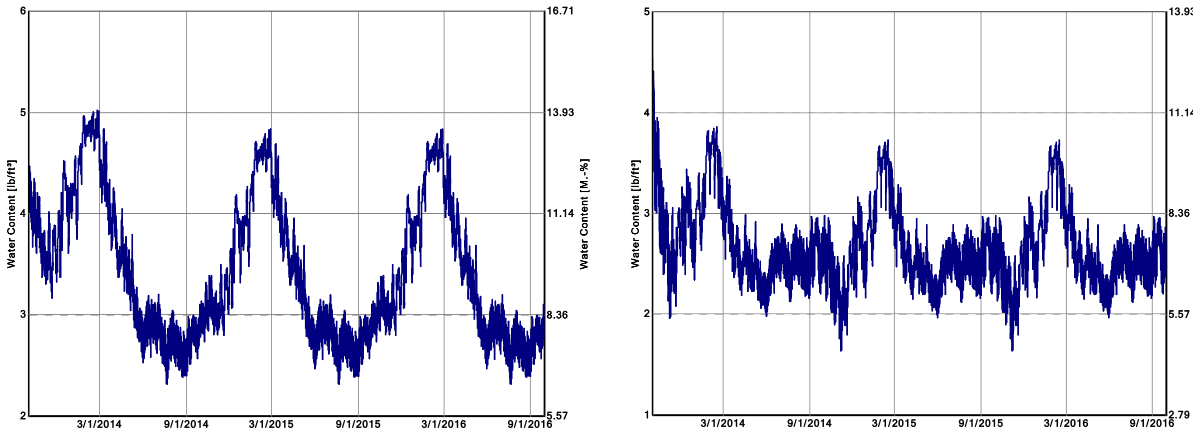

Figure 36: Round 1 - Wall 5 sheathing MC in Houston (Zone 2A), north (left) and south (right)

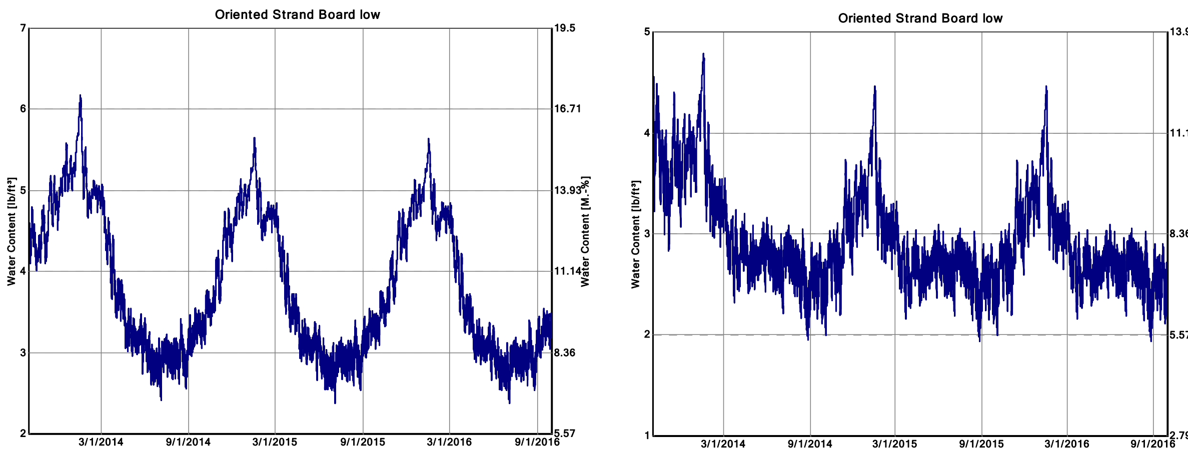

Figure 37: Round 1 - Wall 5 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

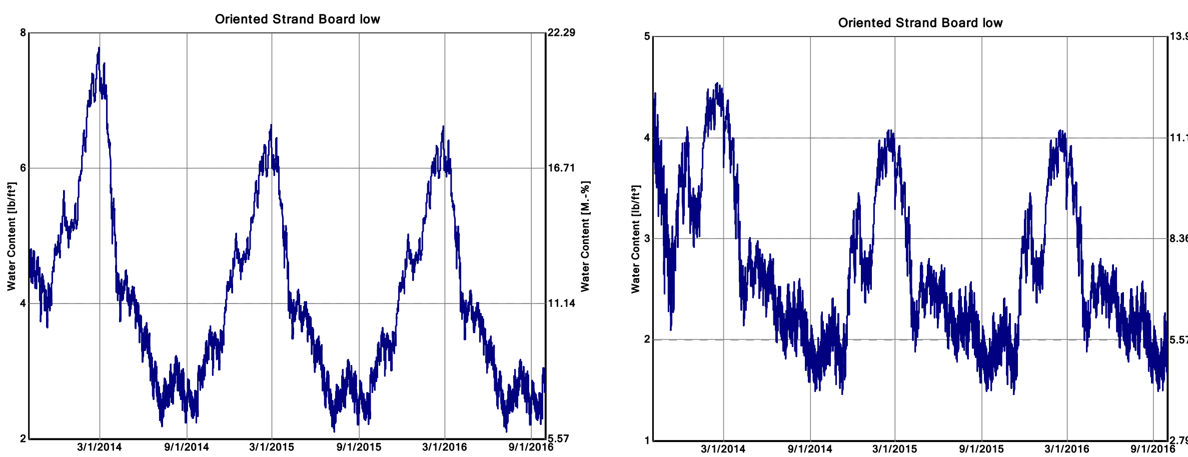

Figure 38: Round 1 - Wall 5 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

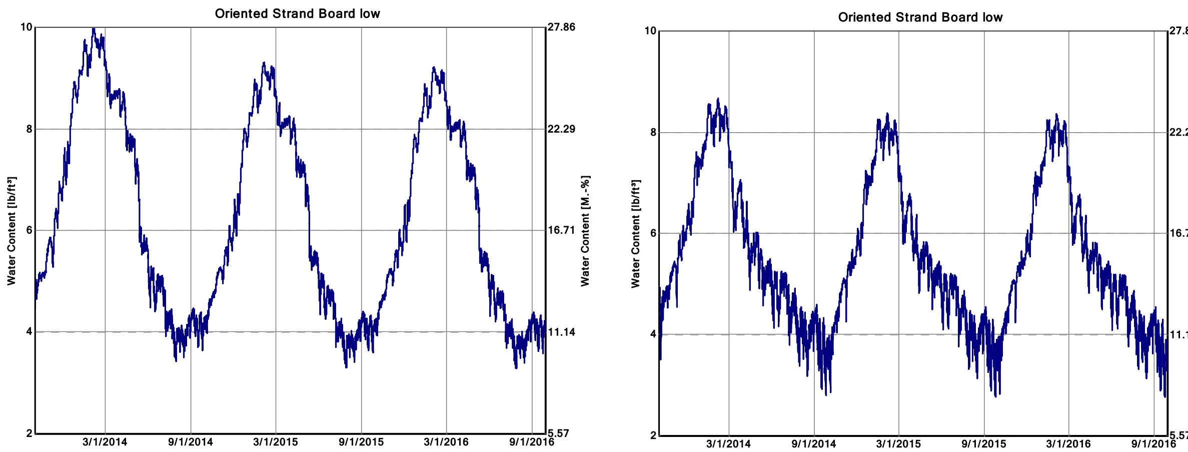

Figure 39: Round 1 - Wall 5 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

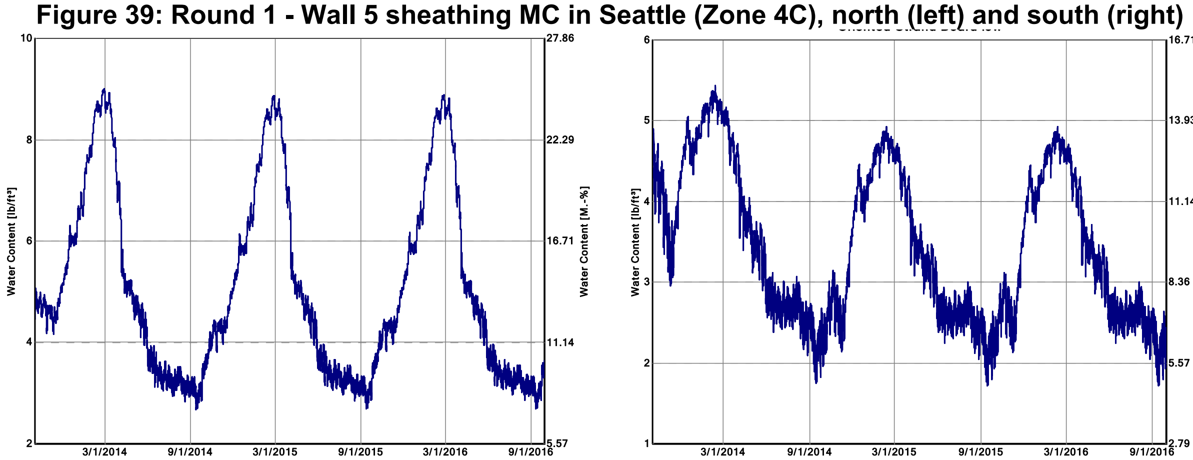

Figure 40: Round 1 - Wall 5 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

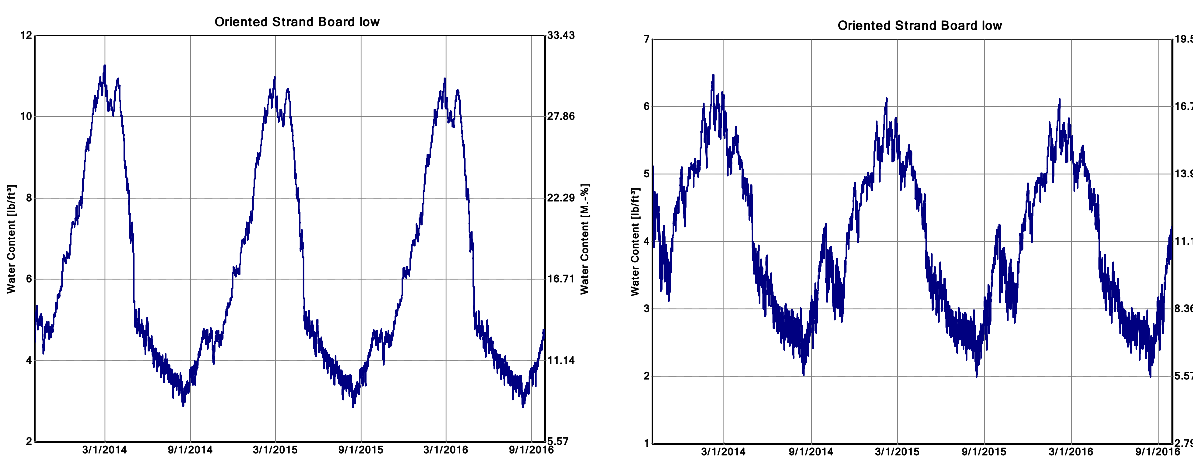

Figure 41: Round 1 - Wall 5 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.1.6 Wall 6 (Vented Stucco-OSB)

Table 12 shows the layers in the sixth wall of the Round One (Figure 42) from exterior to interior and their respective functions.

Table 12: Round 1 – Wall 6 (Vented Stucco-OSB) layers

Layer	Function
Stucco	provides exterior finish for aesthetics
1 layer asphalt saturated Kraft paper (building paper)	provides backing for stucco
Polypropylene drainage mat (½ inch)	provides drainage and ventilation gap
Another layer asphalt saturated Kraft paper (building paper)	functions as air and water control layer
OSB sheathing	provides structural support
2x4 framing	provides structural support
Kraft-faced R-13 fiberglass batt	functions as thermal and vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

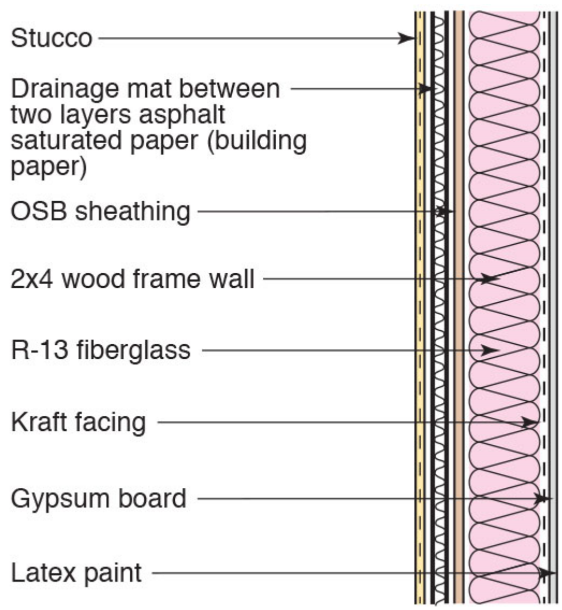

Figure 42: Round 1 - Wall 6 (Vented Stucco-OSB) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate zones; Figure 43 to Figure 48 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

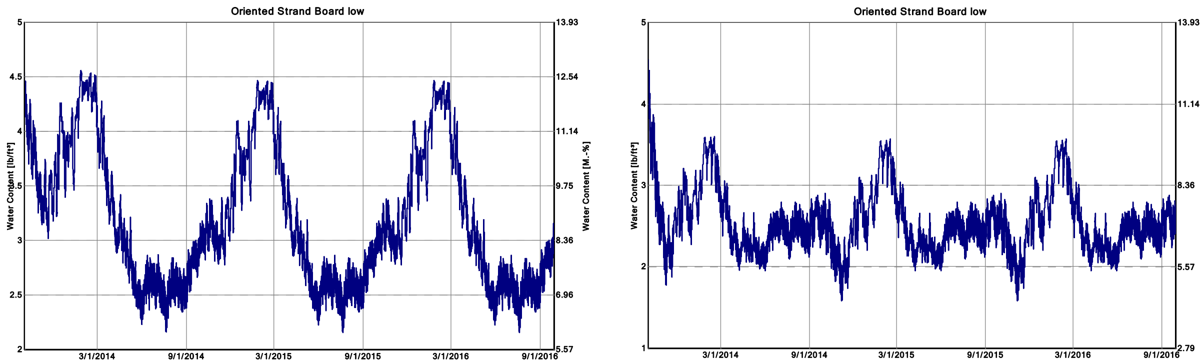

Figure 43: Round 1 - Wall 6 sheathing MC in Houston (Zone 2A), north (left) and south (right)

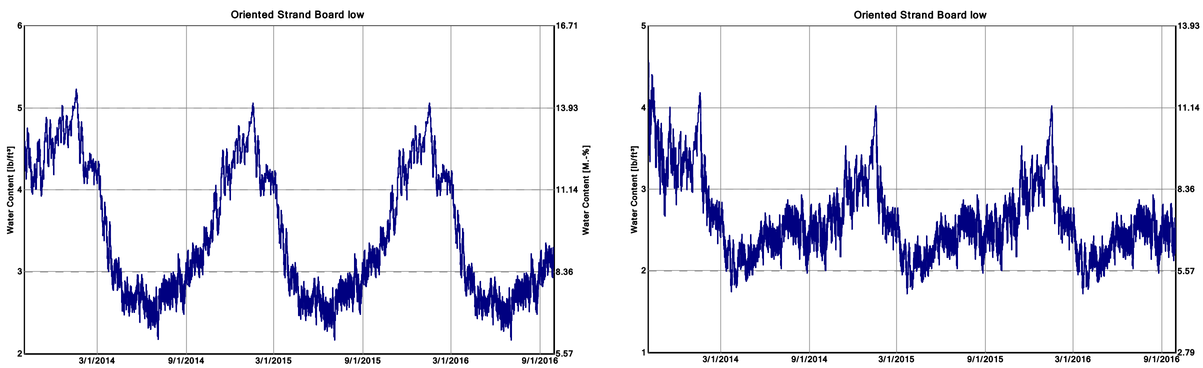

Figure 44: Round 1 - Wall 6 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

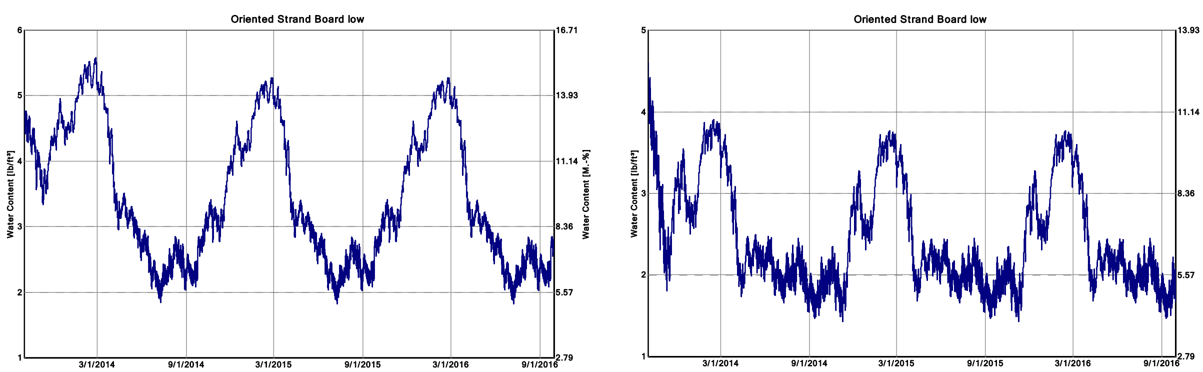

Figure 45: Round 1 - Wall 6 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

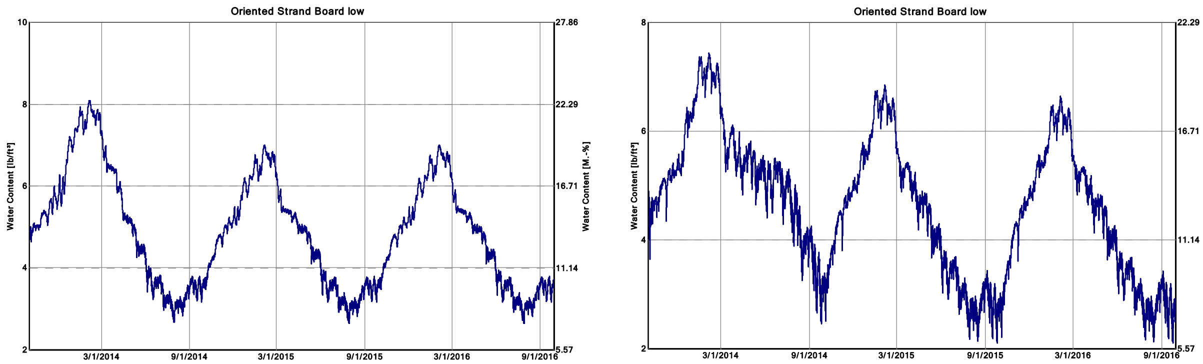

Figure 46: Round 1 - Wall 6 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

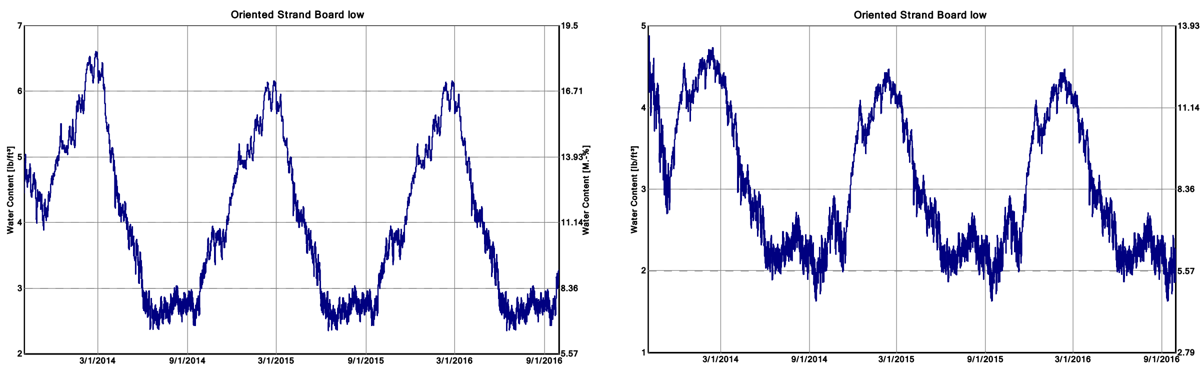

Figure 47: Round 1 - Wall 6 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

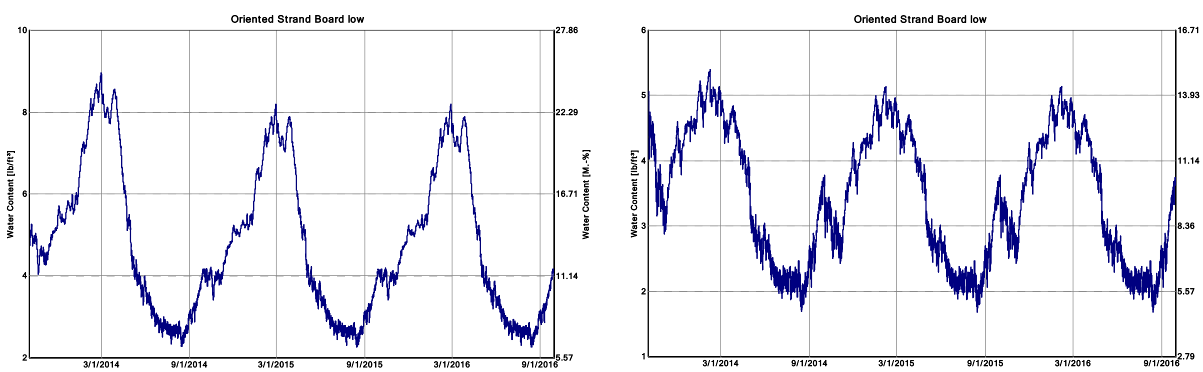

Figure 48: Round 1 - Wall 6 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.2 Round Two (2x6 Framing, R-19 Fiberglass)

In the second round, 2x4 framing with R-13 Kraft faced fiberglass batts is replaced with 2x6 framing with R-19 Kraft faced fiberglass batt in each of the wall systems.

3.2.1 Wall 1 (Wood Siding-Ply)

Table 13 shows the layers in the first wall of the Round Two (Figure 49) from exterior to interior and their respective functions.

Table 13: Round 2 – Wall 1 (Wood Siding-Ply) layers

Layer	Function
Latex painted wood siding	provides exterior finish for aesthetics
Asphalt saturated Kraft paper (building paper)	functions as air and water control layer
Plywood sheathing	provides structural support
2x6 framing	provides structural support
Kraft-faced R-19 fiberglass batt	functions as thermal and vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

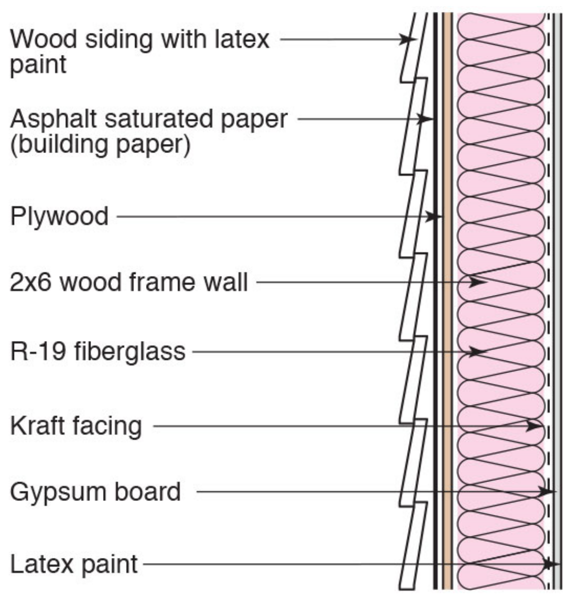

Figure 49: Round 2 - Wall 1 (Wood Siding-Ply) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate locations; Figure 50 to Figure 55 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

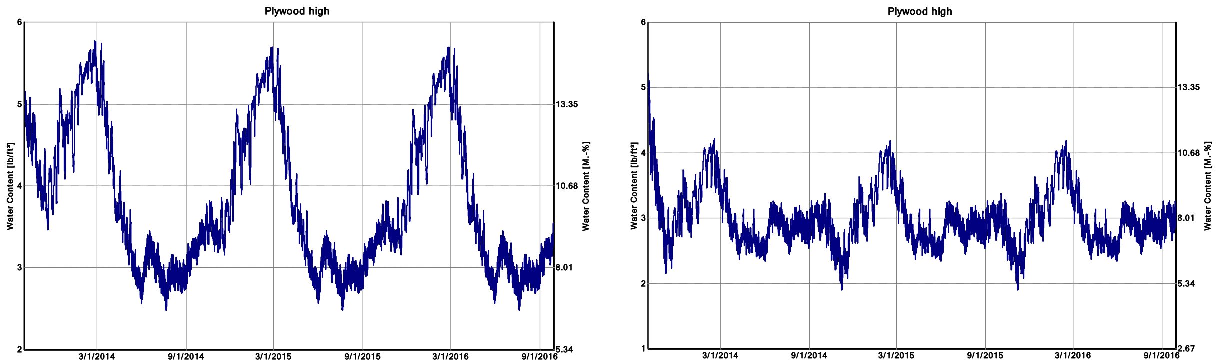

Figure 50: Round 2 - Wall 1 sheathing MC in Houston (Zone 2A), north (left) and south (right)

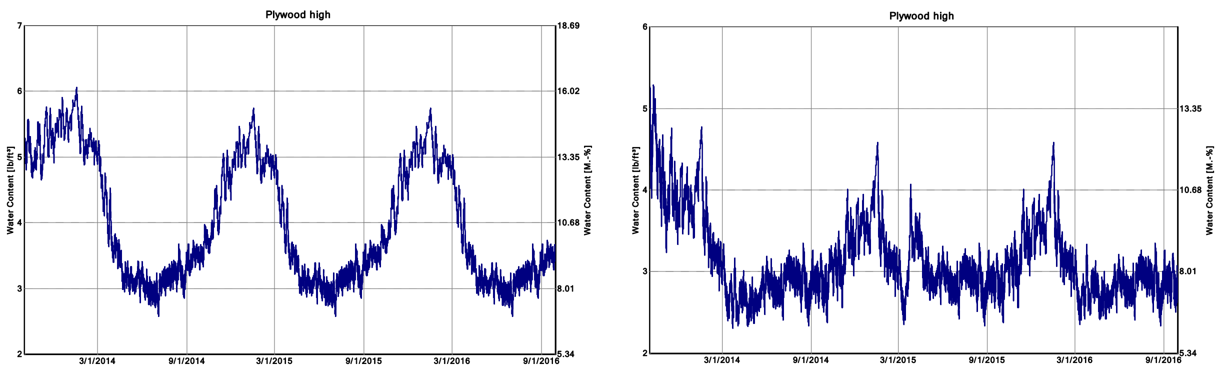

Figure 51: Round 2 - Wall 1 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

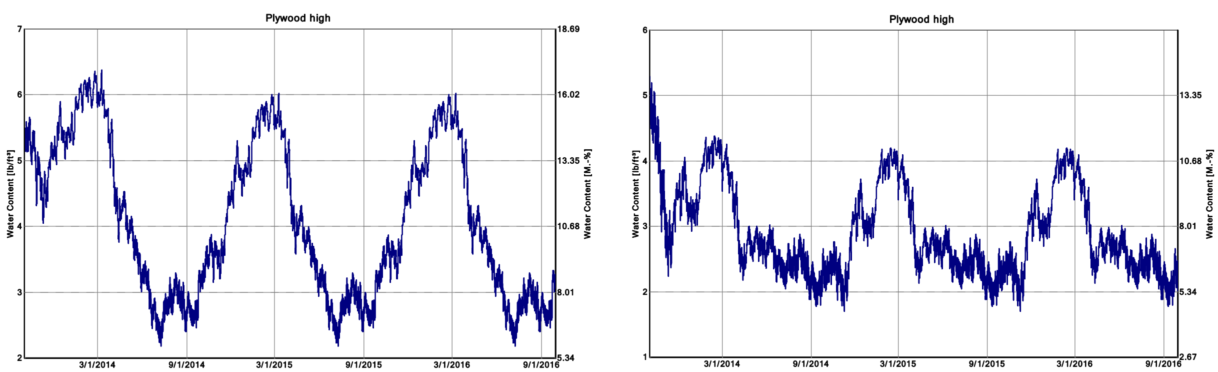

Figure 52: Round 2 - Wall 1 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

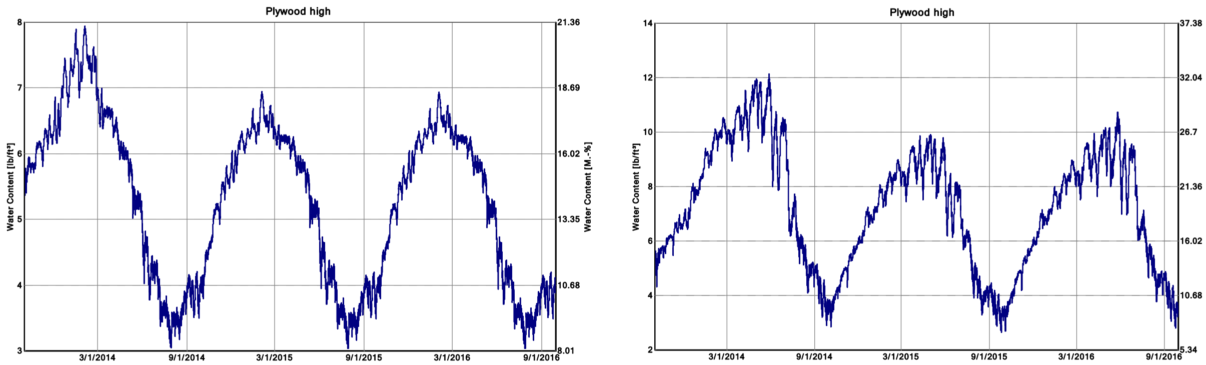

Figure 53: Round 2 - Wall 1 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

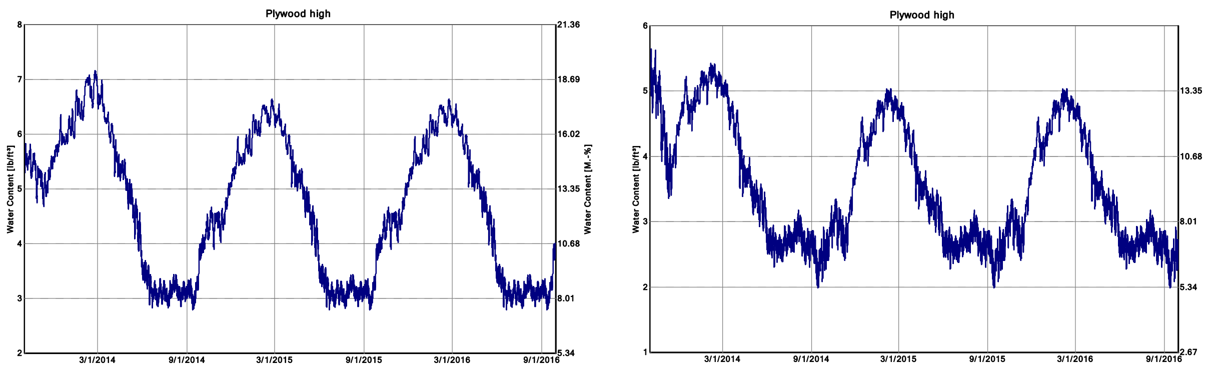

Figure 54: Round 2 - Wall 1 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

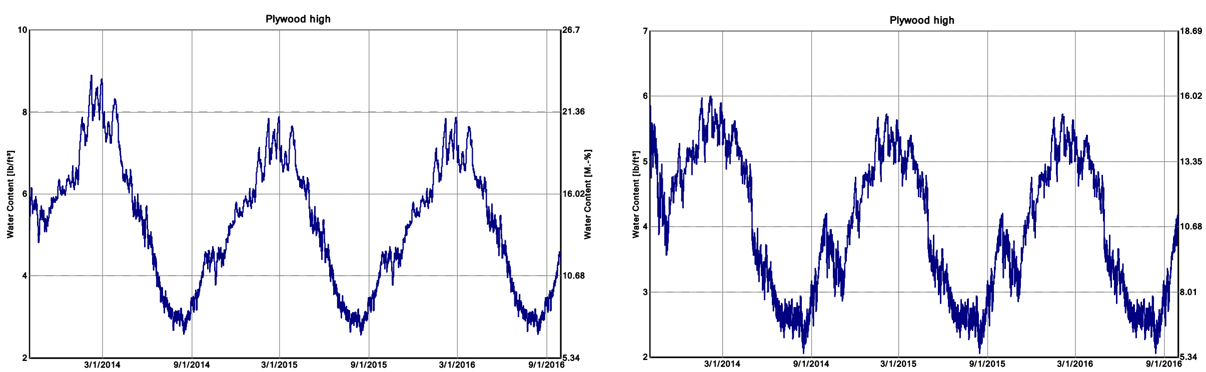

Figure 55: Round 2 - Wall 1 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.2.2 Wall 2 (Vinyl Siding-Ply)

Table 14 shows the layers in the second wall of the Round Two (Figure 56) from exterior to interior and their respective functions.

Table 14: Round 2 – Wall 2 (Vinyl Siding-Ply) layers

Layer	Function
Vinyl siding	provides exterior finish for aesthetics
Asphalt saturated Kraft paper (building paper)	functions as air and water control layer
Plywood sheathing	provides structural support
2x6 framing	provides structural support
Kraft-faced R-19 fiberglass batt	functions as thermal and vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

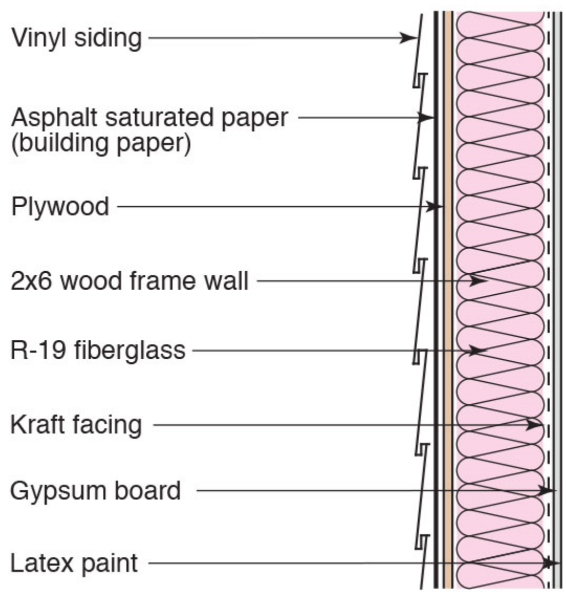

Figure 56: Round 2 - Wall 2 (Vinyl Siding-Ply) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate zones; Figure 57 to Figure 62 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

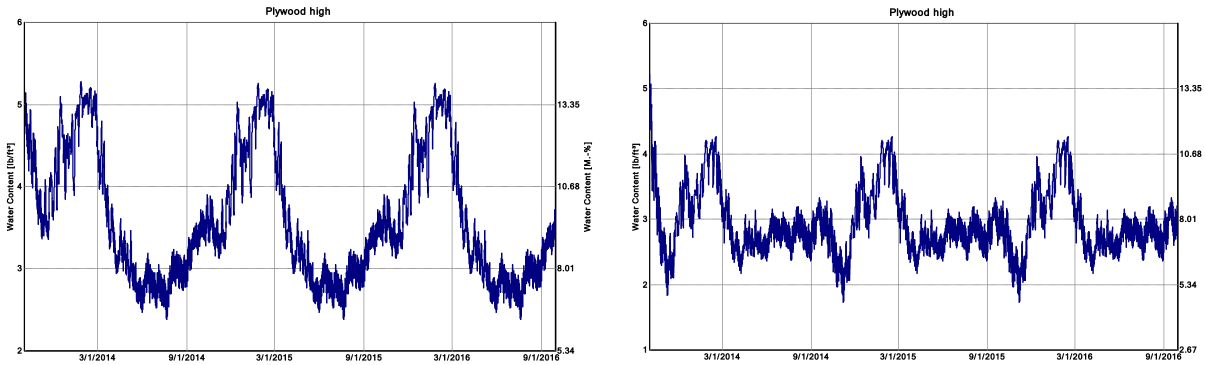

Figure 57: Round 2 - Wall 2 sheathing MC in Houston (Zone 2A), north (left) and south (right)

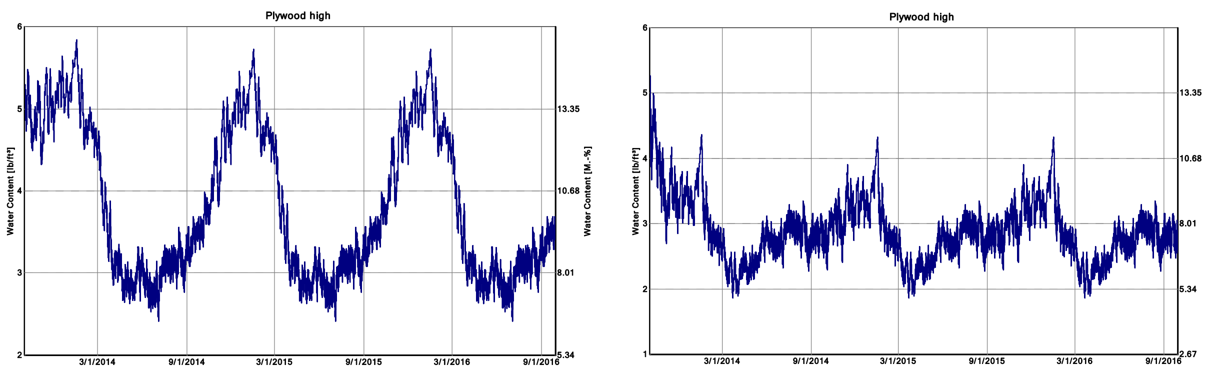

Figure 58: Round 2 - Wall 2 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

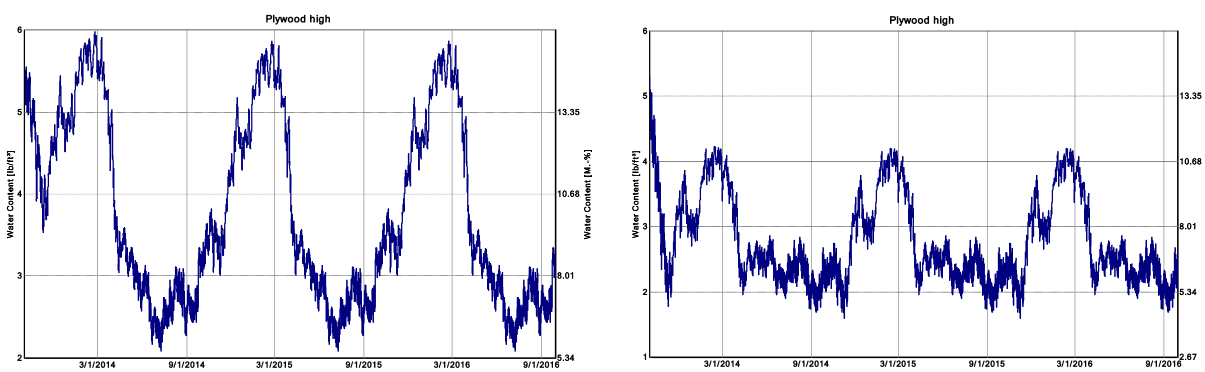

Figure 59: Round 2 - Wall 2 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

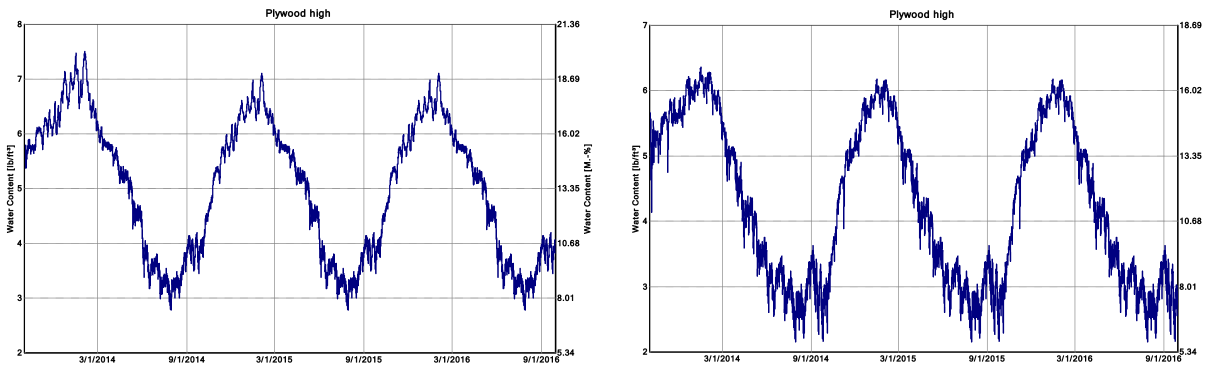

Figure 60: Round 2 - Wall 2 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

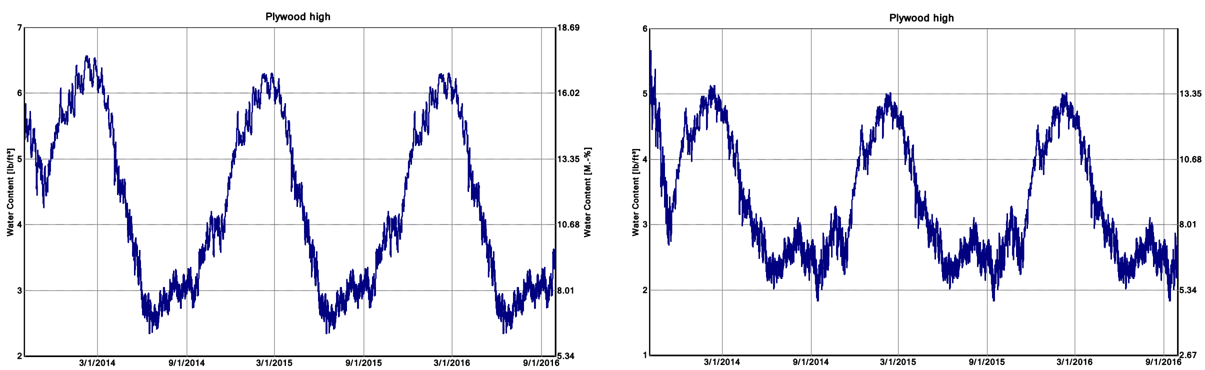

Figure 61: Round 2 - Wall 2 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

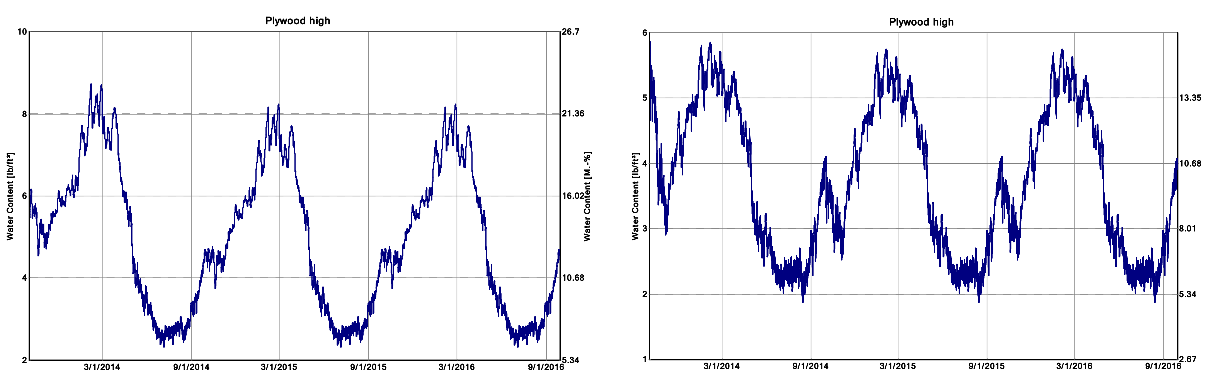

Figure 62: Round 2 - Wall 2 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.2.3 Wall 3 (Vinyl-OSB)

Table 15 shows the layers in the third wall of the Round Two (Figure 63) from exterior to interior and their respective functions.

Table 15: Round 2 – Wall 3 (Vinyl-OSB) layers

Layer	Function
Vinyl siding	provides exterior finish for aesthetics
Asphalt saturated Kraft paper (building paper)	functions as air and water control layer
OSB sheathing	provides structural support
2x6 framing	provides structural support
Kraft-faced R-19 fiberglass batt	functions as thermal and vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

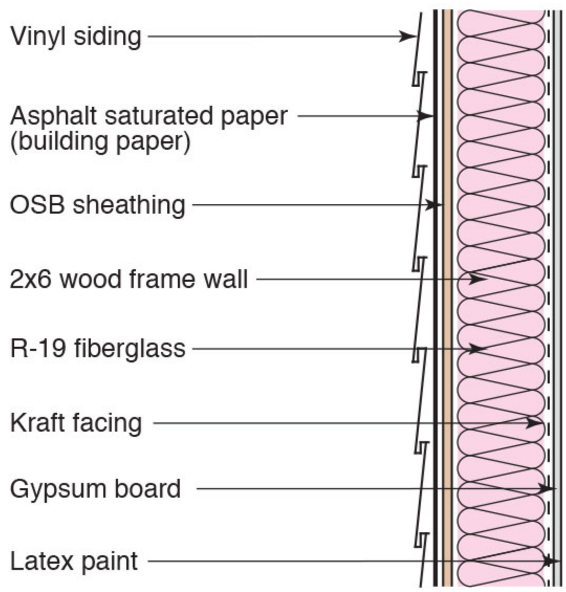

Figure 63: Round 2 - Wall 3 (Vinyl-OSB) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate zones; Figure 64 to Figure 69 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

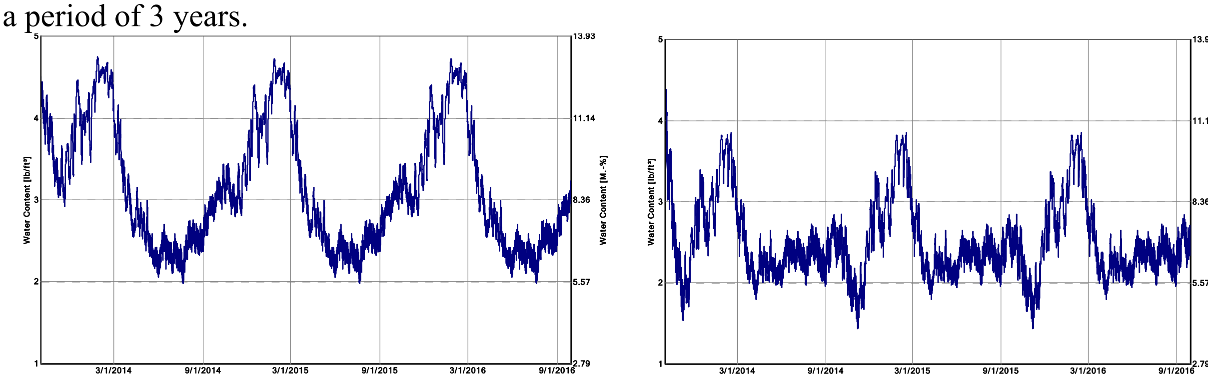

Figure 64: Round 2 - Wall 3 sheathing MC in Houston (Zone 2A), north (left) and south (right)

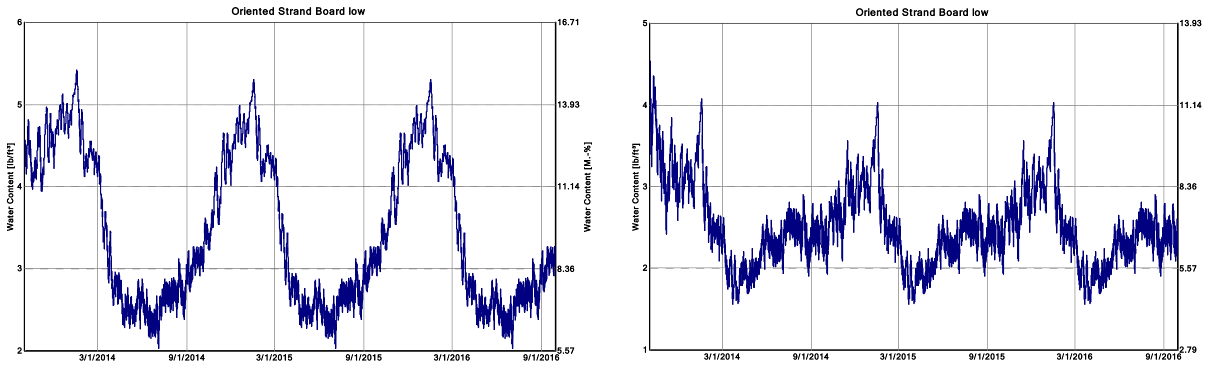

Figure 65: Round 2 - Wall 3 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

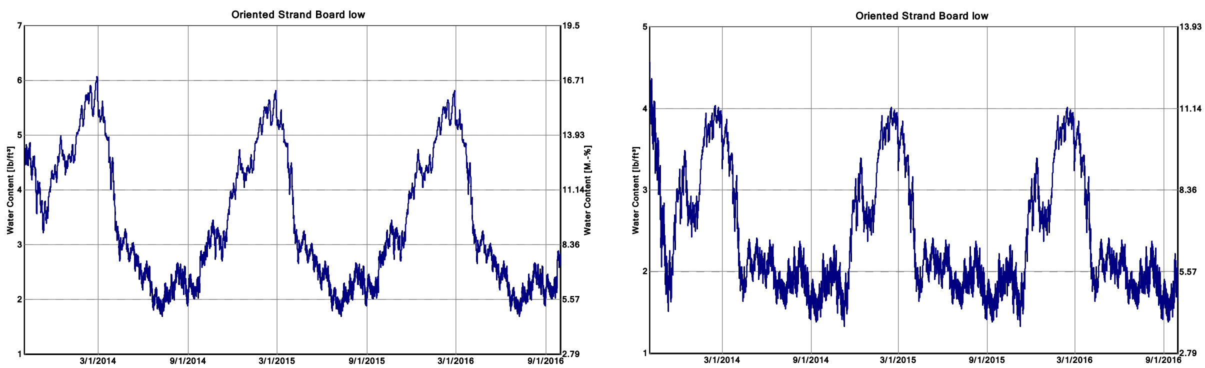

Figure 66: Round 2 - Wall 3 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

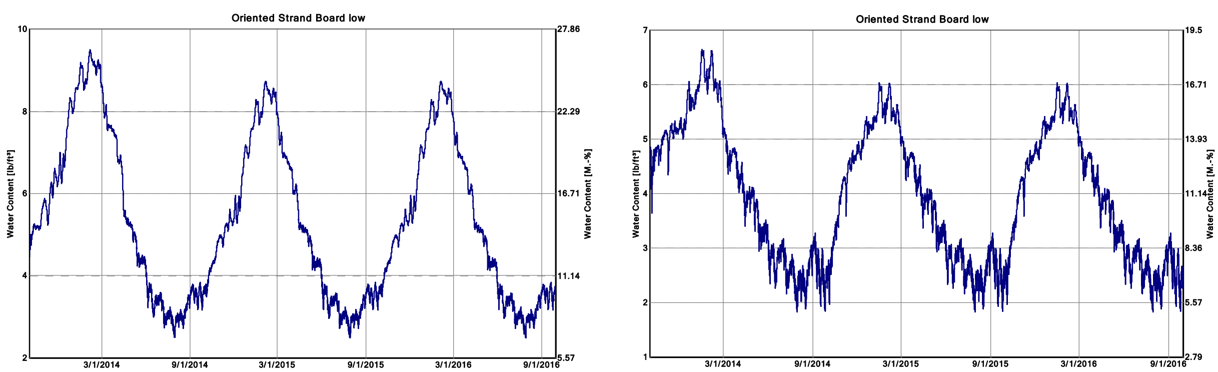

Figure 67: Round 2 - Wall 3 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

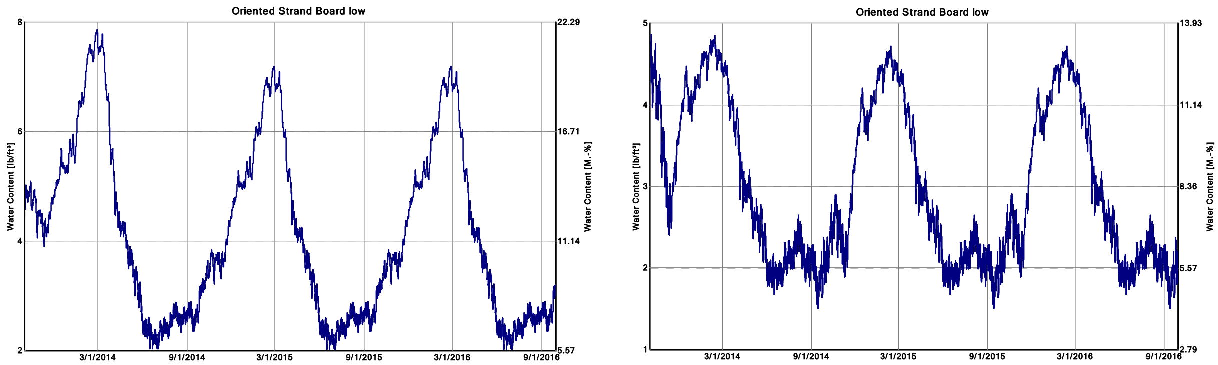

Figure 68: Round 2 - Wall 3 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

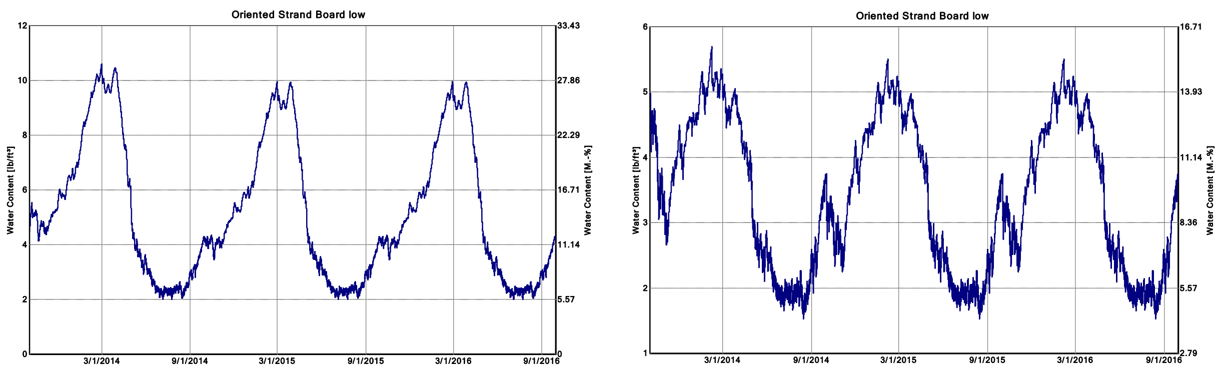

Figure 69: Round 2 - Wall 3 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.2.4 Wall 4 (Brick-OSB)

Table 16 shows the layers in the fourth wall of the Round Two (Figure 70) from exterior to interior and their respective functions.

Table 16: Round 2 – Wall 4 (Brick-OSB) layers

Layer	Function
Brick veneer	provides exterior finish for aesthetics
Asphalt saturated Kraft paper (building paper)	functions as air and water control layer
OSB sheathing	provides structural support
2x6 framing	provides structural support
Kraft-faced R-19 fiberglass batt	functions as thermal and vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

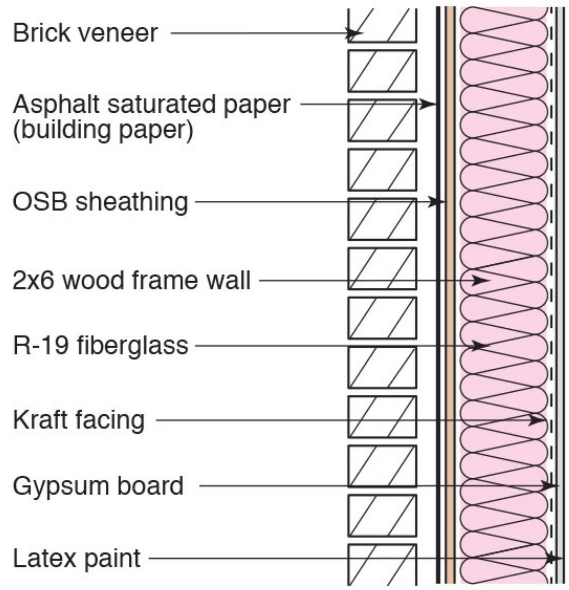

Figure 70: Round 2 - Wall 4 (Brick-OSB) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate zones; Figure 71 to Figure 76 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

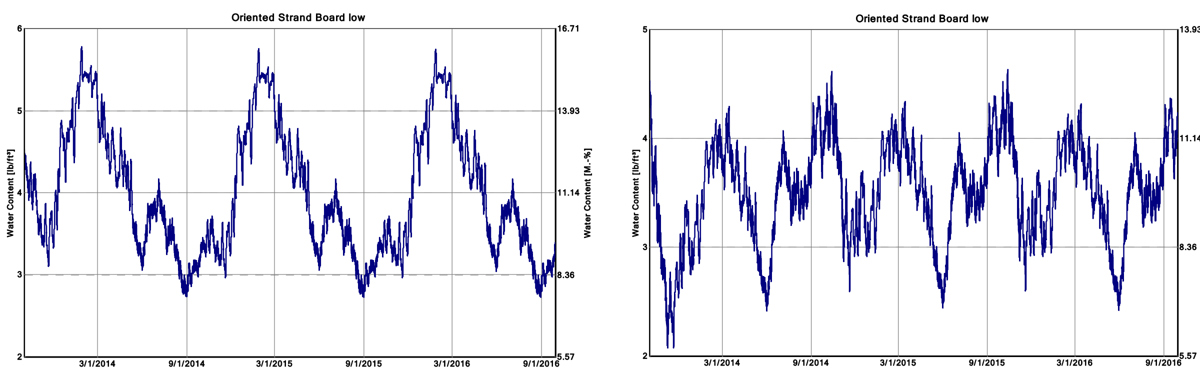

Figure 71: Round 2 - Wall 4 sheathing MC in Houston (Zone 2A), north (left) and south (right)

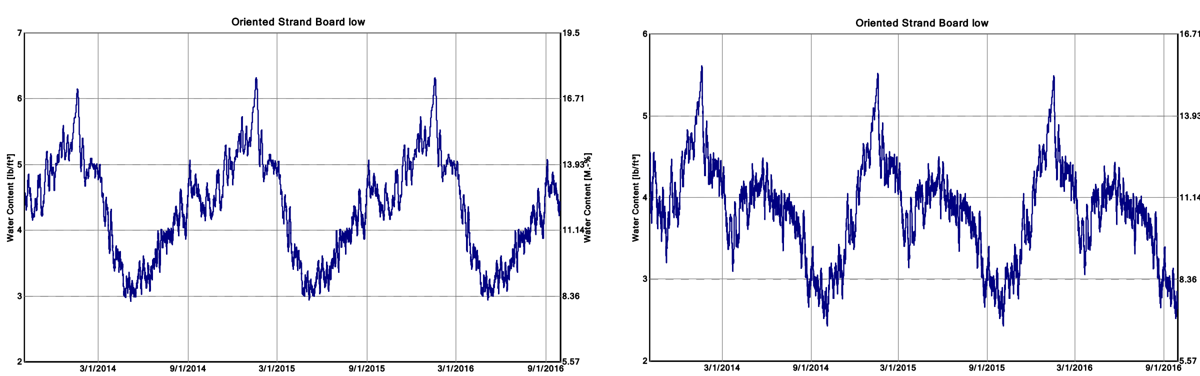

Figure 72: Round 2 - Wall 4 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

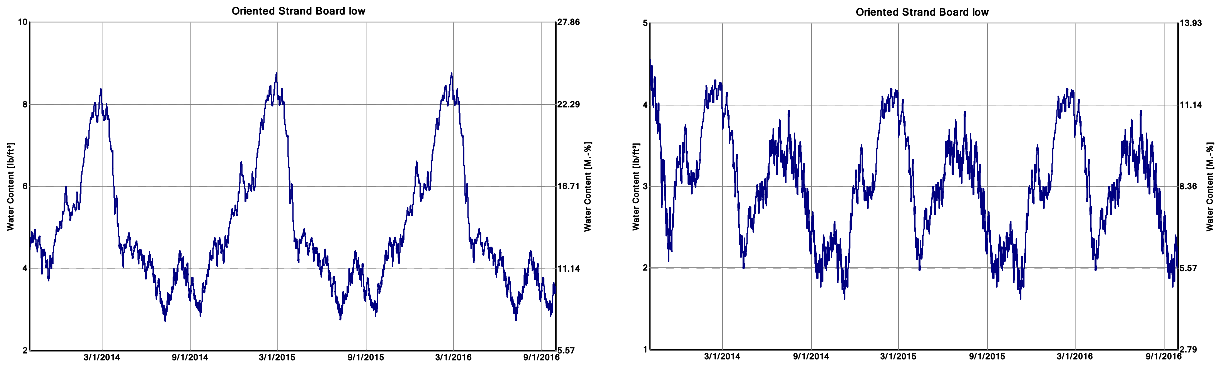

Figure 73: Round 2 - Wall 4 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

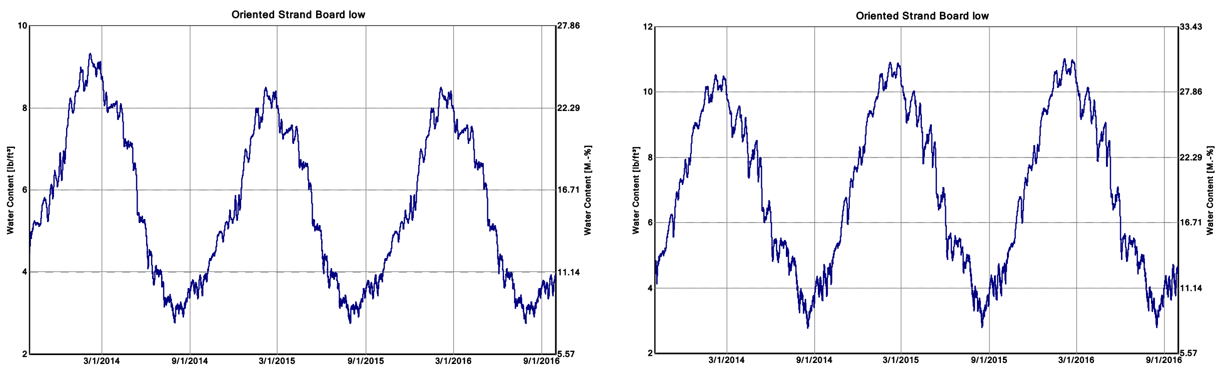

Figure 74: Round 2 - Wall 4 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

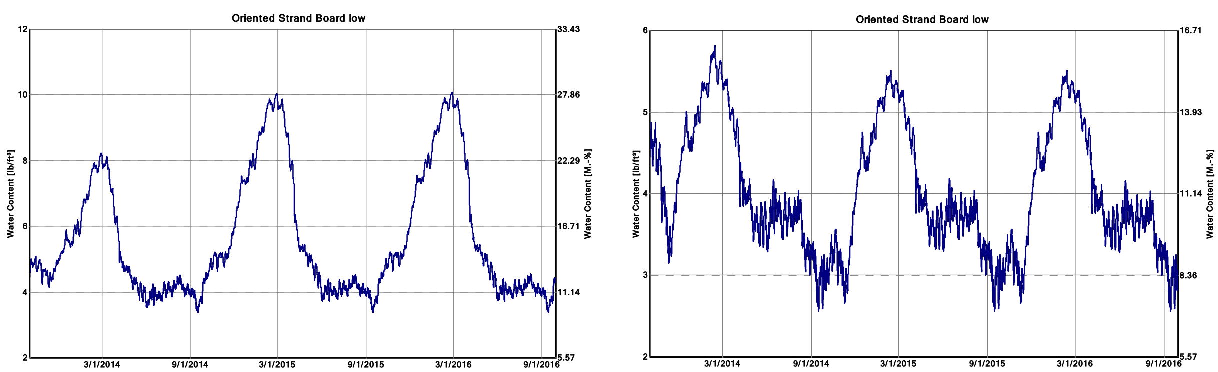

Figure 75: Round 2 - Wall 4 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

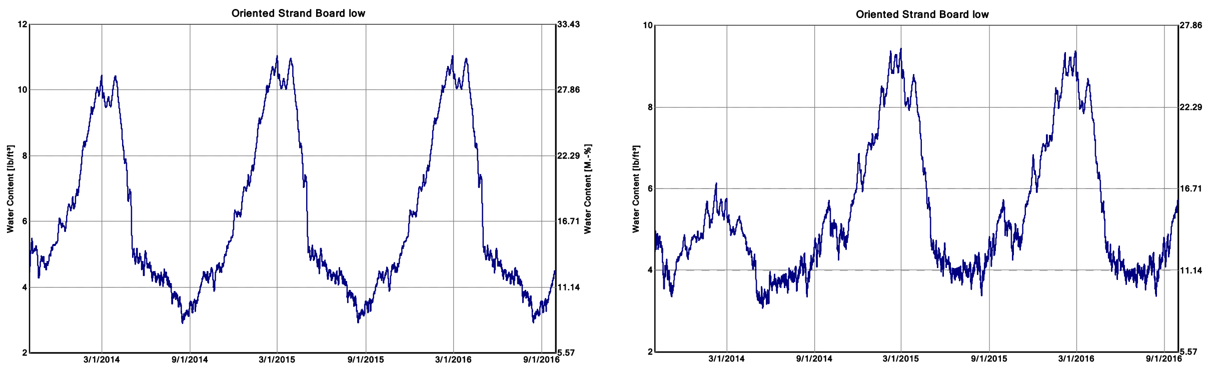

Figure 76: Round 2 - Wall 4 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.2.5 Wall 5 (Stucco-OSB)

Table 17 shows the layers in the fifth wall of the Round Two (Figure 77) from exterior to interior and their respective functions.

Table 17: Round 2 – Wall 5 (Stucco-OSB) layers

Layer	Function
Stucco	provides exterior finish for aesthetics
2 layers asphalt saturated Kraft paper (building paper)	functions as air and water control layer
OSB sheathing	provides structural support
2x6 framing	provides structural support
Kraft-faced R-19 fiberglass batt	functions as thermal and vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

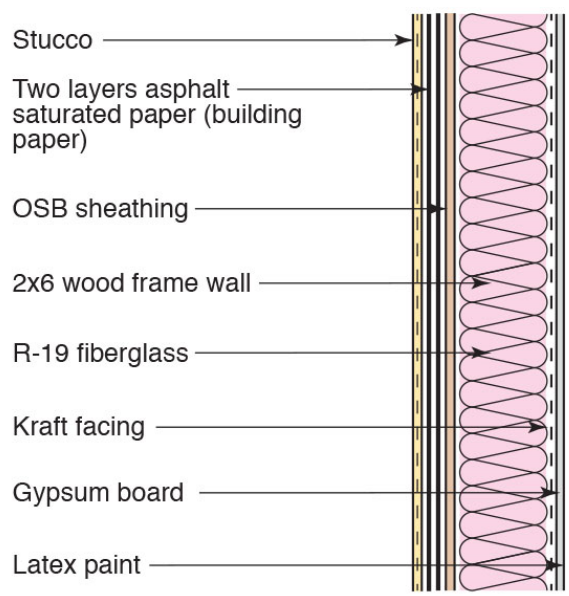

Figure 77: Round 2 - Wall 5 (Stucco-OSB) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate zones; Figure 78 to Figure 83 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

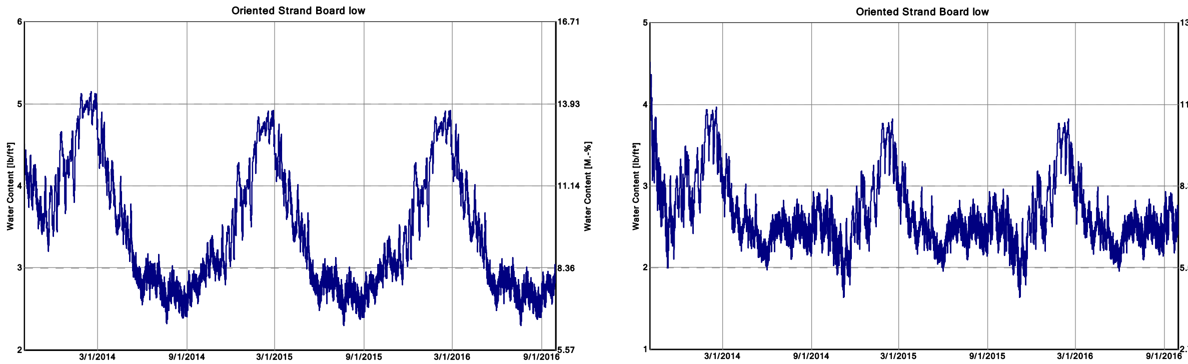

Figure 78: Round 2 - Wall 5 sheathing MC in Houston (Zone 2A), north (left) and south (right)

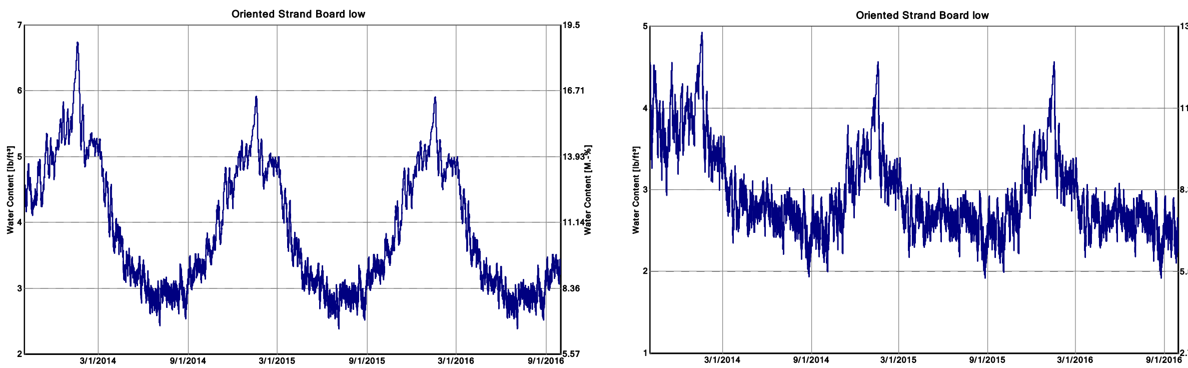

Figure 79: Round 2 - Wall 5 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

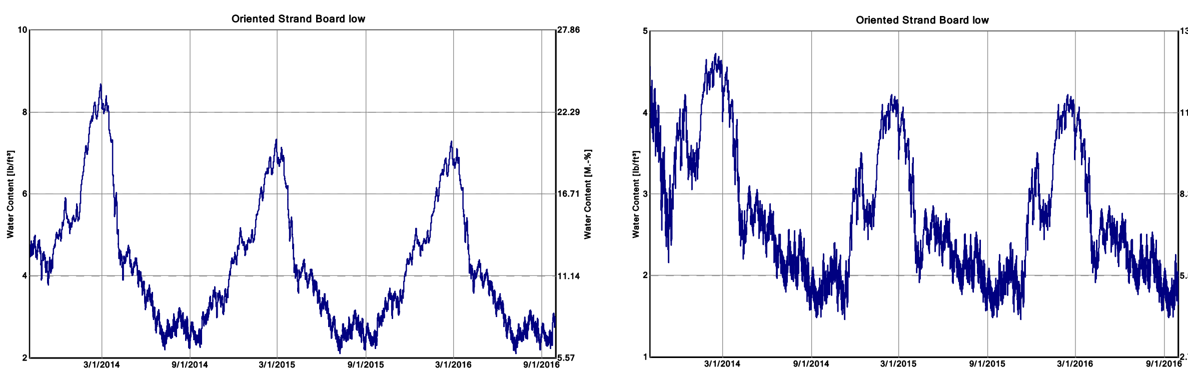

Figure 80: Round 2 - Wall 5 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

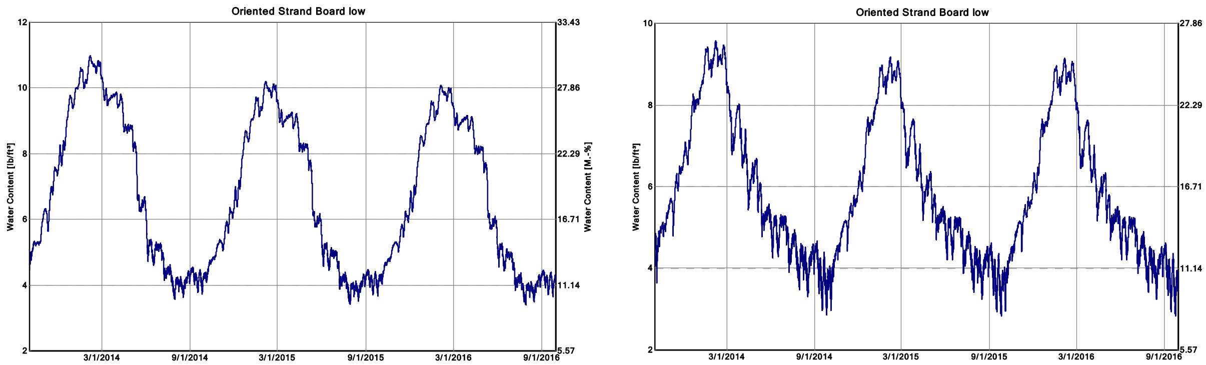

Figure 81: Round 2 - Wall 5 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

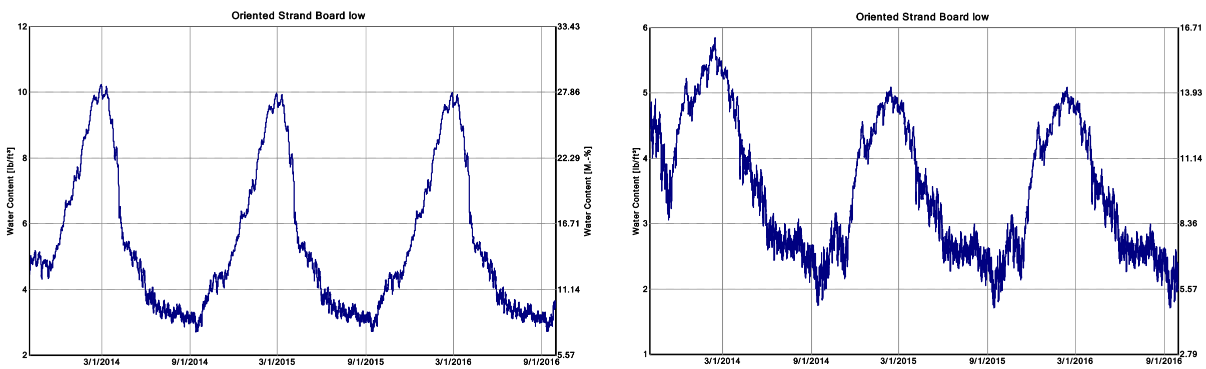

Figure 82: Round 2 - Wall 5 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

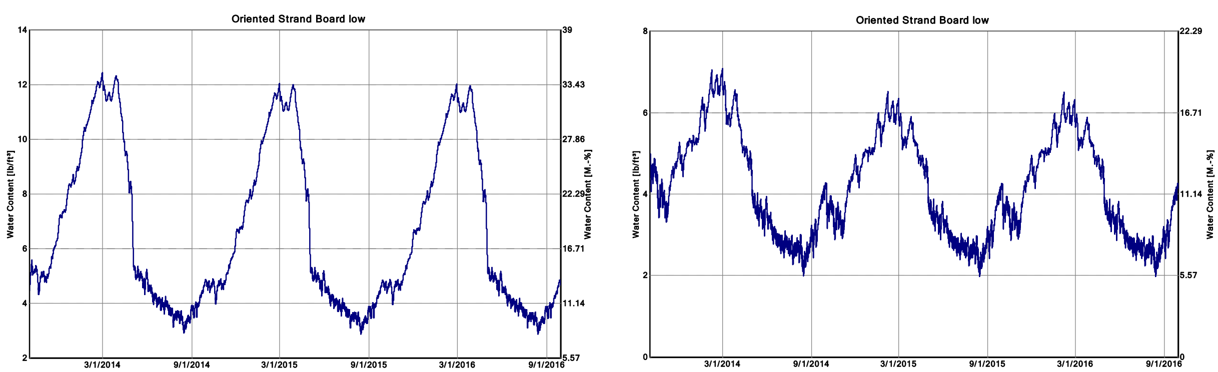

Figure 83: Round 2 - Wall 5 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.2.6 Wall 6 (Vented Stucco-OSB)

Table 18 shows the layers in the sixth wall of the Round Two (Figure 84) from exterior to interior and their respective functions.

Table 18: Round 2 – Wall 6 (Vented Stucco-OSB) layers

Layer	Function
Stucco	provides exterior finish for aesthetics
1 layer asphalt saturated Kraft paper (building paper)	provides backing for stucco
Polypropylene drainage mat (½ in.)	provides drainage and ventilation gap
Another layer asphalt saturated Kraft paper (building paper)	functions as air and water control layer
OSB sheathing	provides structural support
2x6 framing	provides structural support
Kraft-faced R-19 fiberglass batt	functions as thermal and vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

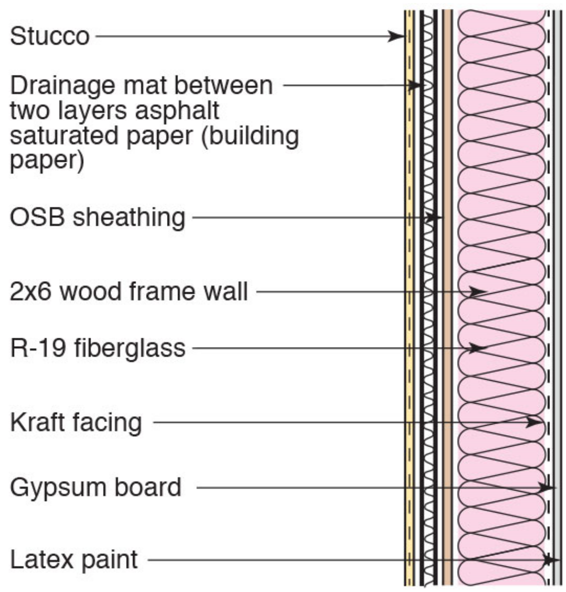

Figure 84: Round 2 - Wall 6 (Vented Stucco-OSB) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate zones; Figure 85 to Figure 90 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

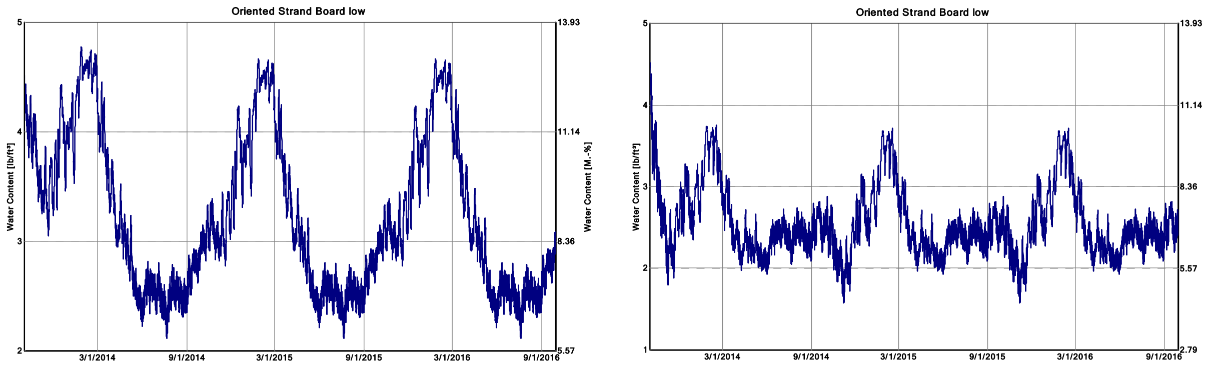

Figure 85: Round 2 - Wall 6 sheathing MC in Houston (Zone 2A), north (left) and south (right)

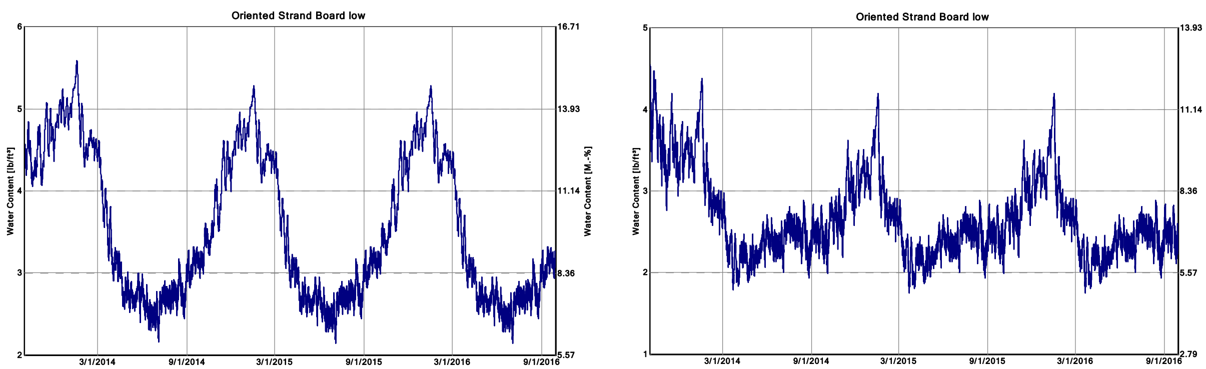

Figure 86: Round 2 - Wall 6 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

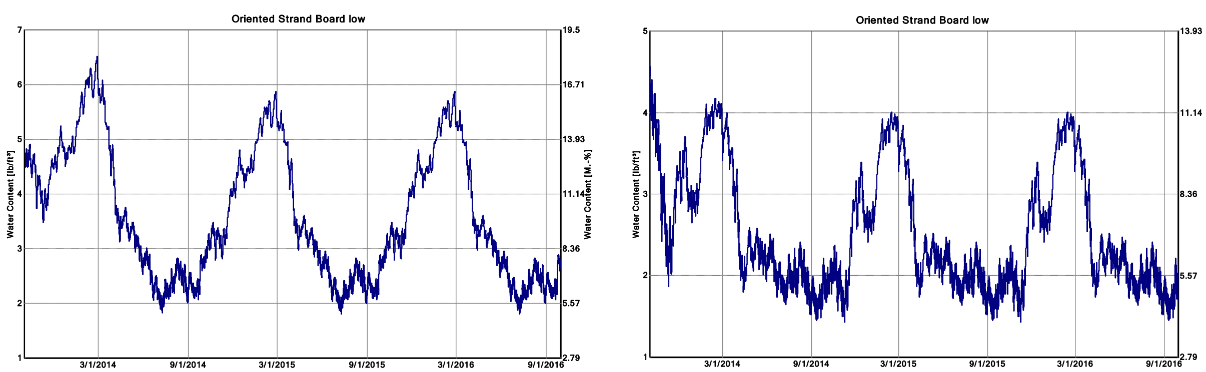

Figure 87: Round 2 - Wall 6 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

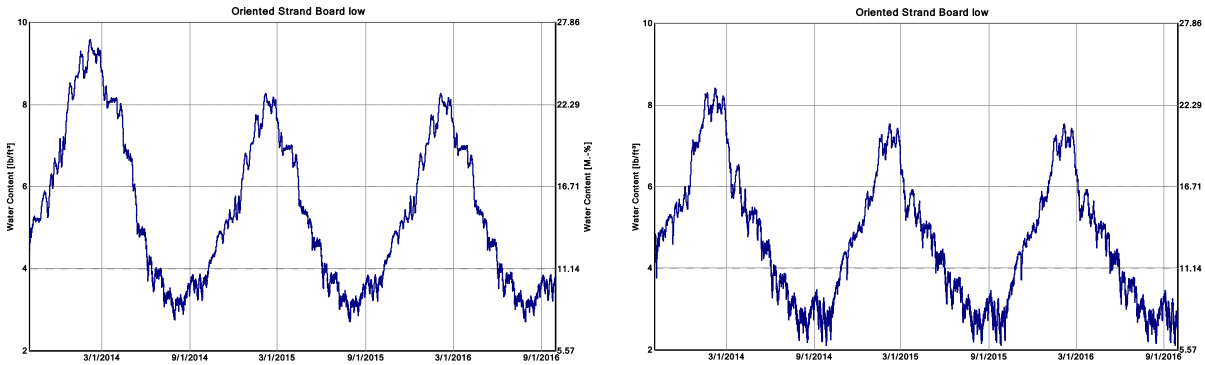

Figure 88: Round 2 - Wall 6 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

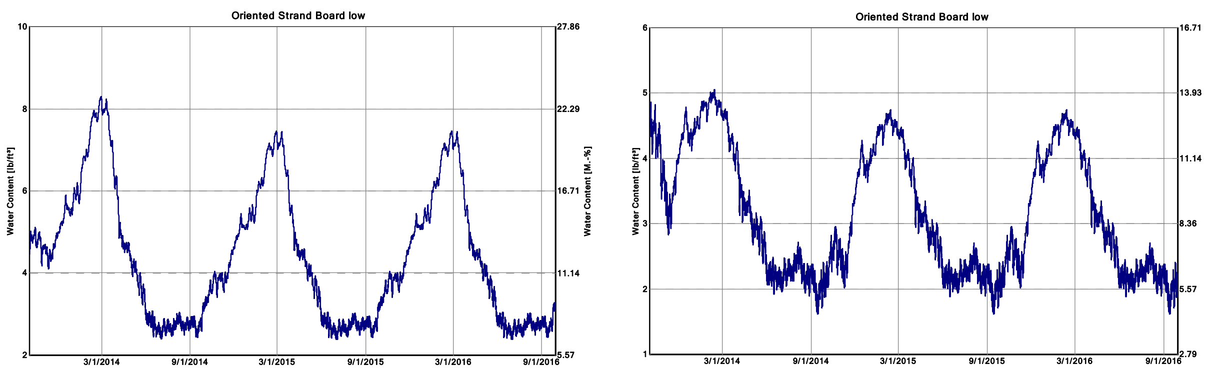

Figure 89: Round 2 - Wall 6 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

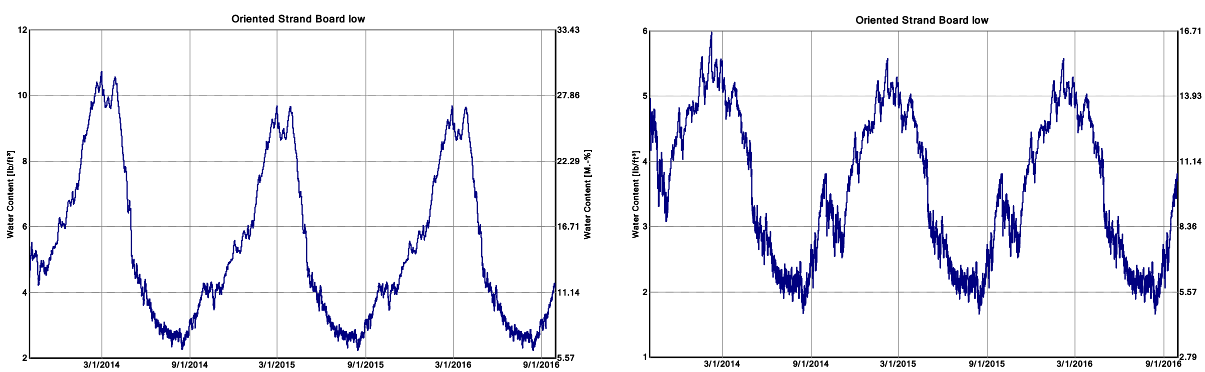

Figure 90: Round 2 - Wall 6 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.3 Round Three (2x6 Framing, R-13 Fiberglass, Kraft Facing→Polyethylene)

In the third round, the round two walls are redone replacing Kraft facing with 6 mil polyethylene.

3.3.1 Wall 1 (Wood Siding-Ply)

Table 19 shows the layers in the first wall of the Round Three (Figure 91) from exterior to interior and their respective functions.

Table 19: Round 3 – Wall 1 (Wood Siding-Ply) layers

Layer	Function
Latex painted wood siding	provides exterior finish for aesthetics
Asphalt saturated Kraft paper (building paper)	functions as air and water control layer
Plywood sheathing	provides structural support
2x6 framing	provides structural support
R-19 fiberglass batt	functions as thermal control layer
6 mil polyethylene	functions as vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

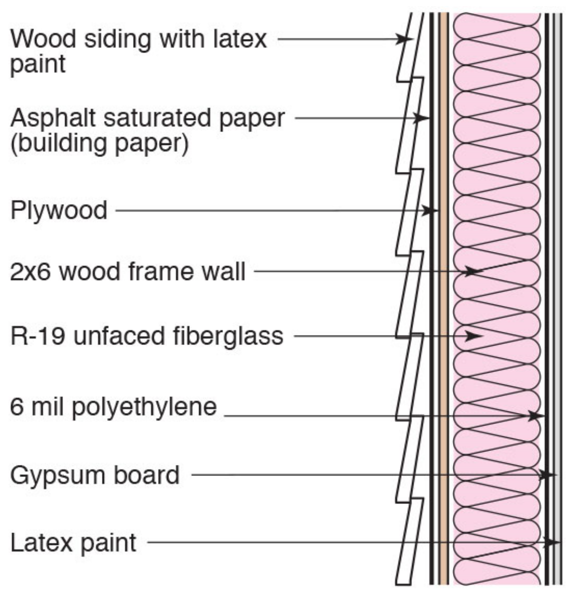

Figure 91: Round 3 - Wall 1 (Wood Siding-Ply) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate locations; Figure 92 to Figure 97 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

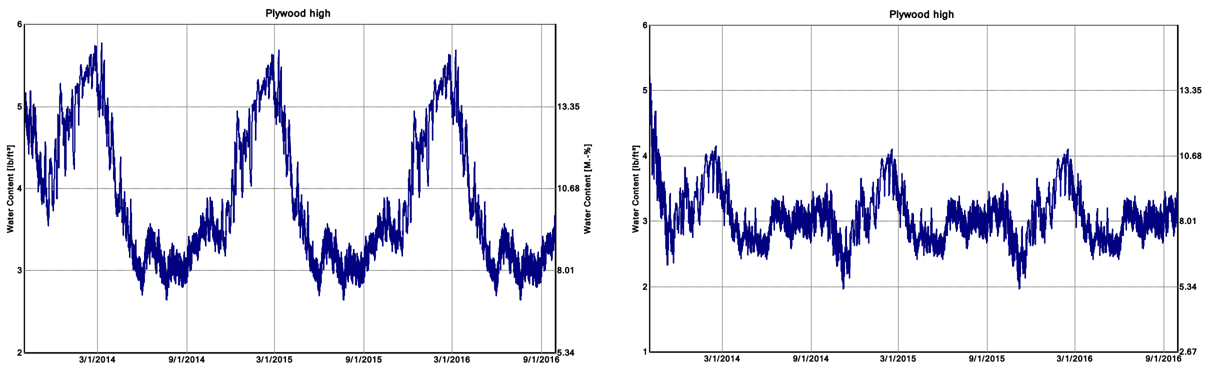

Figure 92: Round 3 - Wall 1 sheathing MC in Houston (Zone 2A), north (left) and south (right)

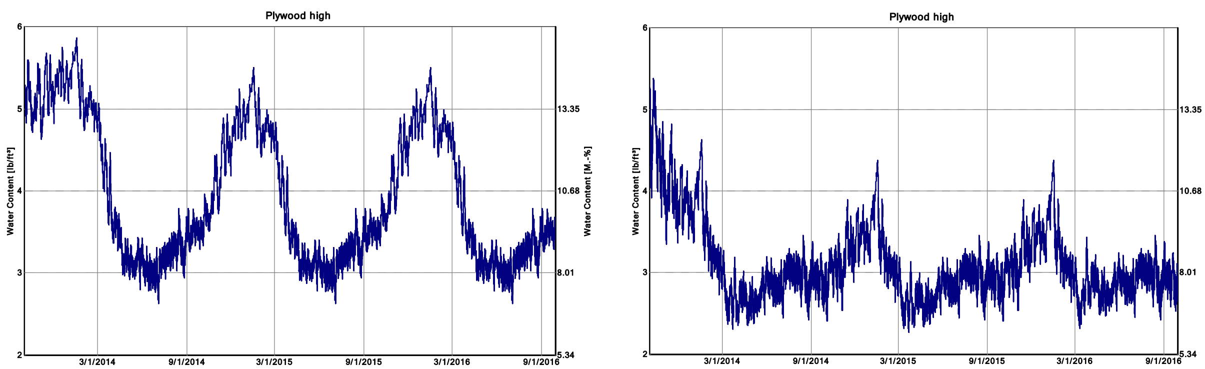

Figure 93: Round 3 - Wall 1 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

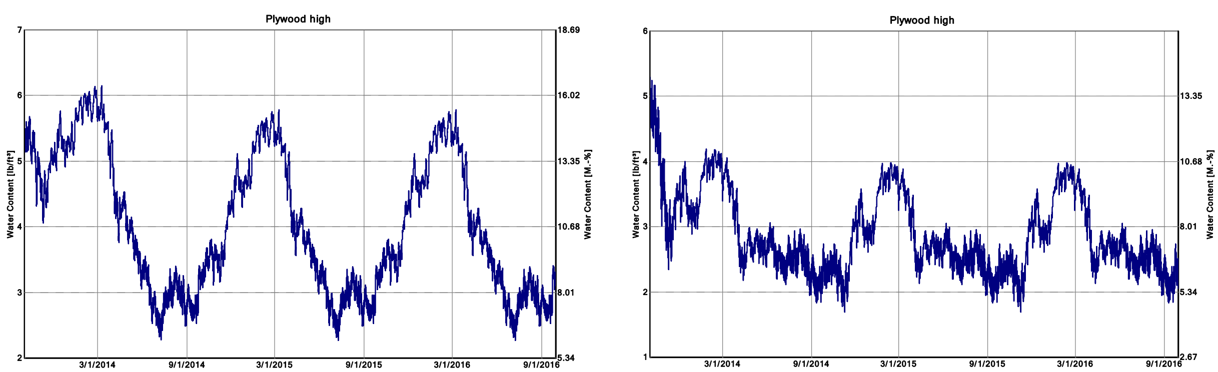

Figure 94: Round 3 - Wall 1 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

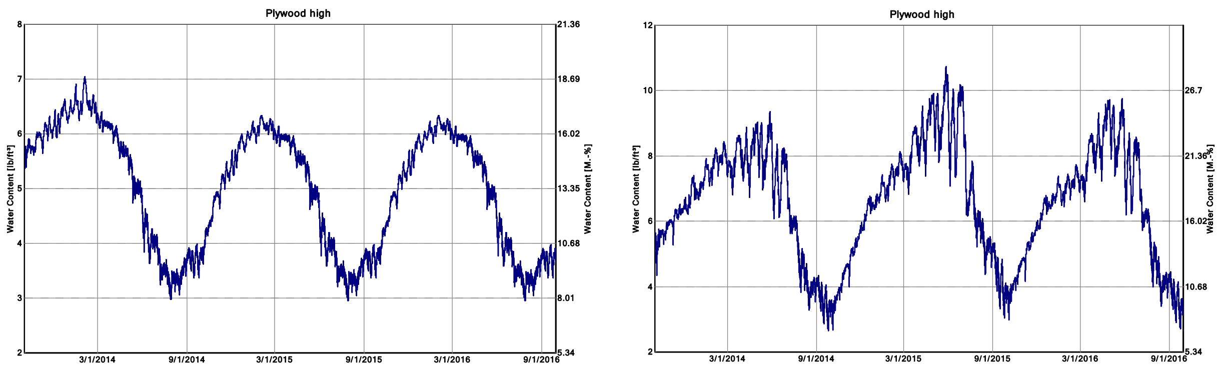

Figure 95: Round 3 - Wall 1 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

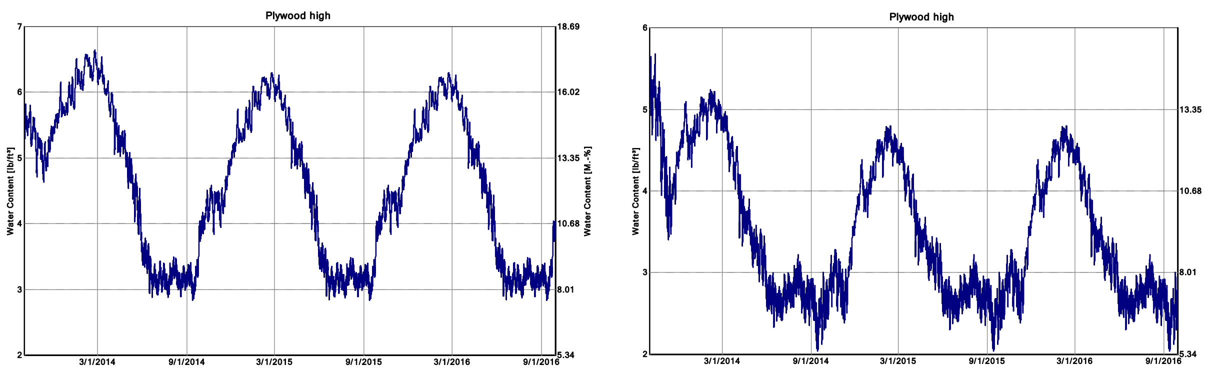

Figure 96: Round 3 - Wall 1 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

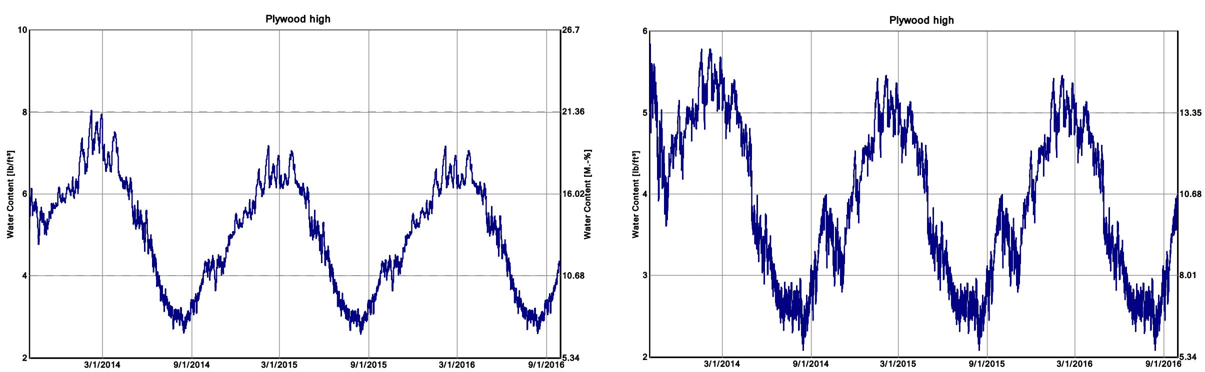

Figure 97: Round 3 - Wall 1 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.3.2 Wall 2 (Vinyl Siding-Ply)

Table 20 shows the layers in the second wall of the Round Three (Figure 98) from exterior to interior and their respective functions.

Table 20: Round 3 – Wall 2 (Vinyl Siding-Ply) layers

Layer	Function
Vinyl siding	provides exterior finish for aesthetics
Asphalt saturated Kraft paper (building paper)	functions as air and water control layer
Plywood sheathing	provides structural support
2x6 framing	provides structural support
R-19 fiberglass batt	functions as thermal control layer
6 mil polyethylene	functions as vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

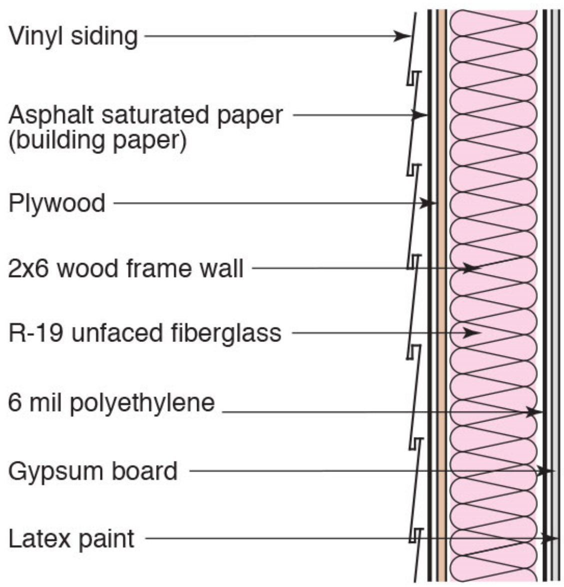

Figure 98: Round 3 - Wall 2 (Vinyl Siding-Ply)configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate zones; Figure 99 to Figure 104 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

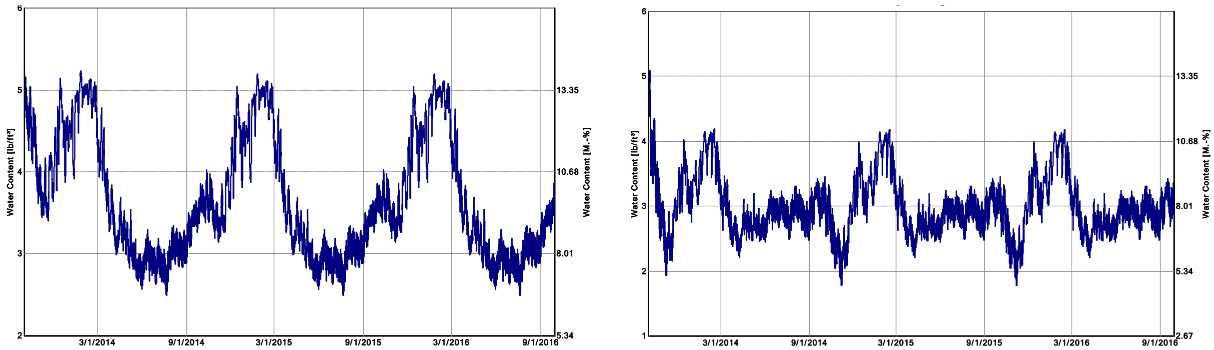

Figure 99: Round 3 - Wall 2 sheathing MC in Houston (Zone 2A), north (left) and south (right)

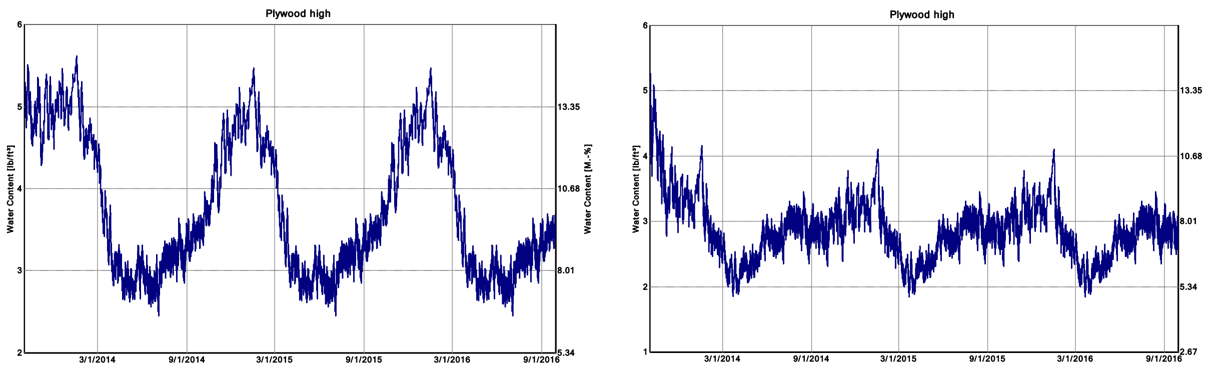

Figure 100: Round 3 - Wall 2 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

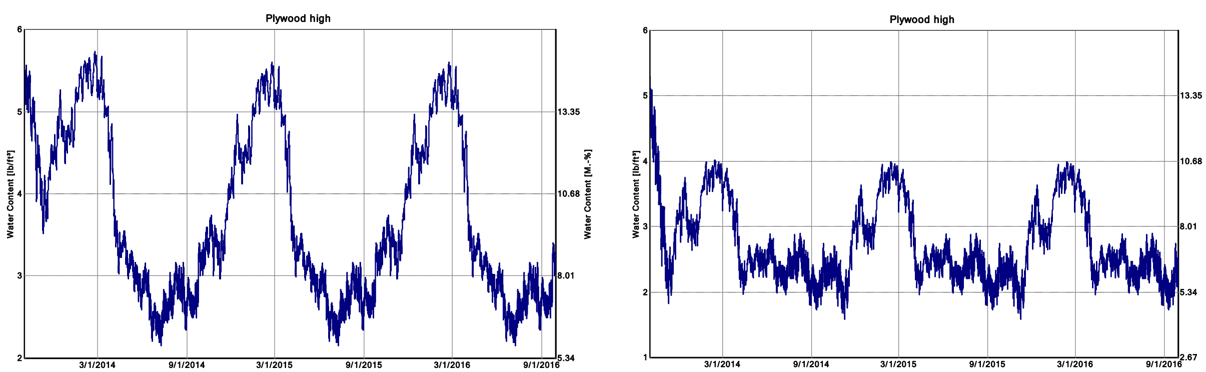

Figure 101: Round 3 - Wall 2 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

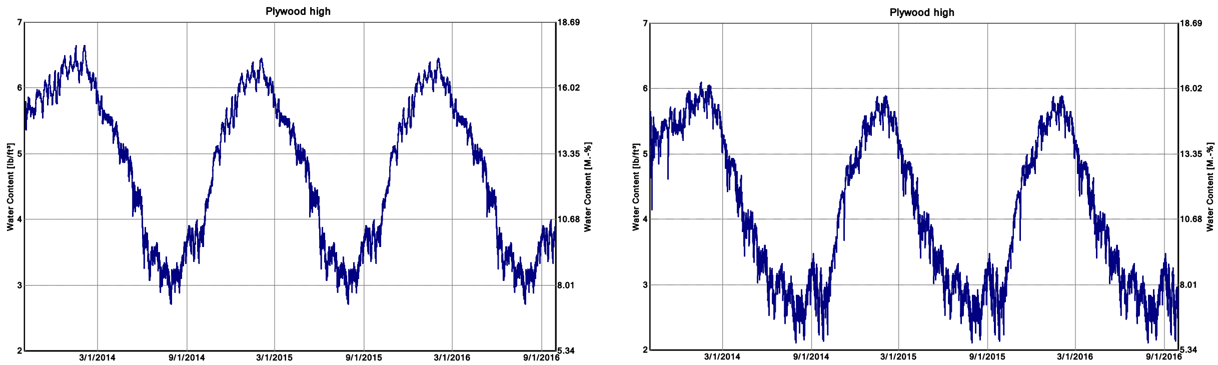

Figure 102: Round 3 - Wall 2 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

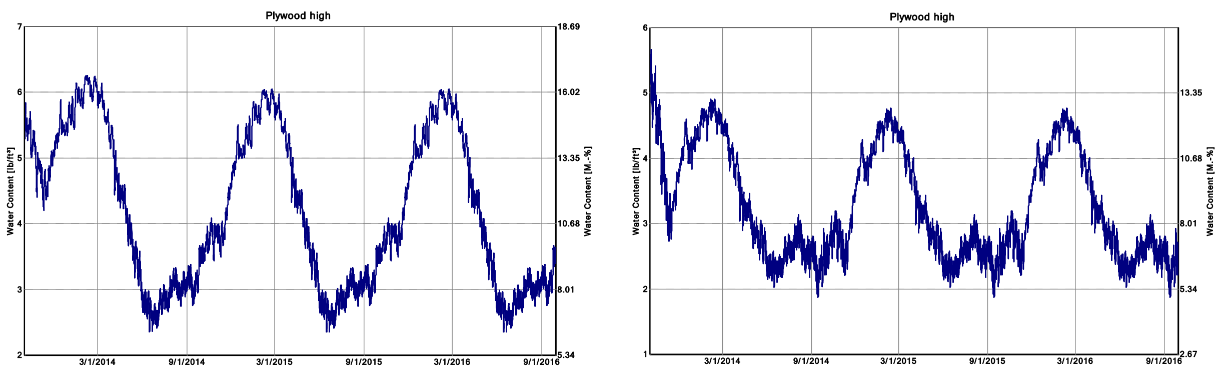

Figure 103: Round 3 - Wall 2 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

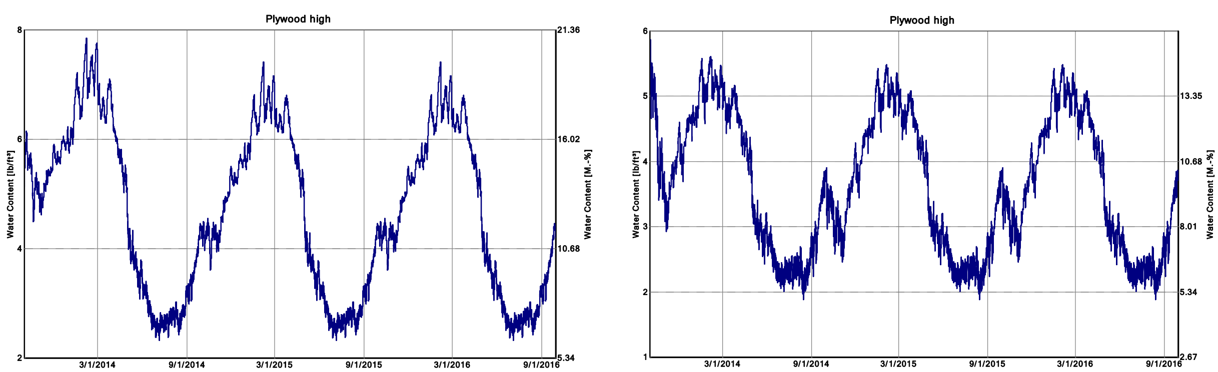

Figure 104: Round 3 - Wall 2 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.3.3 Wall 3 (Vinyl-OSB)

Table 21 shows the layers in the third wall of the Round Three (Figure 105) from exterior to interior and their respective functions.

Table 21: Round 3 – Wall 3 (Vinyl-OSB) layers

Layer	Function
Vinyl siding	provides exterior finish for aesthetics
Asphalt saturated Kraft paper (building paper)	functions as air and water control layer
OSB sheathing	provides structural support
2x6 framing	provides structural support
R-19 fiberglass batt	functions as thermal control layer
6 mil polyethylene	functions as vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

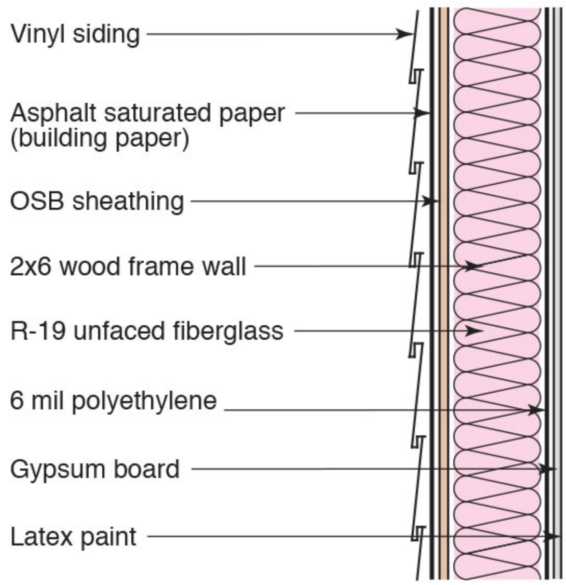

Figure 105: Round 3 - Wall 3 (Vinyl-OSB) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate zones; Figure 106 to Figure 111 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

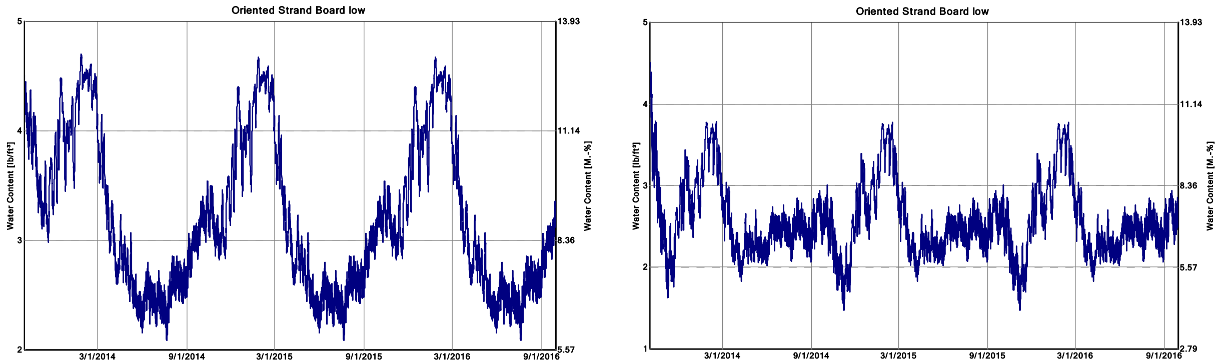

Figure 106: Round 3 - Wall 3 sheathing MC in Houston (Zone 2A), north (left) and south (right)

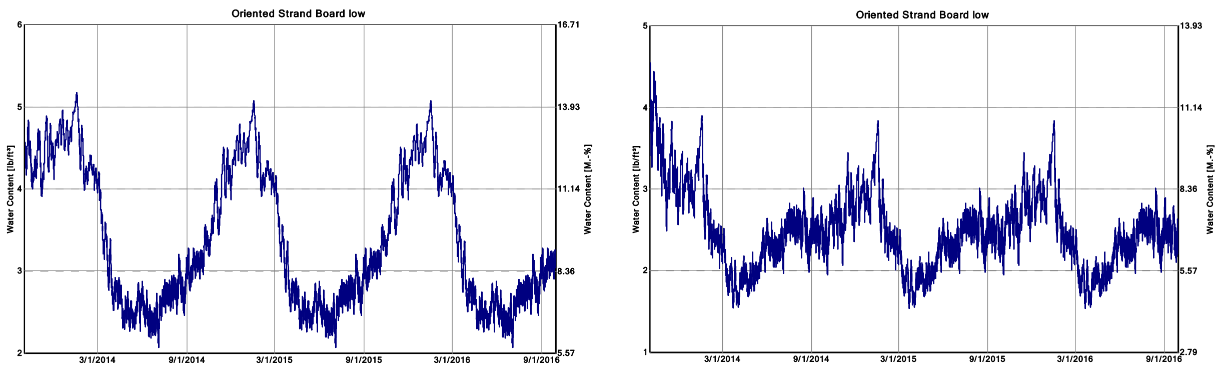

Figure 107: Round 3 - Wall 3 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

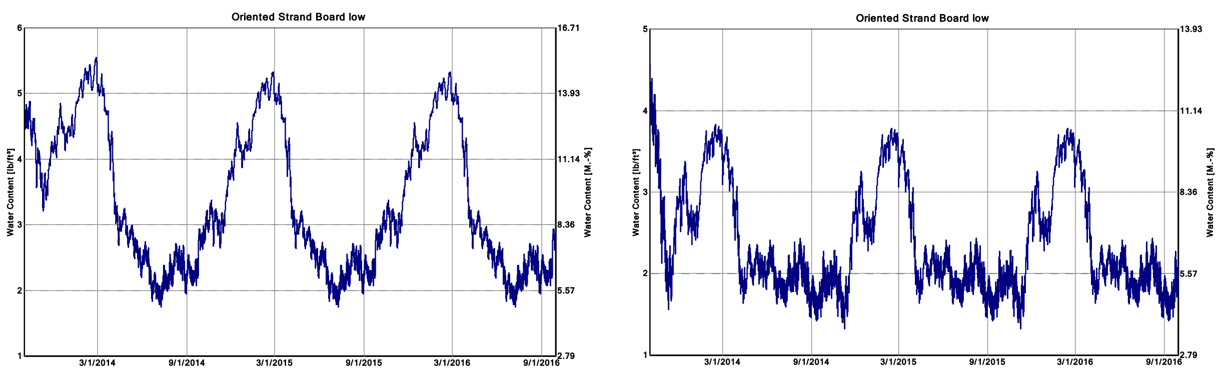

Figure 108: Round 3 - Wall 3 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

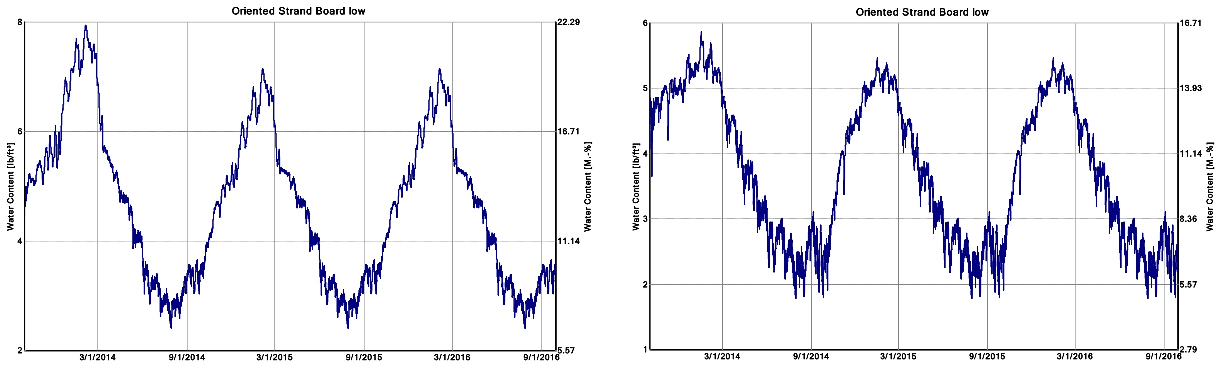

Figure 109: Round 3 - Wall 3 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

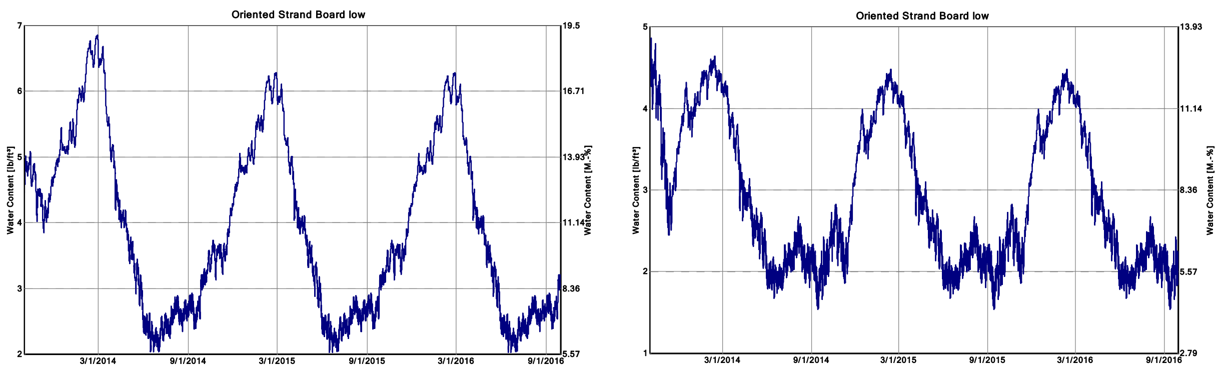

Figure 110: Round 3 - Wall 3 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

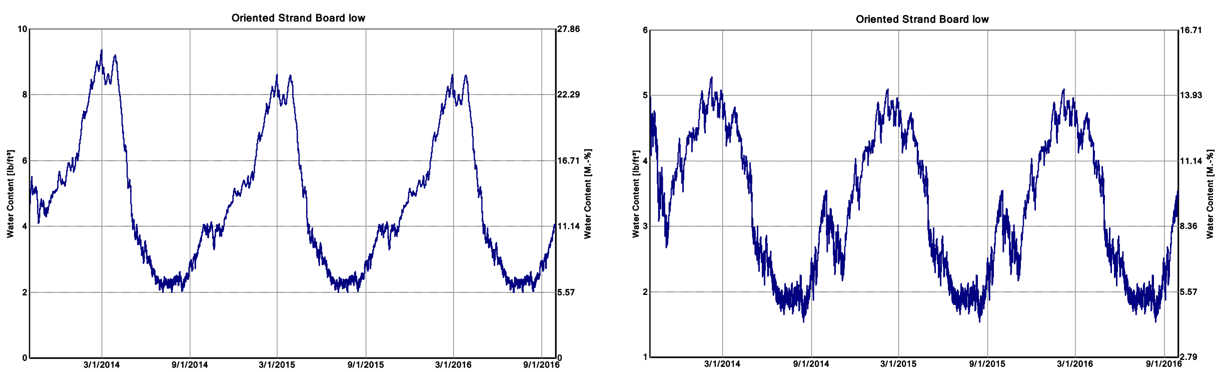

Figure 111: Round 3 - Wall 3 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.3.4 Wall 4 (Brick-OSB)

Table 22 shows the layers in the fourth wall of the Round Three (Figure 112) from exterior to interior and their respective functions.

Table 22: Round 3 – Wall 4 (Brick-OSB) layers

Layer	Function
Brick veneer	provides exterior finish for aesthetics
Asphalt saturated Kraft paper (building paper)	functions as air and water control layer
OSB sheathing	provides structural support
2x6 framing	provides structural support
R-19 fiberglass batt	functions as thermal control layer
6 mil polyethylene	functions as vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

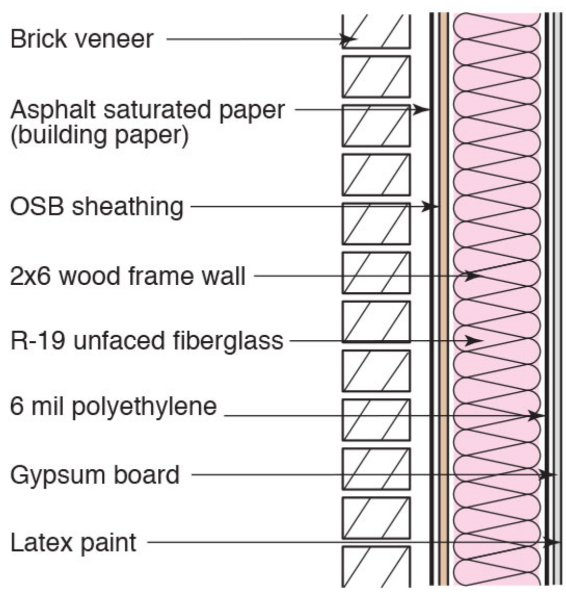

Figure 112: Round 3 - Wall 4 (Brick-OSB) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate zones; Figure 113 to Figure 118 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

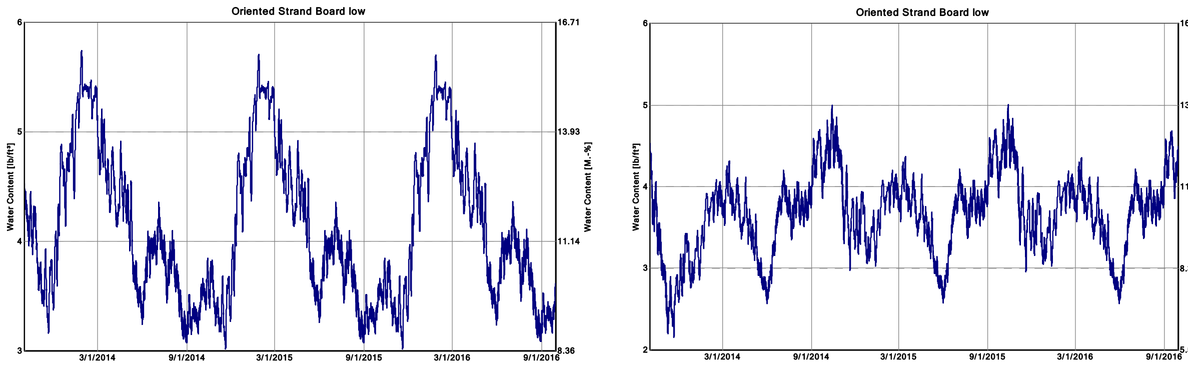

Figure 113: Round 3 - Wall 4 sheathing MC in Houston (Zone 2A), north (left) and south (right)

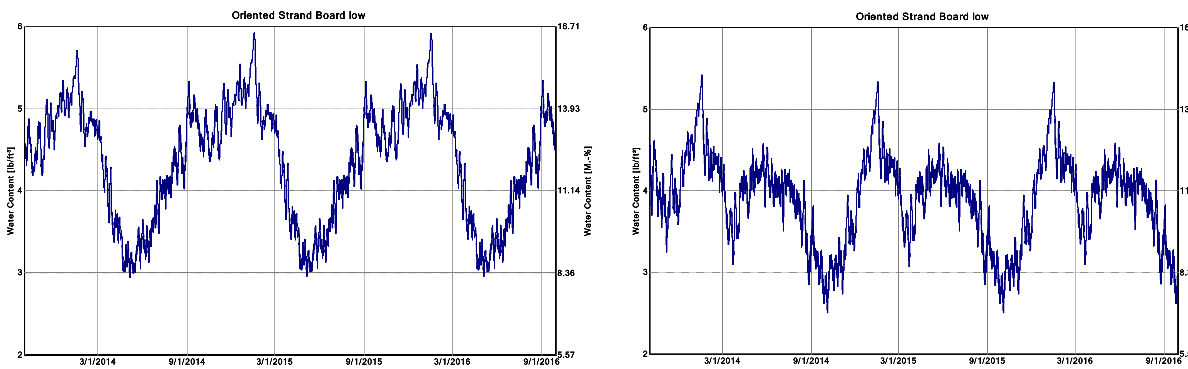

Figure 114: Round 3 - Wall 4 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

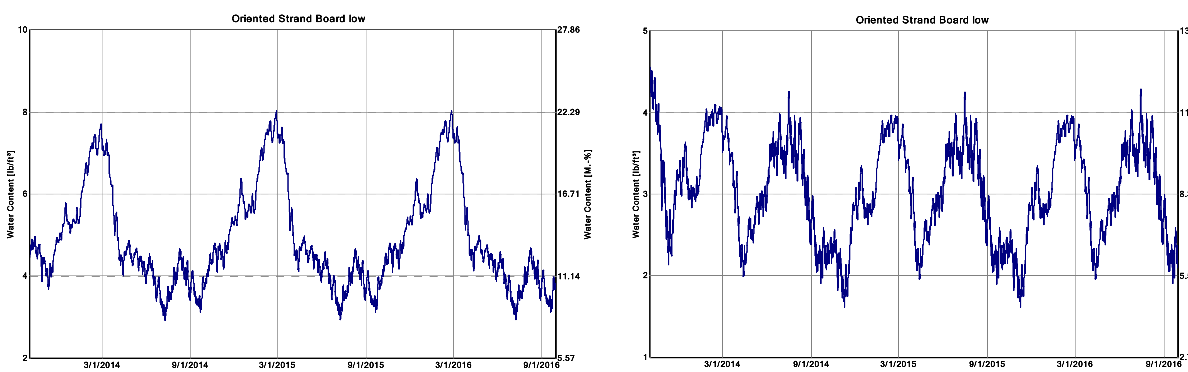

Figure 115: Round 3 - Wall 4 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

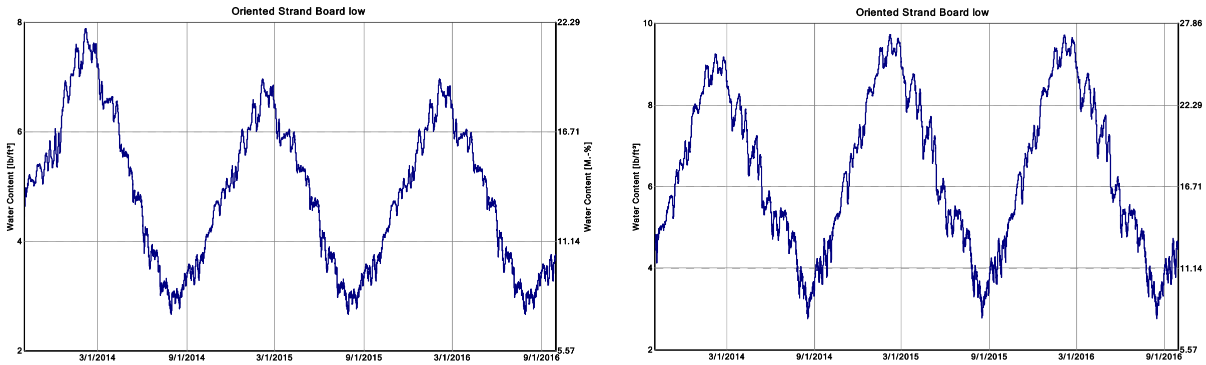

Figure 116: Round 3 - Wall 4 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

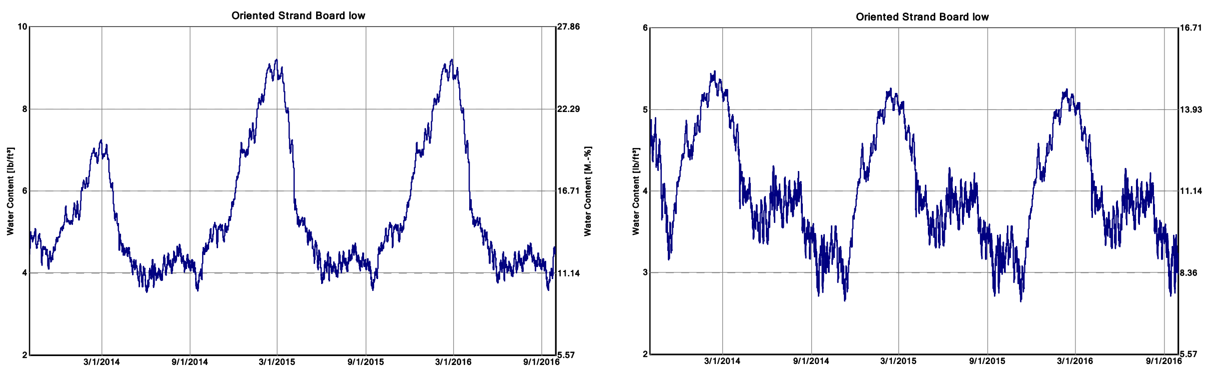

Figure 117: Round 3 - Wall 4 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

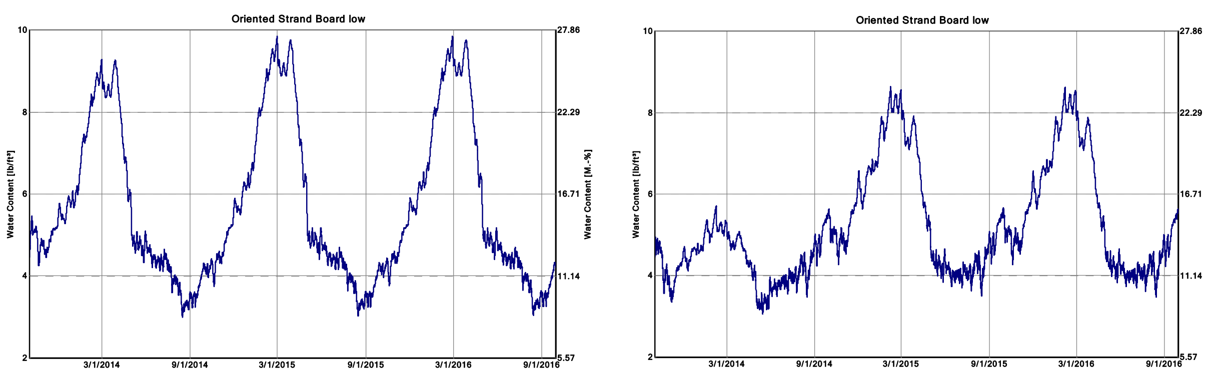

Figure 118: Round 3 - Wall 4 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.3.5 Wall 5 (Stucco-OSB)

Table 23 shows the layers in the fifth wall of the Round Three (Figure 119) from exterior to interior and their respective functions.

Table 23: Round 3 – Wall 5 (Stucco-OSB) layers

Layer	Function
Stucco	provides exterior finish for aesthetics
2 layers asphalt saturated Kraft paper (building paper)	functions as air and water control layer
OSB sheathing	provides structural support
2x6 framing	provides structural support
R-19 fiberglass batt	functions as thermal control layer
6 mil polyethylene	functions as vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

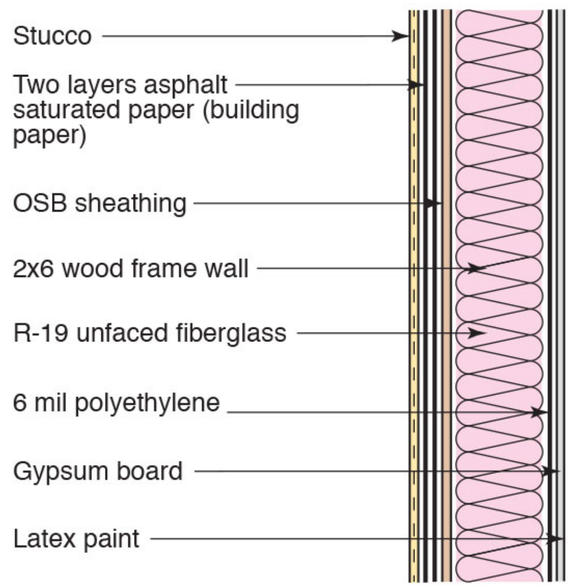

Figure 119: Round 3 - Wall 5 (Stucco-OSB) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate zones; Figure 120 to Figure 125 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

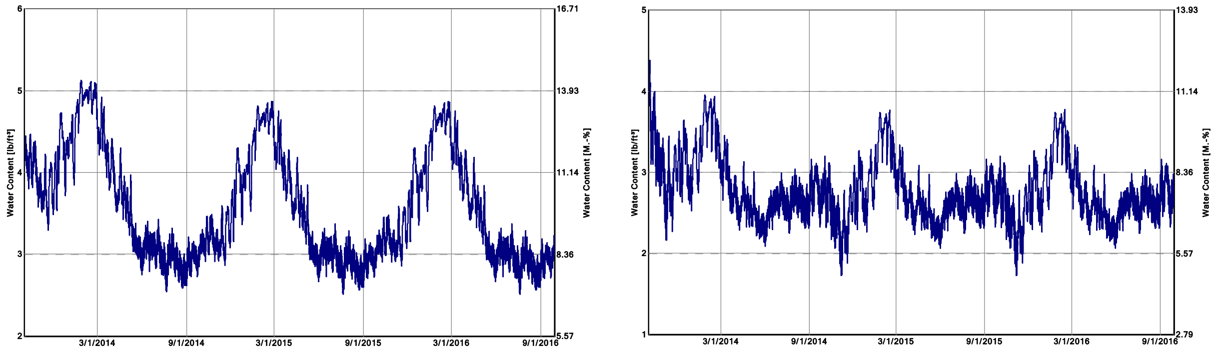

Figure 120: Round 3 - Wall 5 sheathing MC in Houston (Zone 2A), north (left) and south (right)

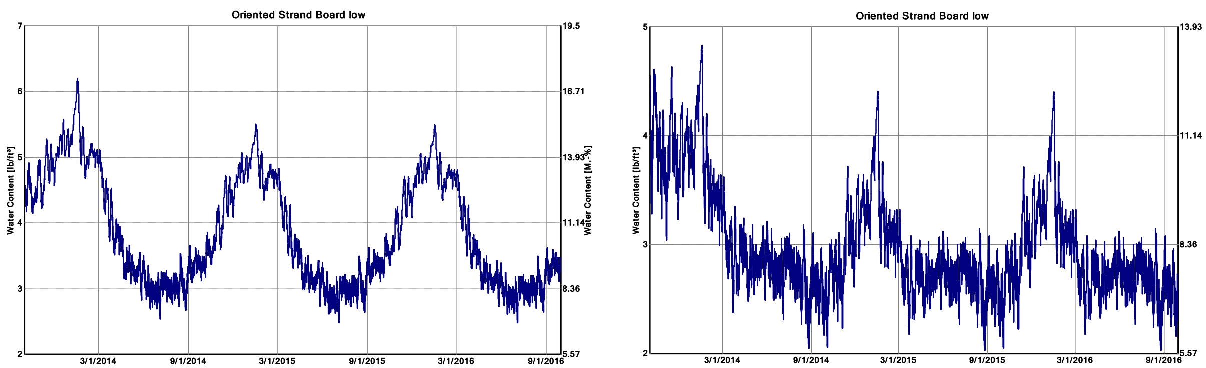

Figure 121: Round 3 - Wall 5 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

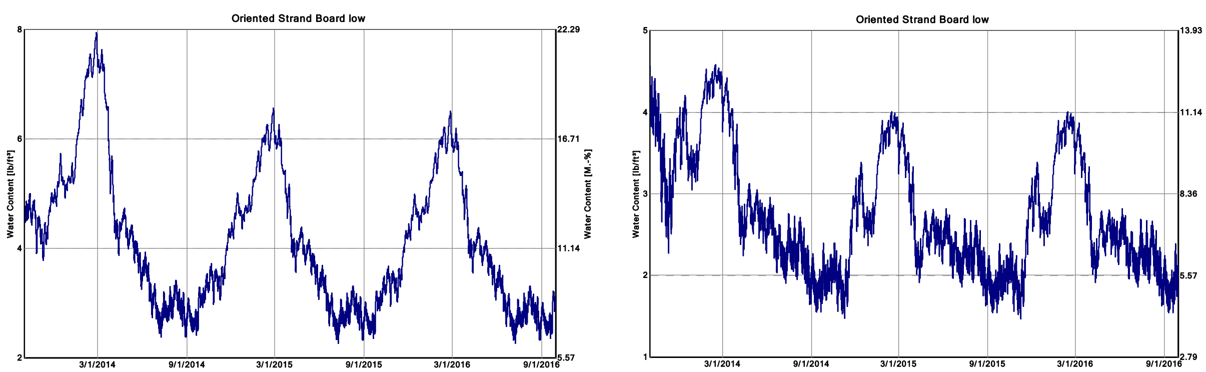

Figure 122: Round 3 - Wall 5 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

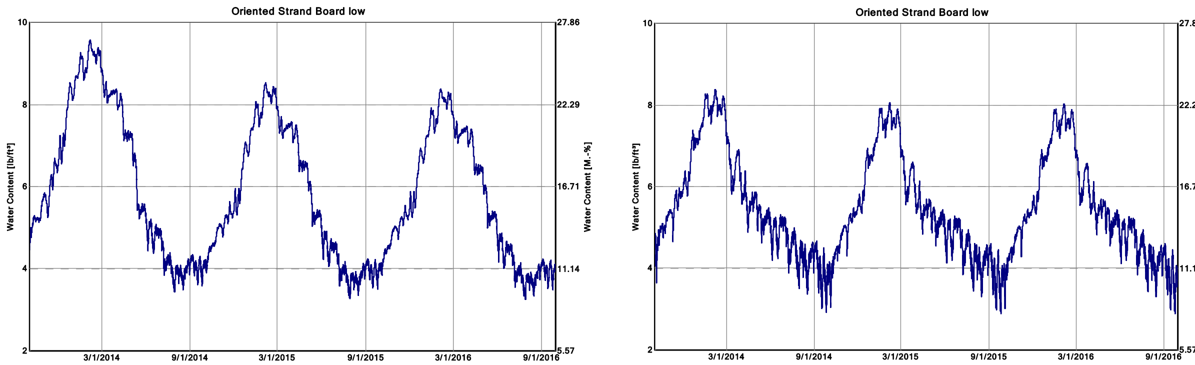

Figure 123: Round 3 - Wall 5 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

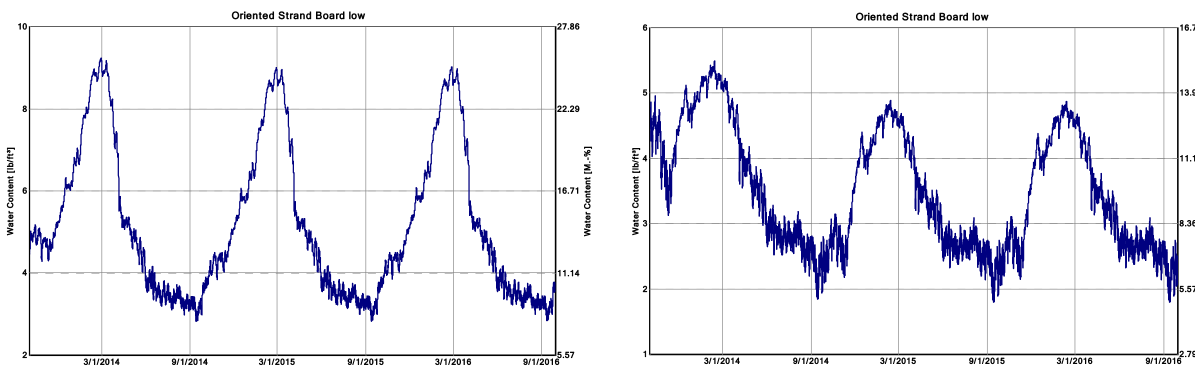

Figure 124: Round 3 - Wall 5 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

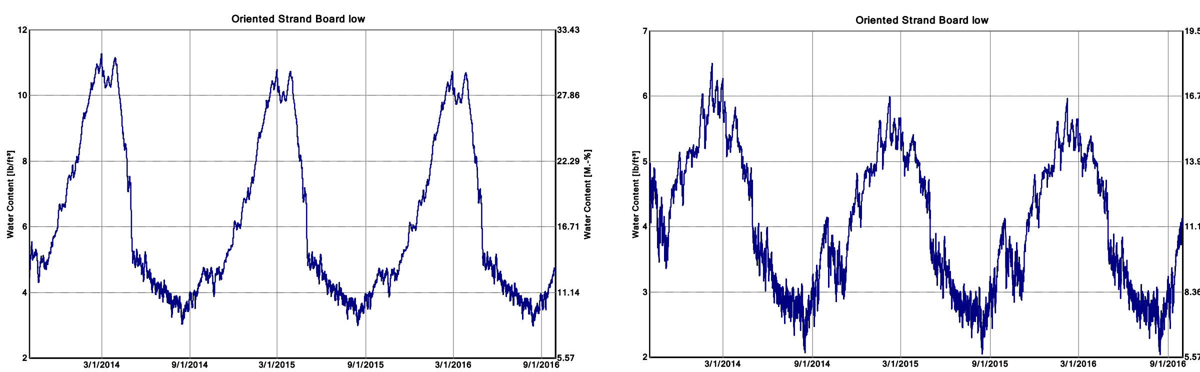

Figure 125: Round 3 - Wall 5 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

3.3.6 Wall 6 (Vented Stucco-OSB)

Table 24 shows the layers in the sixth wall of the Round Three (Figure 126) from exterior to interior and their respective functions.

Table 24: Round 3 – Wall 6 (Vented Stucco-OSB) layers

Layer	Function
Stucco	provides exterior finish for aesthetics
1 layer asphalt saturated Kraft paper (building paper)	provides backing for stucco
Polypropylene drainage mat (½ in.)	provides drainage and ventilation gap
Another layer asphalt saturated Kraft **paper (building paper)**	functions as air and water control layer
OSB sheathing	provides structural support
2x6 framing	provides structural support
R-19 fiberglass batt	functions as thermal control layer
6 mil polyethylene	functions as vapor control layer
Gypsum wall board	provides interior finish
Latex paint	functions as vapor drive throttle

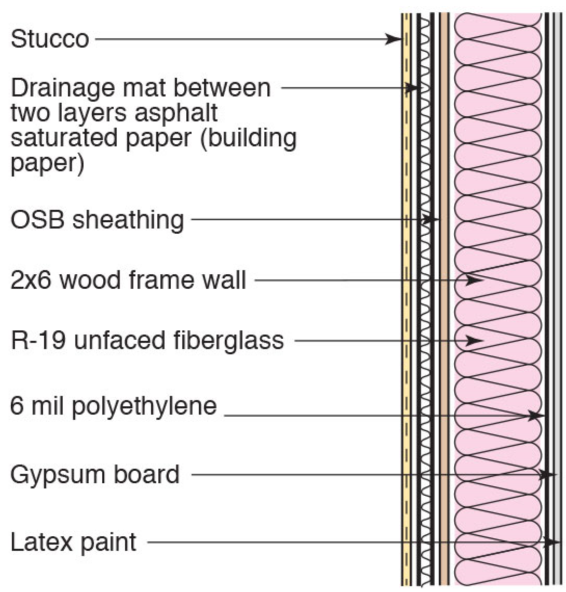

Figure 126: Round 3 - Wall 6 (Vented Stucco-OSB) configuration

WUFI simulations are run on this wall on both north and south orientations in 6 climate zones; Figure 127 to Figure 132 show the moisture content graphs of the inner face of wall sheathing over a period of 3 years.

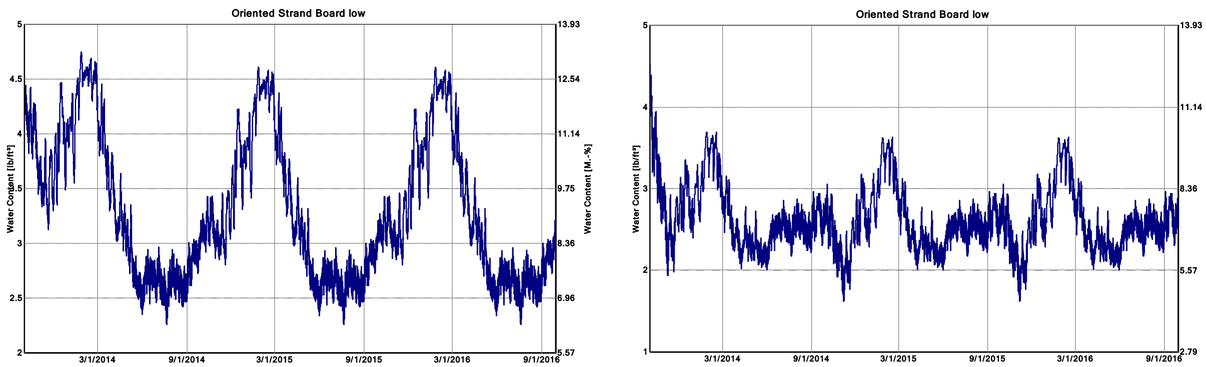

Figure 127: Round 3 - Wall 6 sheathing MC in Houston (Zone 2A), north (left) and south (right)

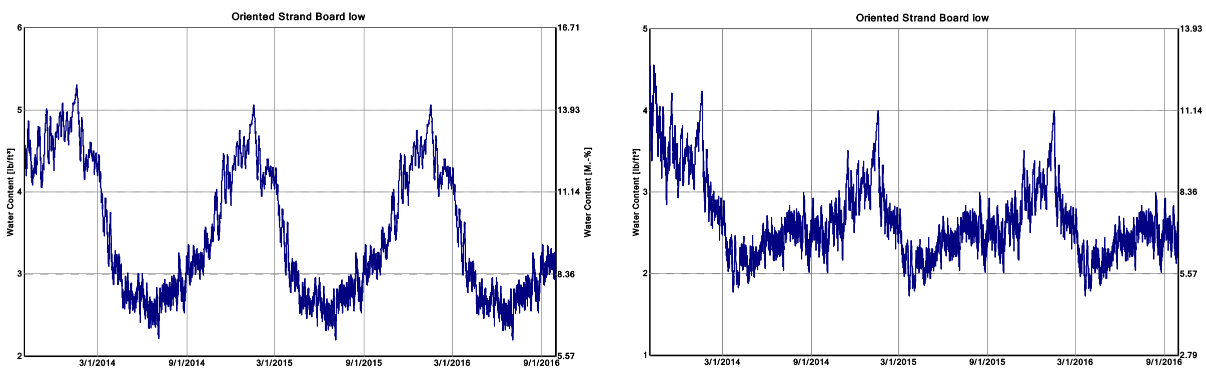

Figure 128: Round 3 - Wall 6 sheathing MC in Atlanta (Zone 3A), north (left) and south (right)

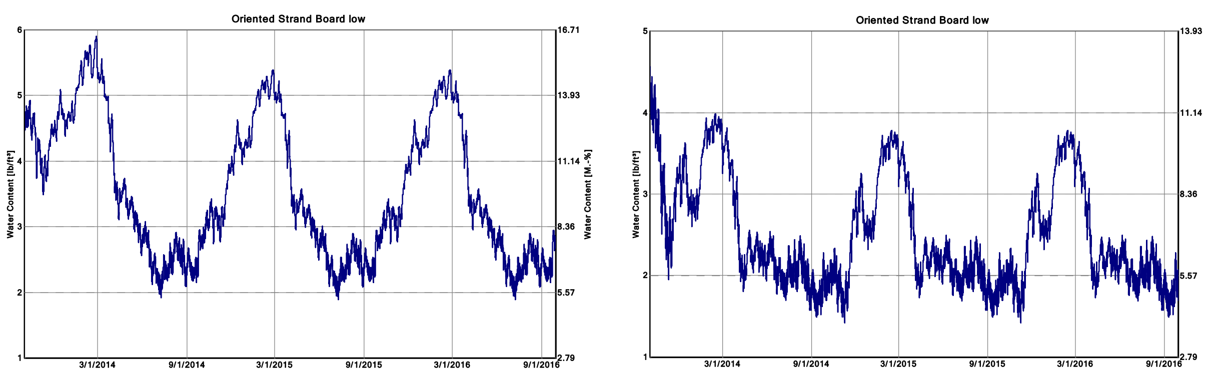

Figure 129: Round 3 - Wall 6 sheathing MC in Kansas City (Zone 4A), north (left) and south (right)

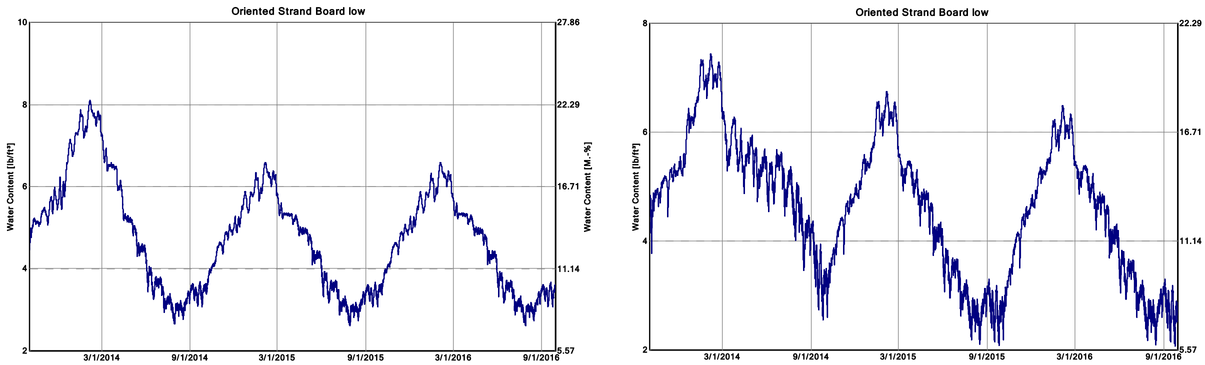

Figure 130: Round 3 - Wall 6 sheathing MC in Seattle (Zone 4C), north (left) and south (right)

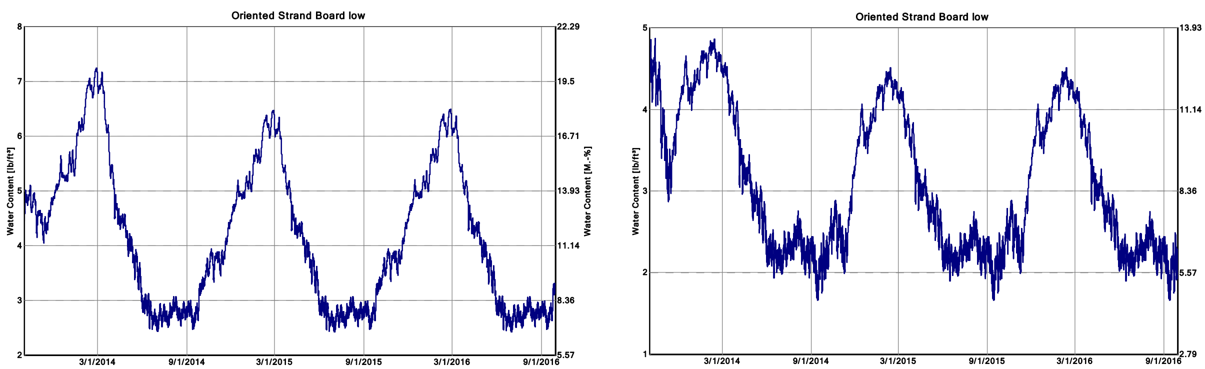

Figure 131: Round 3 - Wall 6 sheathing MC in Chicago (Zone 5A), north (left) and south (right)

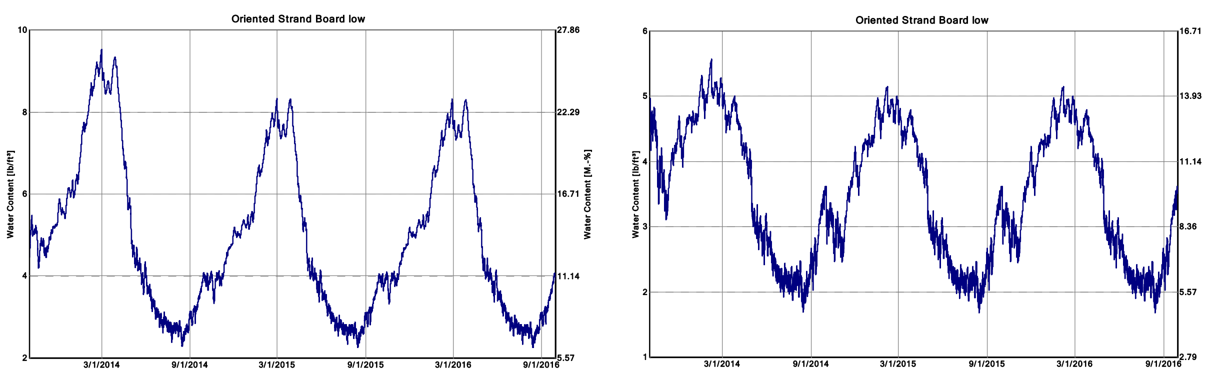

Figure 132: Round 3 - Wall 6 sheathing MC in Minneapolis (Zone 6A), north (left) and south (right)

4 Conclusions

The Technical Report describes the modeling of typical wall assemblies that have performed well historically in various climate zones. The WUFI (*Wärme und Feuchte instationär*) software (Version 5.3) model was used. A library of input data and results are provided. The provided information can be generalized for application to a broad population of houses, within the limits of existing experience.

The WUFI software model was calibrated or "tuned" using wall assemblies with historically successful performance. The primary performance criteria or failure criteria establishing historic performance was moisture content of the exterior sheathing – More specifically, historic reports of decay, based on observation of large numbers of wall assemblies ("buildings") over a decade or longer. The primary "tuning" parameters (simulation inputs) were airflow and specifying appropriate material properties. "Rational" hygric loads were established based on experience – specifically rain wetting and interior moisture (RH levels). The "tuning" parameters were limited or bounded by published data or experience.

The WUFI software model is a one-dimensional combined heat and moisture flow model. Typical building assemblies are multi-layer systems with complex three-dimensional airflow pathways. One-dimensional combined heat and moisture flow models have proven difficult to use for analysis in these types of assemblies due to the complexity added by the airflow component.

One challenge for a one-dimensional combined heat and moisture flow model is to address the rain and airflow components.

Rain is a significant moisture load: modeling the rain transport mechanism—a three dimensional phenomena in a multi-layer system—adds more complexity. The WUFI rain modeling inputs had the following assumptions:

- 30 percent of this water bounces off the wall and 70 percent is retained on the wall
- 1 percent of the 70 percent (the "retained water') is assumed to penetrate to the back side of the cladding
- 1 percent of the 1 percent is assumed to penetrate the water control layer and enter into the sheathing.

WUFI software is capable of modeling cladding ventilation, by introducing interior or exterior condition air into an airspace within the assembly. This allows for explicit (and correct) modeling of ventilated rainscreen behaviors, including vinyl siding (bypass of vapor-impermeable vinyl material with airflow) or brick veneer construction.

This airflow model within WUFI also allows the analysis of "through the assembly airflow" (i.e., air leakage through typical imperfect assemblies). This flow can be approximated as follows. Two arbitrary 5 mm (3/16 inch) airspaces are created at the interface of the cavity insulation and the structural sheathing. One airspace is coupled to the interior, simulating moves airtransported moisture from the interior to the interior face of the exterior sheathing. The other airspace is coupled to the exterior, and simulates air leakage from the exterior into the cavity.

Running the rainwater and airflow "tuned" WUFI software model generated the library of input data and results presented. The results agree with historical experience of these assemblies constructed in the climate zones modeled.

The WUFI templates provided with this report supply useful information resources to new or less-experienced users. The files present various custom settings that will help avoid results that will require overly conservative enclosure assemblies. Overall, better material data, consistent initial assumptions, and consistent inputs among practitioners will improve the quality of WUFI modeling, and improve the level of sophistication in the field.

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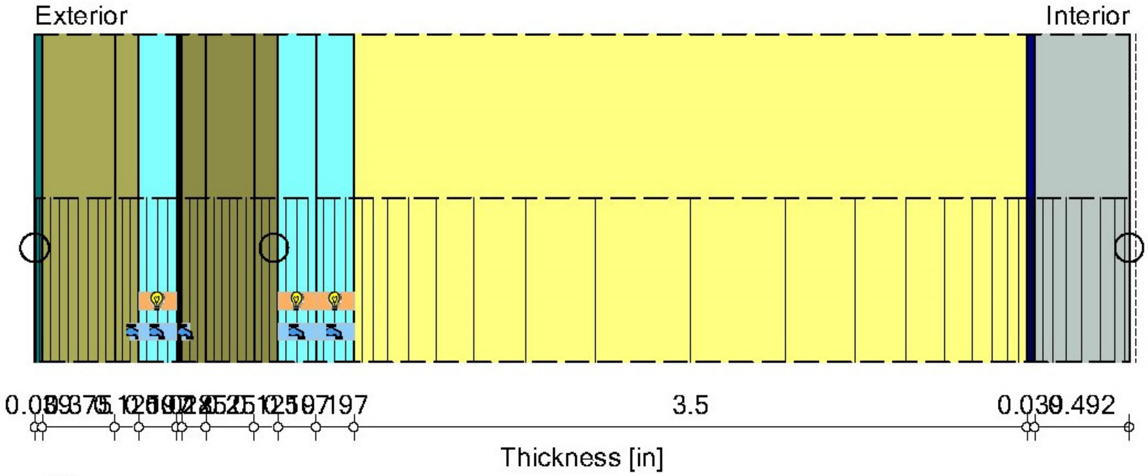
Appendix A: WUFI Component Assemblies

Round One – Wall 1 (Wood Siding-Ply)



○ - Monitor positions

- Heat/Moisture source/sink positions

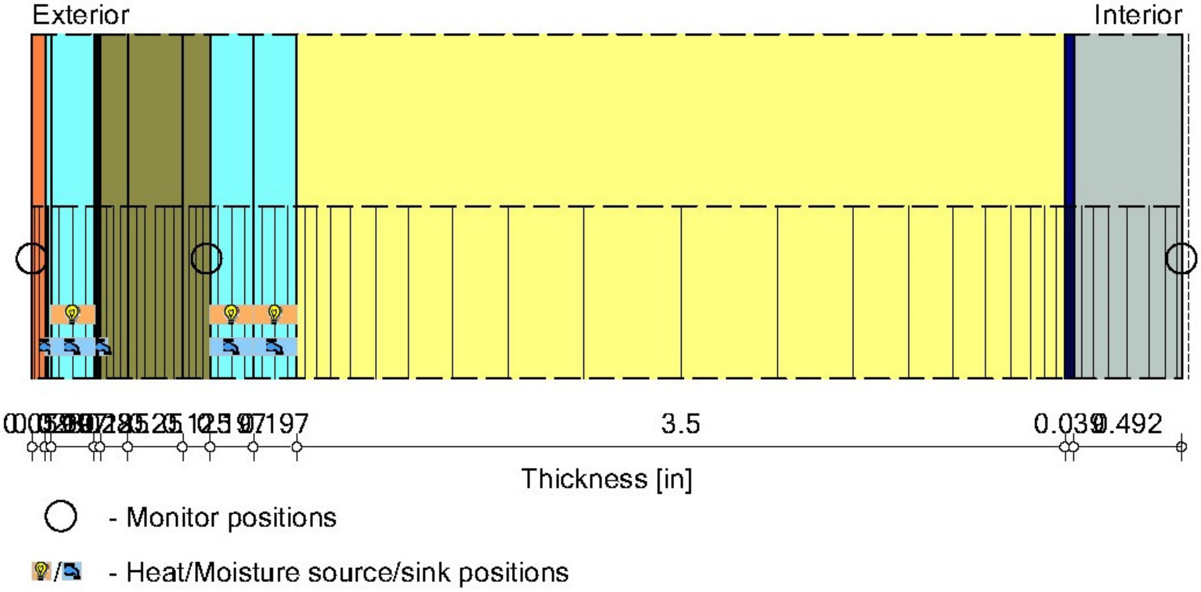
Materials:

- *(BSC) Latex Paint & Oil Primer for Wood Siding	0.039 in
- *Southern Yellow Pine	0.375 in
- *Southern Yellow Pine	0.125 in
- *Air Layer 5 mm; without additional moisture capacity	0.197 in
- *Bituminous Paper (#15 Felt)	0.028 in
- Plywood high	0.125 in
- Plywood high	0.25 in
- Plywood high	0.125 in
- *Air Layer 5 mm	0.197 in
- *Air Layer 5 mm	0.197 in
- *Fibre Glass (unlocked)	3.5 in
- *(BSC) Kraft Paper	0.039 in
- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 5.69 in
R-Value: 18.03 h ft² °F/Btu
U-Value: 0.052 Btu/h ft²°F

Round One – Wall 2 (Vinyl Siding-Ply)



Materials:

- *Vinyl Siding (no vapor perm)	0.059 in
- Air Layer 5 mm; without additional moisture capacity	0.028 in
- *Air Layer 5 mm; without additional moisture capacity	0.197 in
- *Bituminous Paper (#15 Felt)	0.028 in
- Plywood high	0.125 in
- Plywood high	0.25 in
- Plywood high	0.125 in
- *Air Layer 5 mm	0.197 in
- *Air Layer 5 mm	0.197 in
- *Fibre Glass (unlocked)	3.5 in
- *(BSC) Kraft Paper	0.039 in
- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 5.24 in
R-Value: 17.56 h ft² °F/Btu
U-Value: 0.054 Btu/h ft²°F

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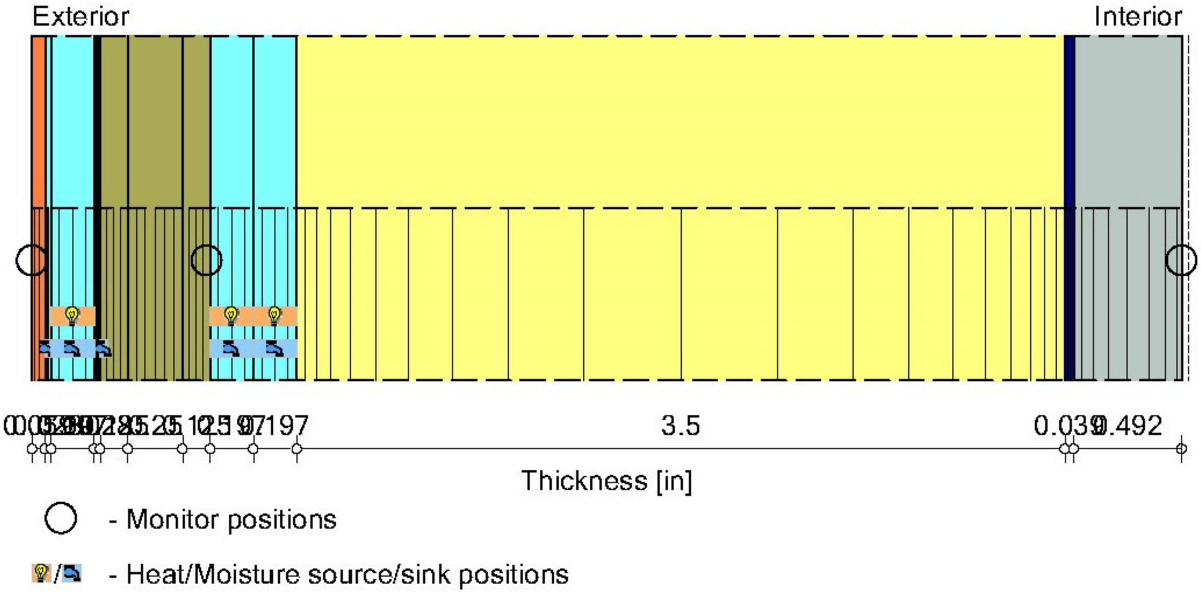
Round One – Wall 3 (Vinyl-OSB)



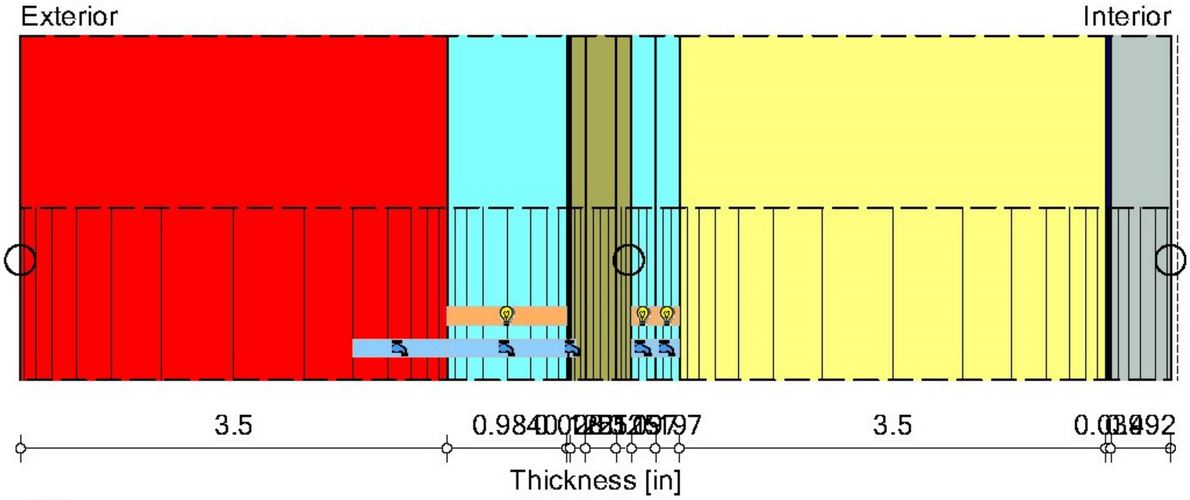
Materials:

- *Vinyl Siding (no vapor perm)	0.059 in
- Air Layer 5 mm; without additional moisture capacity	0.028 in
- *Air Layer 5 mm; without additional moisture capacity	0.197 in
- *Bituminous Paper (#15 Felt)	0.028 in
- Oriented Strand Board low	0.125 in
- Oriented Strand Board low	0.25 in
- Oriented Strand Board low	0.125 in
- *Air Layer 5 mm	0.197 in
- *Air Layer 5 mm	0.197 in
- *Fibre Glass (unlocked)	3.5 in
- *(BSC) Kraft Paper	0.039 in
- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 5.24 in
R-Value: 17.69 h ft² °F/Btu
U-Value: 0.053 Btu/h ft²°F

Round One – Wall 4 (Brick-OSB)



- Monitor positions

- Heat/Moisture source/sink positions

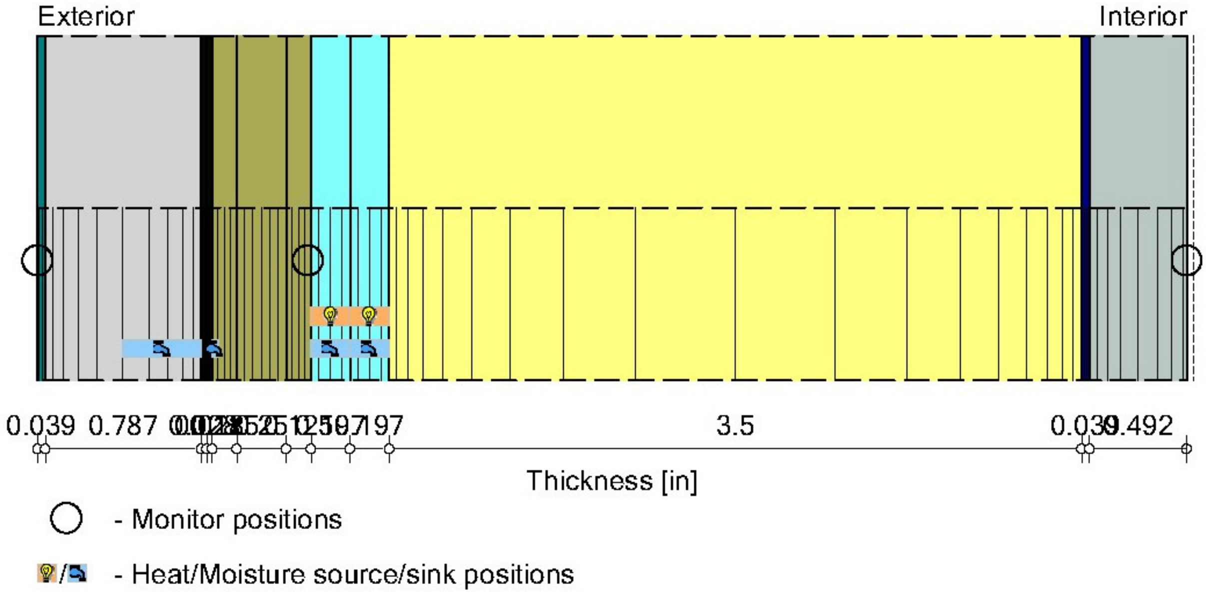
Materials:

- Solid Brick Masonry	3.5 in
- Air Layer 25 mm; without additional moisture capacity	0.984 in
- *Bituminous Paper (#15 Felt)	0.028 in
- Oriented Strand Board low	0.125 in
- Oriented Strand Board low	0.25 in
- Oriented Strand Board low	0.125 in
- *Air Layer 5 mm	0.197 in
- *Air Layer 5 mm	0.197 in
- *Fibre Glass (unlocked)	3.5 in
- *(BSC) Kraft Paper	0.039 in
- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 9.44 in
R-Value: 18.6 h ft² °F/Btu
U-Value: 0.051 Btu/h ft²°F

Round One – Wall 5 (Stucco-OSB)



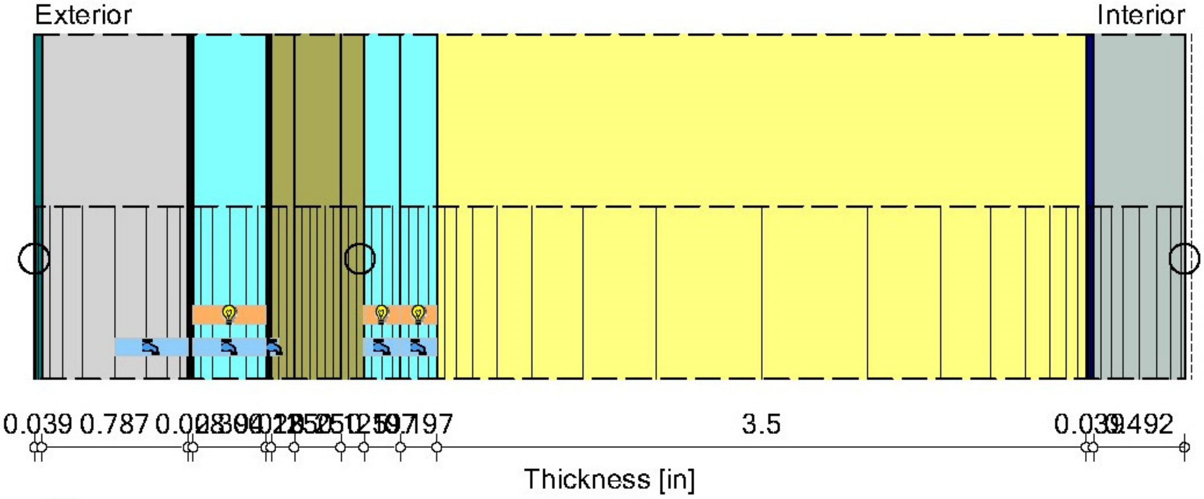
Materials:

- *(BSC) Latex Paint & Oil Primer for Wood Siding	0.039 in
- Regular Portland Stucco	0.787 in
- *Bituminous Paper (#15 Felt) Outer	0.028 in
- *Bituminous Paper (#15 Felt) Inner	0.028 in
- Oriented Strand Board low	0.125 in
- Oriented Strand Board low	0.25 in
- Oriented Strand Board low	0.125 in
- *Air Layer 5 mm	0.197 in
- *Air Layer 5 mm	0.197 in
- *Fibre Glass (unlocked)	3.5 in
- *(BSC) Kraft Paper	0.039 in
- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 5.81 in
R-Value: 17.23 h ft² °F/Btu
U-Value: 0.055 Btu/h ft²°F

Round One – Wall 6 (Vented Stucco-OSB)



- Monitor positions

- Heat/Moisture source/sink positions

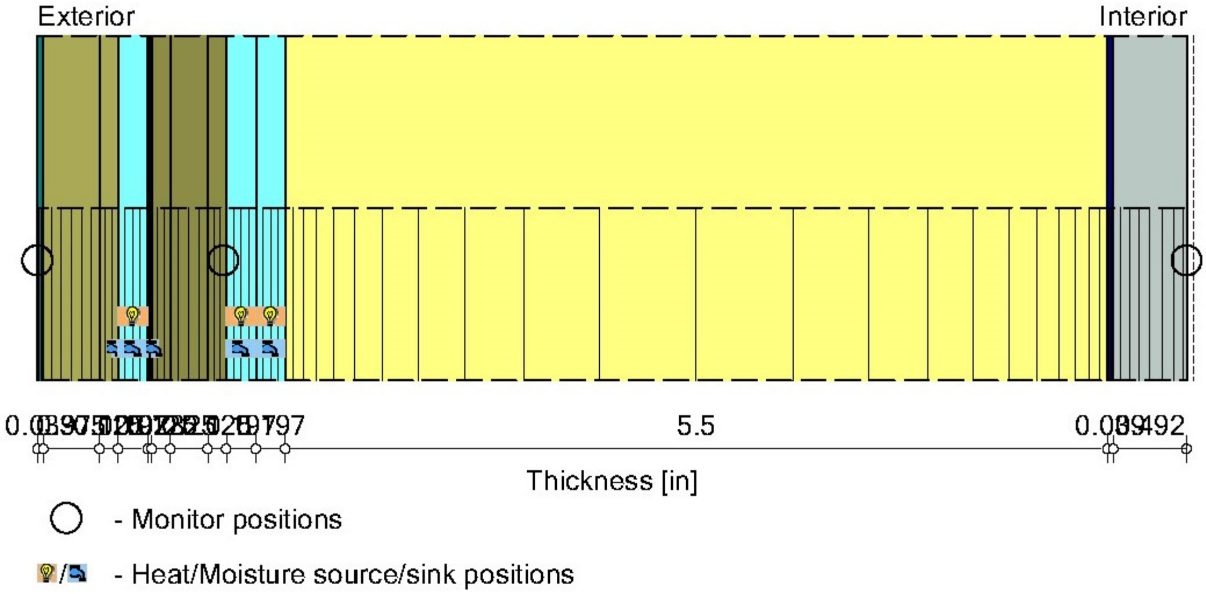
Materials:

- *(BSC) Latex Paint & Oil Primer for Wood Siding	0.039 in
- Regular Portland Stucco	0.787 in
- *Bituminous Paper (#15 Felt) Outer	0.028 in
- Air Layer 10 mm; without additional moisture capacity	0.394 in
- *Bituminous Paper (#15 Felt) Inner	0.028 in
- Oriented Strand Board low	0.125 in
- Oriented Strand Board low	0.25 in
- Oriented Strand Board low	0.125 in
- *Air Layer 5 mm	0.197 in
- *Air Layer 5 mm	0.197 in
- *Fibre Glass (unlocked)	3.5 in
- *(BSC) Kraft Paper	0.039 in
- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 6.2 in
R-Value: 18.04 h ft² °F/Btu
U-Value: 0.052 Btu/h ft²°F

Round Two – Wall 1 (Wood Siding-Ply)



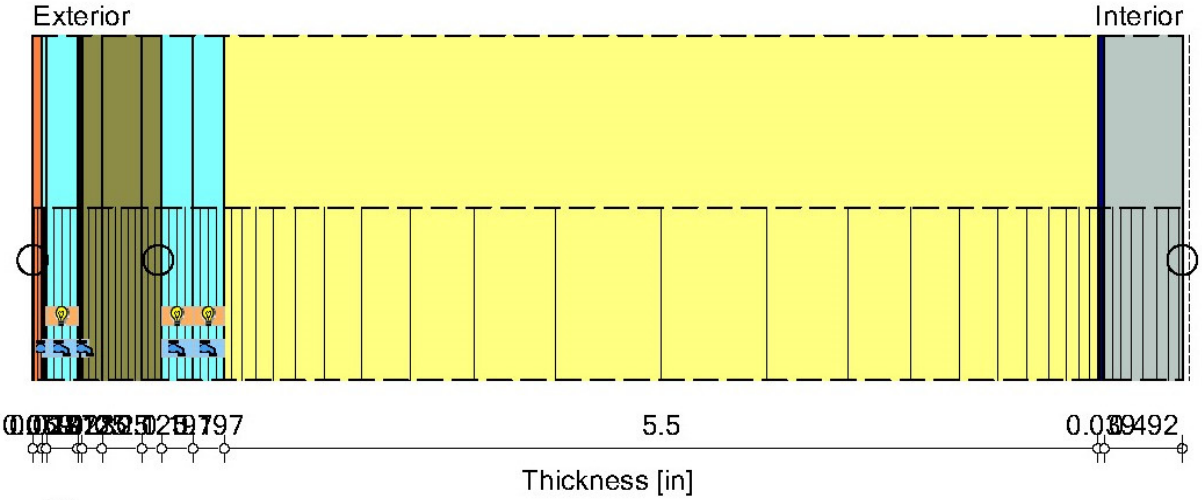
Materials:

- *(BSC) Latex Paint & Oil Primer for Wood Siding	0.039 in
- *Southern Yellow Pine	0.375 in
- *Southern Yellow Pine	0.125 in
- *Air Layer 5 mm; without additional moisture capacity	0.197 in
- *Bituminous Paper (#15 Felt)	0.028 in
- Plywood high	0.125 in
- Plywood high	0.25 in
- Plywood high	0.125 in
- *Air Layer 5 mm	0.197 in
- *Air Layer 5 mm	0.197 in
- *Fibre Glass (unlocked)	5.5 in
- *(BSC) Kraft Paper	0.039 in
- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 7.69 in
R-Value: 26.29 h ft² °F/Btu
U-Value: 0.037 Btu/h ft²°F

Round Two – Wall 2 (Vinyl Siding-Ply)



○ - Monitor positions

- Heat/Moisture source/sink positions

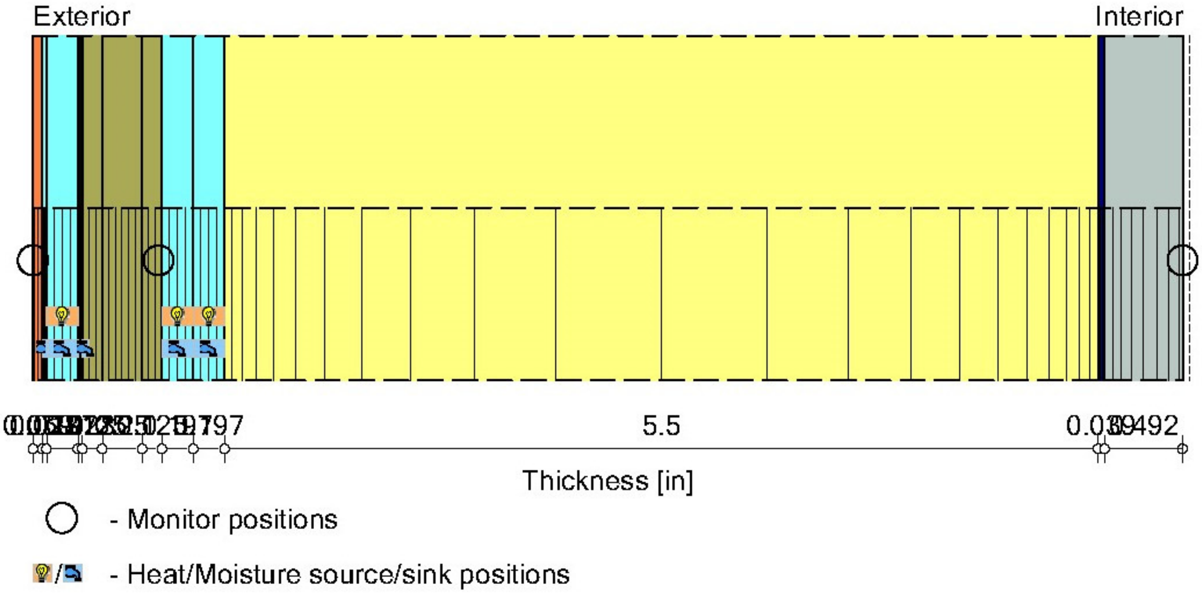
Materials:

- *Vinyl Siding (no vapor perm)	0.059 in
- Air Layer 5 mm; without additional moisture capacity	0.028 in
- *Air Layer 5 mm; without additional moisture capacity	0.197 in
- *Bituminous Paper (#15 Felt)	0.028 in
- Plywood high	0.125 in
- Plywood high	0.25 in
- Plywood high	0.125 in
- *Air Layer 5 mm	0.197 in
- *Air Layer 5 mm	0.197 in
- *Fibre Glass (unlocked)	5.5 in
- *(BSC) Kraft Paper	0.039 in
- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 7.24 in
R-Value: 25.82 h ft² °F/Btu
U-Value: 0.037 Btu/h ft²°F

Round Two – Wall 3 (Vinyl-OSB)



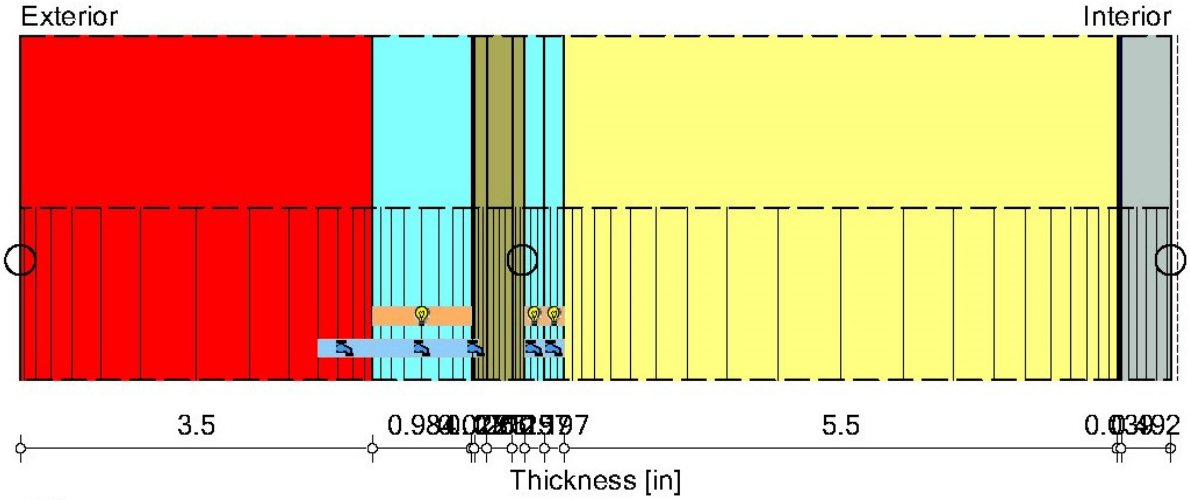
Materials:

	- *Vinyl Siding (no vapor perm)	0.059 in
	- Air Layer 5 mm; without additional moisture capacity	0.028 in
	- *Air Layer 5 mm; without additional moisture capacity	0.197 in
	- *Bituminous Paper (#15 Felt)	0.028 in
	- Oriented Strand Board low	0.125 in
	- Oriented Strand Board low	0.25 in
	- Oriented Strand Board low	0.125 in
	- *Air Layer 5 mm	0.197 in
	- *Air Layer 5 mm	0.197 in
	- *Fibre Glass (unlocked)	5.5 in
	- *(BSC) Kraft Paper	0.039 in
	- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 7.24 in
R-Value: 25.95 h ft² °F/Btu
U-Value: 0.037 Btu/h ft²°F

Round Two – Wall 4 (Brick-OSB)



○ - Monitor positions

- Heat/Moisture source/sink positions

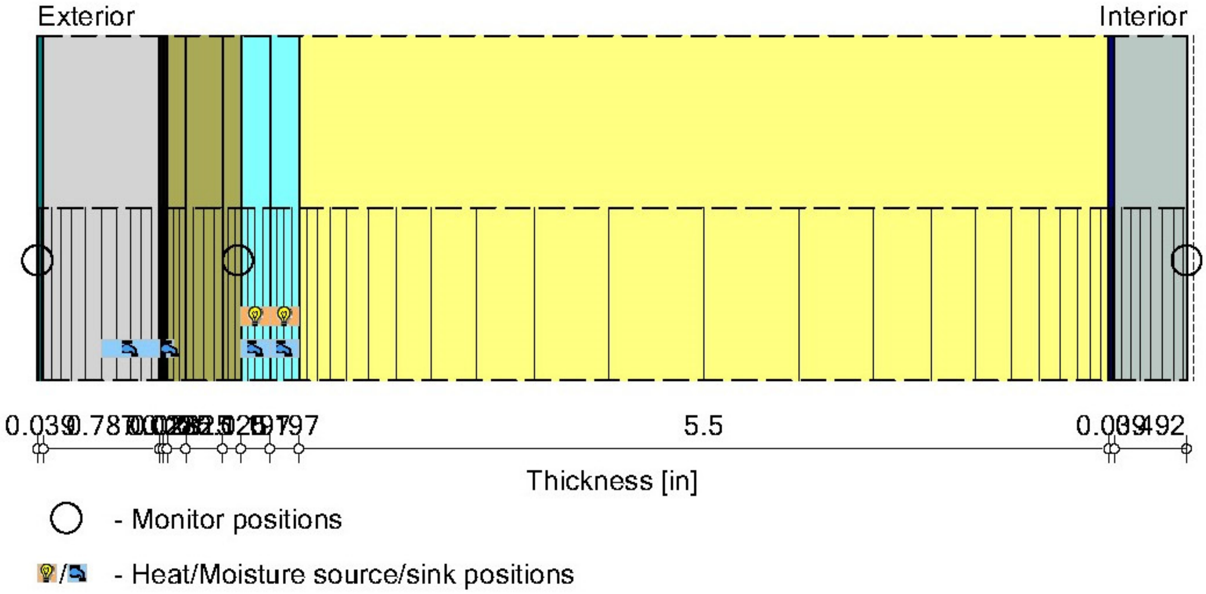
Materials:

- Solid Brick Masonry	3.5 in
- Air Layer 25 mm; without additional moisture capacity	0.984 in
- *Bituminous Paper (#15 Felt)	0.028 in
- Oriented Strand Board low	0.125 in
- Oriented Strand Board low	0.25 in
- Oriented Strand Board low	0.125 in
- *Air Layer 5 mm	0.197 in
- *Air Layer 5 mm	0.197 in
- *Fibre Glass (unlocked)	5.5 in
- *(BSC) Kraft Paper	0.039 in
- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 11.44 in
R-Value: 26.85 h ft² °F/Btu
U-Value: 0.036 Btu/h ft²°F

Round Two – Wall 5 (Stucco-OSB)



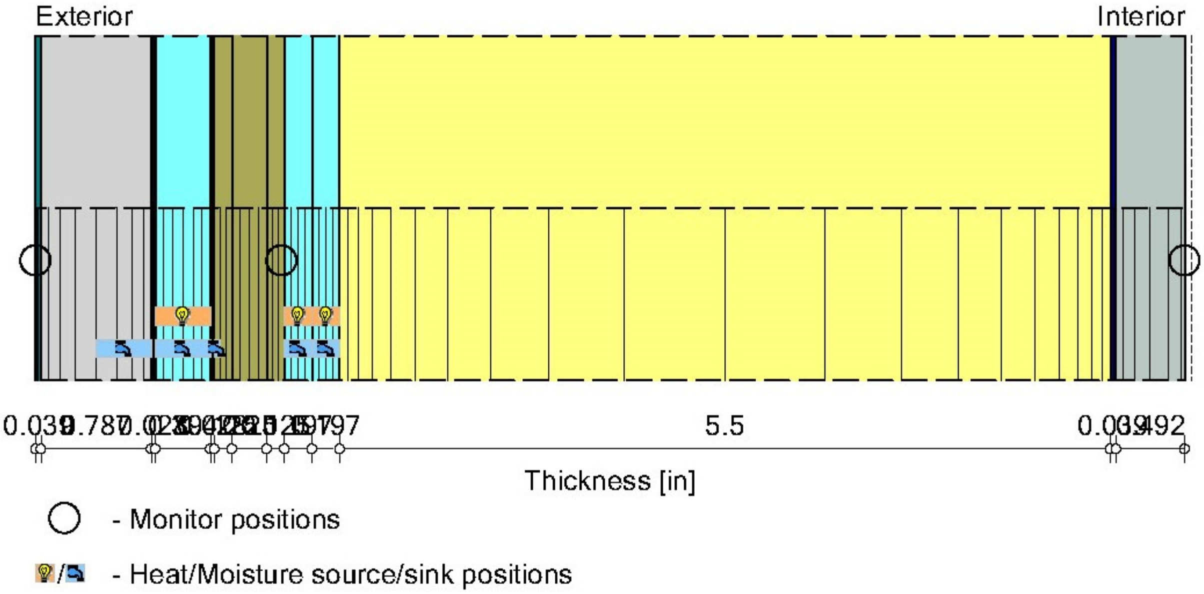
Materials:

- *(BSC) Latex Paint & Oil Primer for Wood Siding	0.039 in
- Regular Portland Stucco	0.787 in
- *Bituminous Paper (#15 Felt) Outer	0.028 in
- *Bituminous Paper (#15 Felt) Inner	0.028 in
- Oriented Strand Board low	0.125 in
- Oriented Strand Board low	0.25 in
- Oriented Strand Board low	0.125 in
- *Air Layer 5 mm	0.197 in
- *Air Layer 5 mm	0.197 in
- *Fibre Glass (unlocked)	5.5 in
- *(BSC) Kraft Paper	0.039 in
- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 7.81 in
R-Value: 25.49 h ft² °F/Btu
U-Value: 0.038 Btu/h ft²°F

Round Two – Wall 6 (Vented Stucco-OSB)



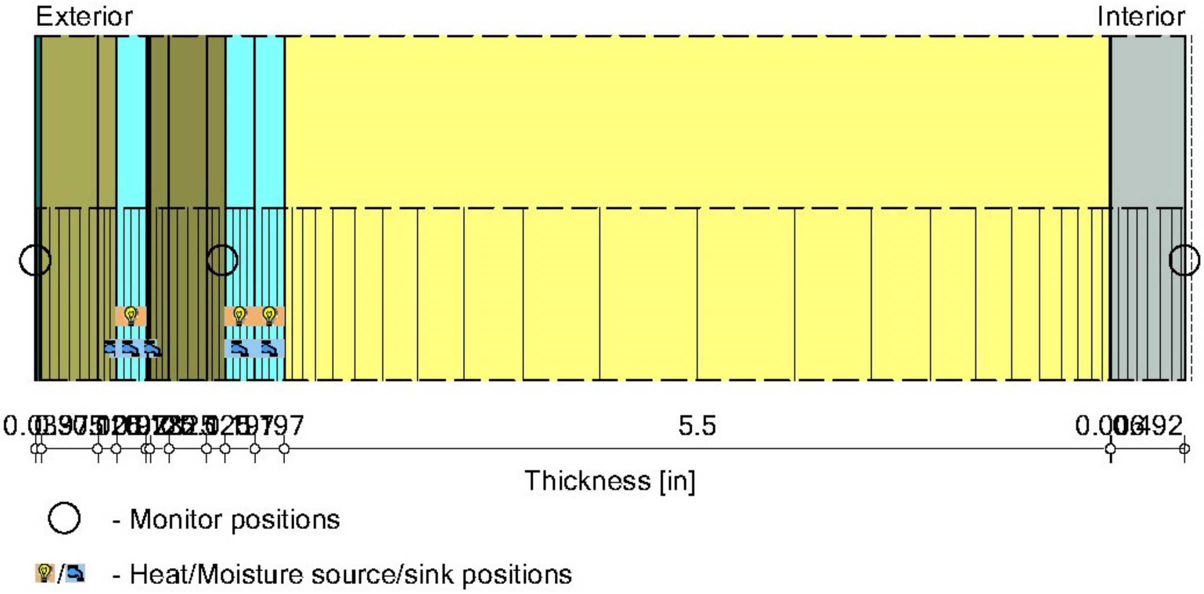
Materials:

	- *(BSC) Latex Paint & Oil Primer for Wood Siding	0.039 in
	- Regular Portland Stucco	0.787 in
	- *Bituminous Paper (#15 Felt) Outer	0.028 in
	- Air Layer 10 mm; without additional moisture capacity	0.394 in
	- *Bituminous Paper (#15 Felt) Inner	0.028 in
	- Oriented Strand Board low	0.125 in
	- Oriented Strand Board low	0.25 in
	- Oriented Strand Board low	0.125 in
	- *Air Layer 5 mm	0.197 in
	- *Air Layer 5 mm	0.197 in
	- *Fibre Glass (unlocked)	5.5 in
	- *(BSC) Kraft Paper	0.039 in
	- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 8.2 in
R-Value: 26.29 h ft² °F/Btu
U-Value: 0.037 Btu/h ft²°F

Round Three – Wall 1 (Wood Siding-Ply)



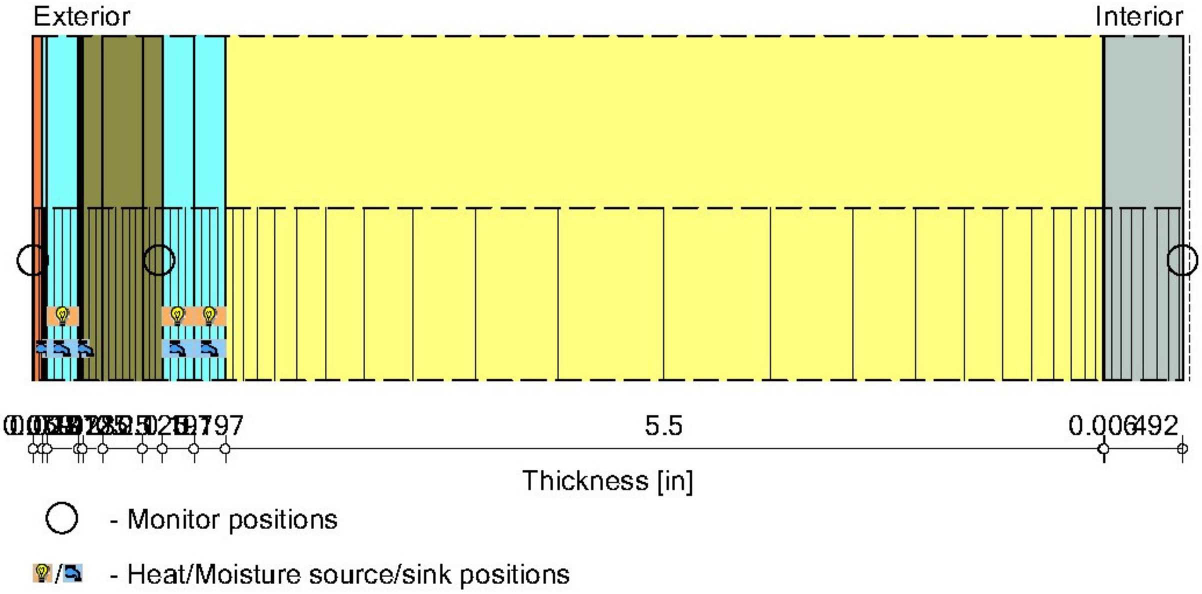
Materials:

- *(BSC) Latex Paint & Oil Primer for Wood Siding	0.039 in
- *Southern Yellow Pine	0.375 in
- *Southern Yellow Pine	0.125 in
- *Air Layer 5 mm; without additional moisture capacity	0.197 in
- *Bituminous Paper (#15 Felt)	0.028 in
- Plywood high	0.125 in
- Plywood high	0.25 in
- Plywood high	0.125 in
- *Air Layer 5 mm	0.197 in
- *Air Layer 5 mm	0.197 in
- *Fibre Glass (unlocked)	5.5 in
- vapor retarder (0.1perm)	0.006 in
- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 7.66 in
R-Value: 26.28 h ft² °F/Btu
U-Value: 0.037 Btu/h ft²°F

Round Three – Wall 2 (Vinyl Siding-Ply)



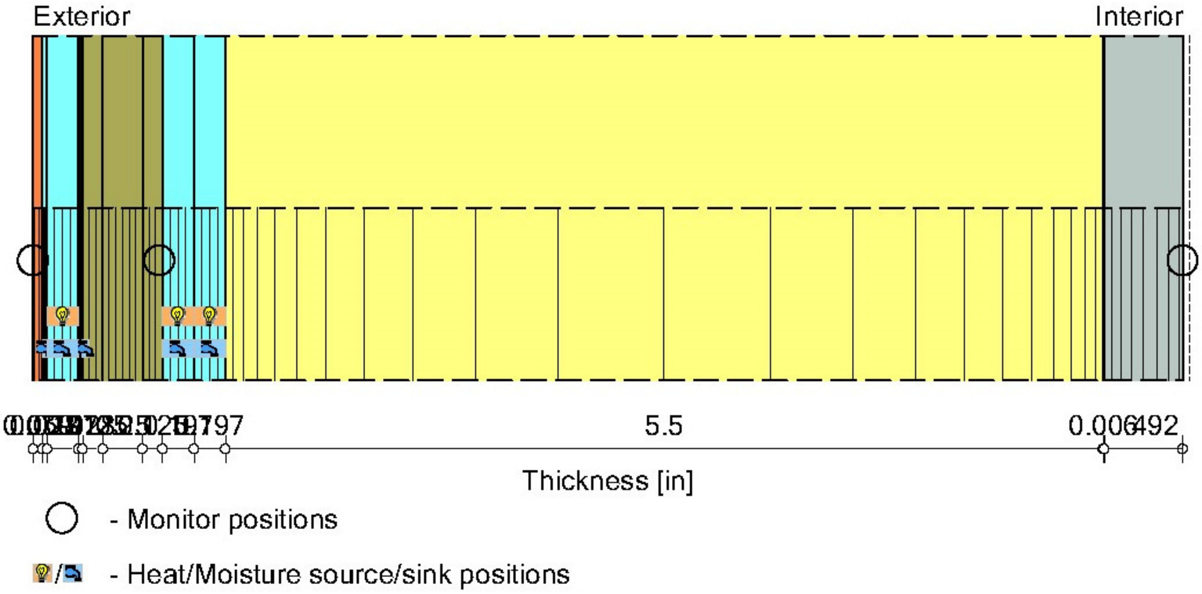
Materials:

(orange)	- *Vinyl Siding (no vapor perm)	0.059 in
(cyan)	- Air Layer 5 mm; without additional moisture capacity	0.028 in
(cyan)	- *Air Layer 5 mm; without additional moisture capacity	0.197 in
(black)	- *Bituminous Paper (#15 Felt)	0.028 in
(olive)	- Plywood high	0.125 in
(olive)	- Plywood high	0.25 in
(olive)	- Plywood high	0.125 in
(cyan)	- *Air Layer 5 mm	0.197 in
(cyan)	- *Air Layer 5 mm	0.197 in
(yellow)	- *Fibre Glass (unlocked)	5.5 in
(blue)	- vapor retarder (0.1perm)	0.006 in
(grey)	- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 7.2 in
R-Value: 25.8 h ft² °F/Btu
U-Value: 0.037 Btu/h ft²°F

Round Three – Wall 3 (Vinyl-OSB)



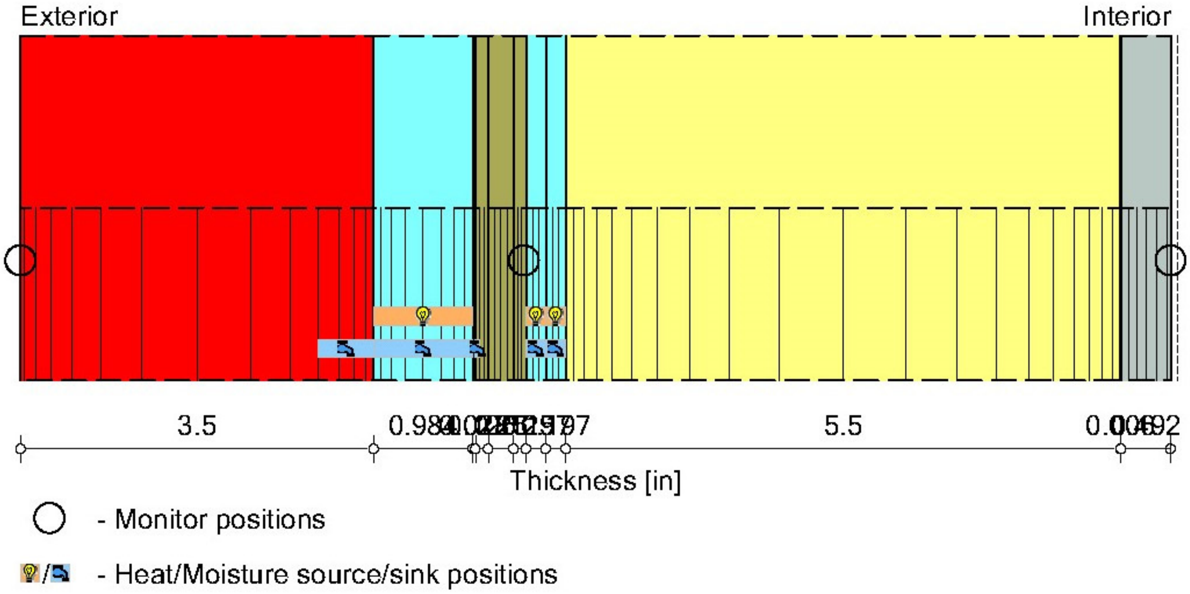
Materials:

- *Vinyl Siding (no vapor perm)	0.059 in
- Air Layer 5 mm; without additional moisture capacity	0.028 in
- *Air Layer 5 mm; without additional moisture capacity	0.197 in
- *Bituminous Paper (#15 Felt)	0.028 in
- Oriented Strand Board low	0.125 in
- Oriented Strand Board low	0.25 in
- Oriented Strand Board low	0.125 in
- *Air Layer 5 mm	0.197 in
- *Air Layer 5 mm	0.197 in
- *Fibre Glass (unlocked)	5.5 in
- vapor retarder (0.1perm)	0.006 in
- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 7.2 in
R-Value: 25.94 h ft² °F/Btu
U-Value: 0.037 Btu/h ft²°F

Round Three – Wall 4 (Brick-OSB)



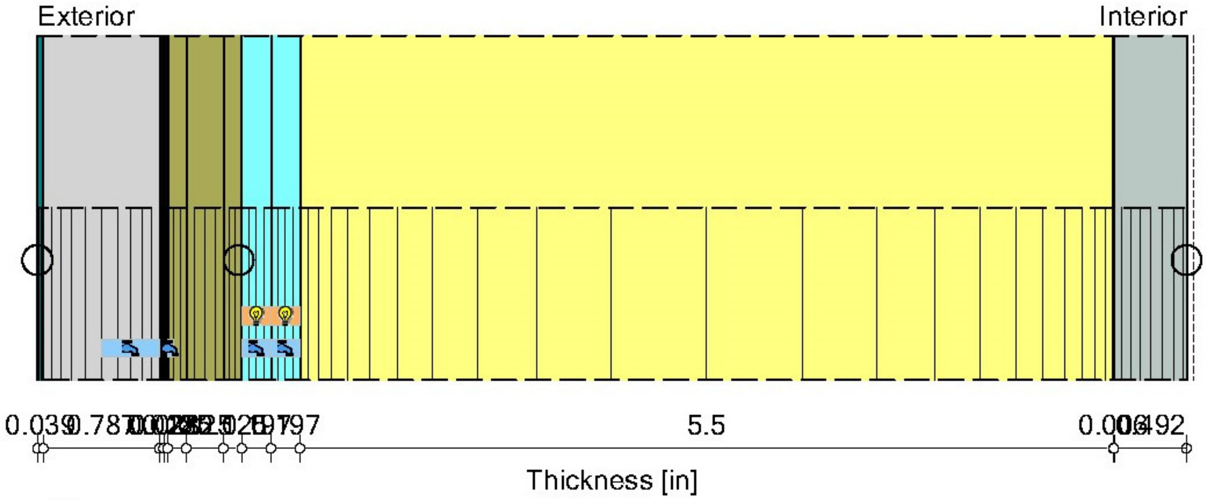
Materials:

- Solid Brick Masonry	3.5 in
- Air Layer 25 mm; without additional moisture capacity	0.984 in
- *Bituminous Paper (#15 Felt)	0.028 in
- Oriented Strand Board low	0.125 in
- Oriented Strand Board low	0.25 in
- Oriented Strand Board low	0.125 in
- *Air Layer 5 mm	0.197 in
- *Air Layer 5 mm	0.197 in
- *Fibre Glass (unlocked)	5.5 in
- vapor retarder (0.1perm)	0.006 in
- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 11.4 in
R-Value: 26.84 h ft² °F/Btu
U-Value: 0.036 Btu/h ft²°F

Round Three – Wall 5 (Stucco-OSB)



- Monitor positions

- Heat/Moisture source/sink positions

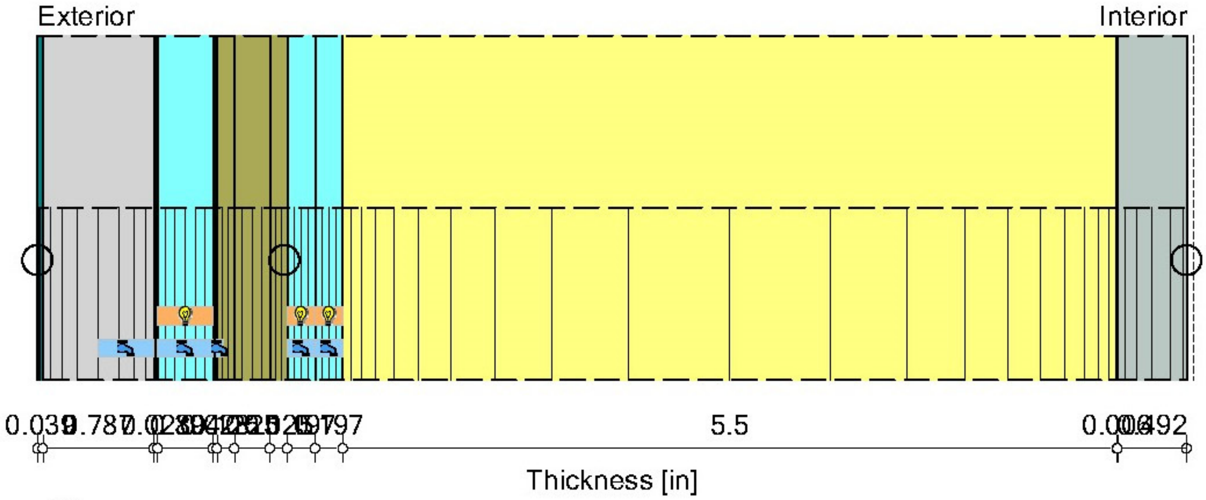
Materials:

- *(BSC) Latex Paint & Oil Primer for Wood Siding	0.039 in
- Regular Portland Stucco	0.787 in
- *Bituminous Paper (#15 Felt) Outer	0.028 in
- *Bituminous Paper (#15 Felt) Inner	0.028 in
- Oriented Strand Board low	0.125 in
- Oriented Strand Board low	0.25 in
- Oriented Strand Board low	0.125 in
- *Air Layer 5 mm	0.197 in
- *Air Layer 5 mm	0.197 in
- *Fibre Glass (unlocked)	5.5 in
- vapor retarder (0.1perm)	0.006 in
- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

Total Thickness: 7.77 in
R-Value: 25.48 h ft² °F/Btu
U-Value: 0.038 Btu/h ft²°F

Round Three – Wall 6 (Vented Stucco-OSB)



- Monitor positions

- Heat/Moisture source/sink positions

Materials:

- *(BSC) Latex Paint & Oil Primer for Wood Siding	0.039 in
- Regular Portland Stucco	0.787 in
- *Bituminous Paper (#15 Felt) Outer	0.028 in
- Air Layer 10 mm; without additional moisture capacity	0.394 in
- *Bituminous Paper (#15 Felt) Inner	0.028 in
- Oriented Strand Board low	0.125 in
- Oriented Strand Board low	0.25 in
- Oriented Strand Board low	0.125 in
- *Air Layer 5 mm	0.197 in
- *Air Layer 5 mm	0.197 in
- *Fibre Glass (unlocked)	5.5 in
- vapor retarder (0.1perm)	0.006 in
- *Gypsum Board (USA)	0.492 in

Sd-Value Int. [perm]: 10,0

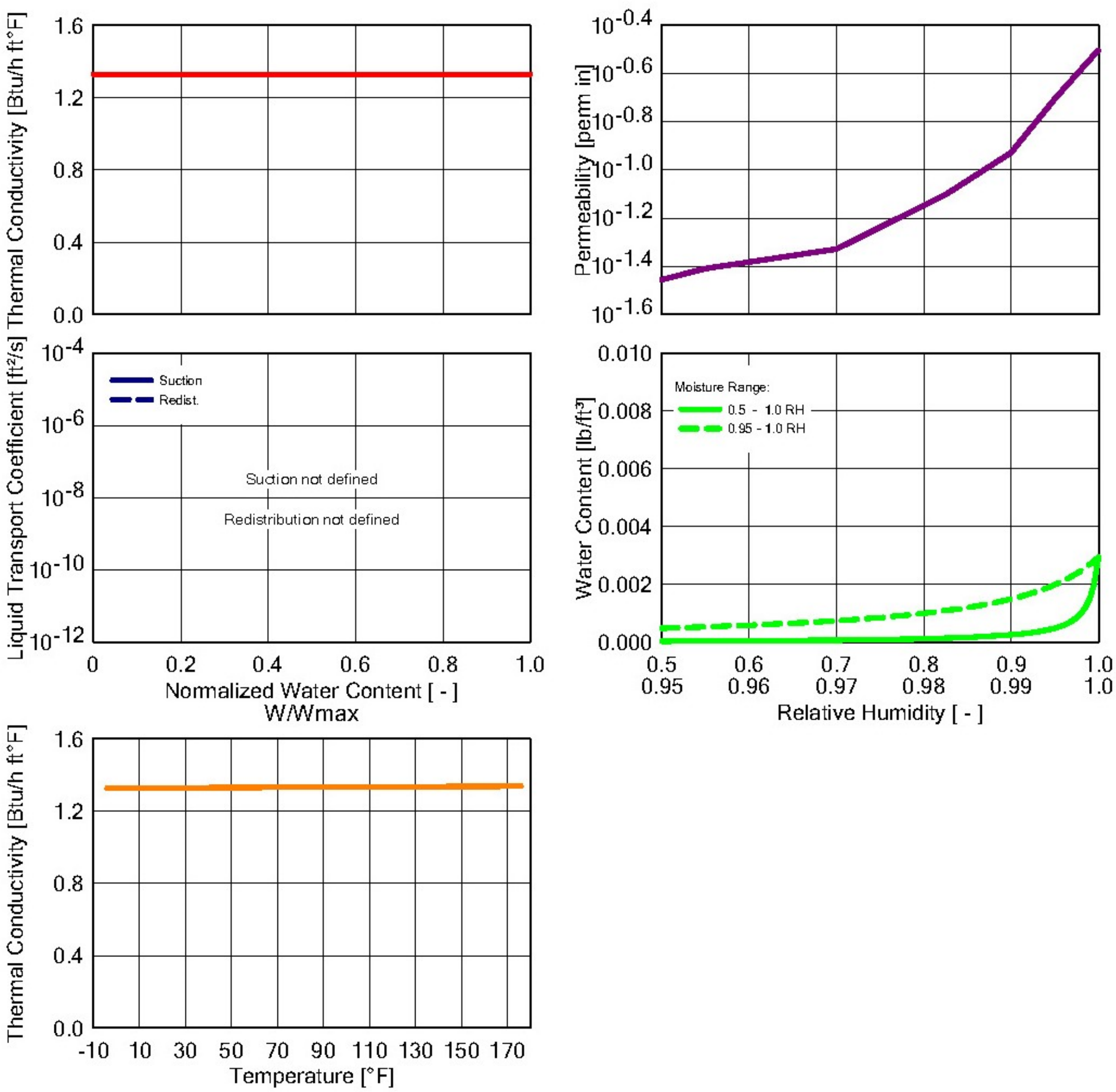
Total Thickness: 8.17 in
R-Value: 26.28 h ft² °F/Btu
U-Value: 0.037 Btu/h ft²°F

Appendix B: WUFI Materials

Material: *(BSC) Latex Paint & Oil Primer for Wood Siding

Checking Input Data

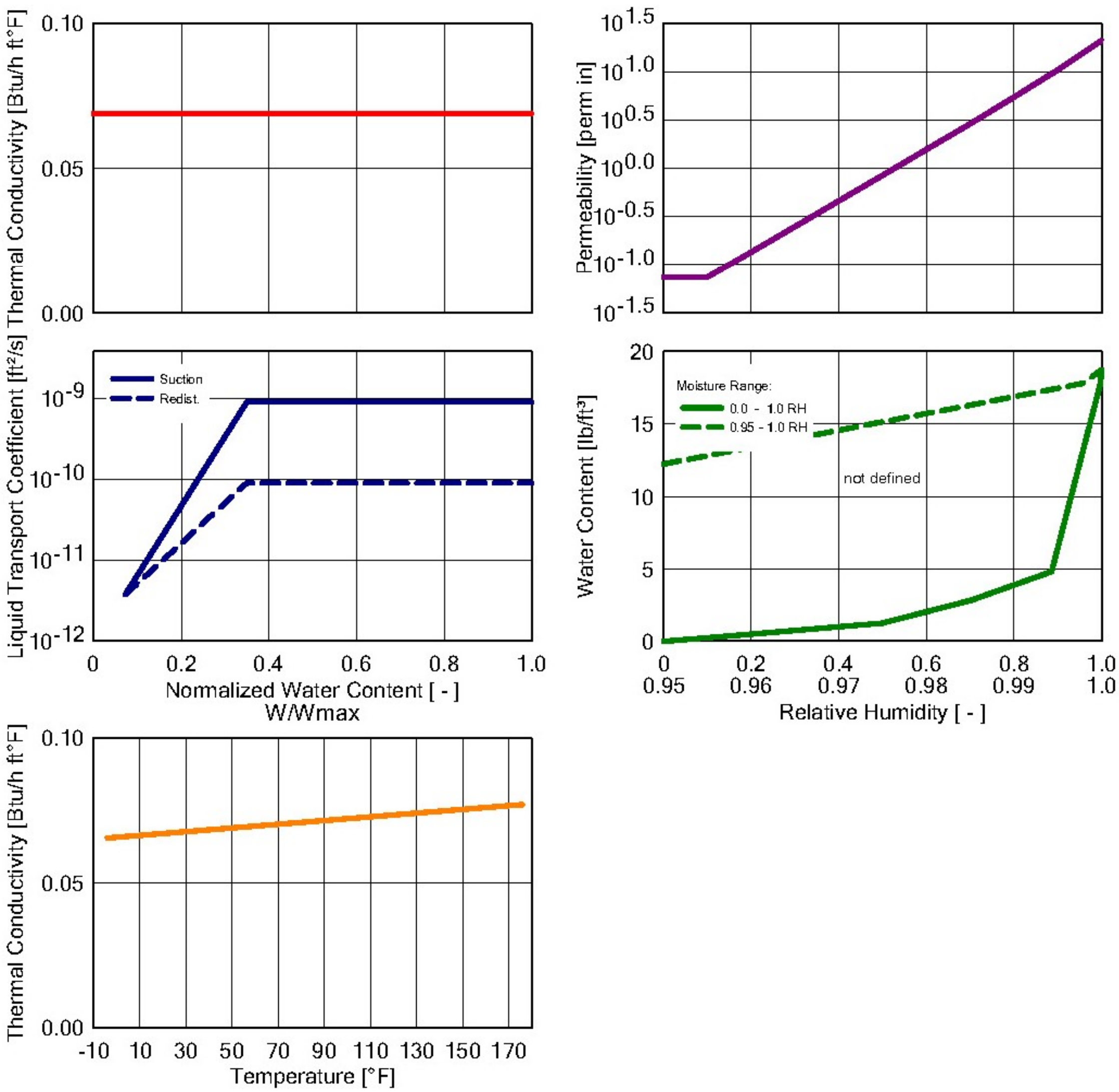
Property	Unit	Value
Bulk density	[lb/ft³]	8,116
Porosity	[ft³/ft³]	0,001
Specific Heat Capacity, Dry	[Btu/lb°F]	0,549
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	1,329
Permeability	[perm in]	0,035
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000640



Material: *Southern Yellow Pine

Checking Input Data

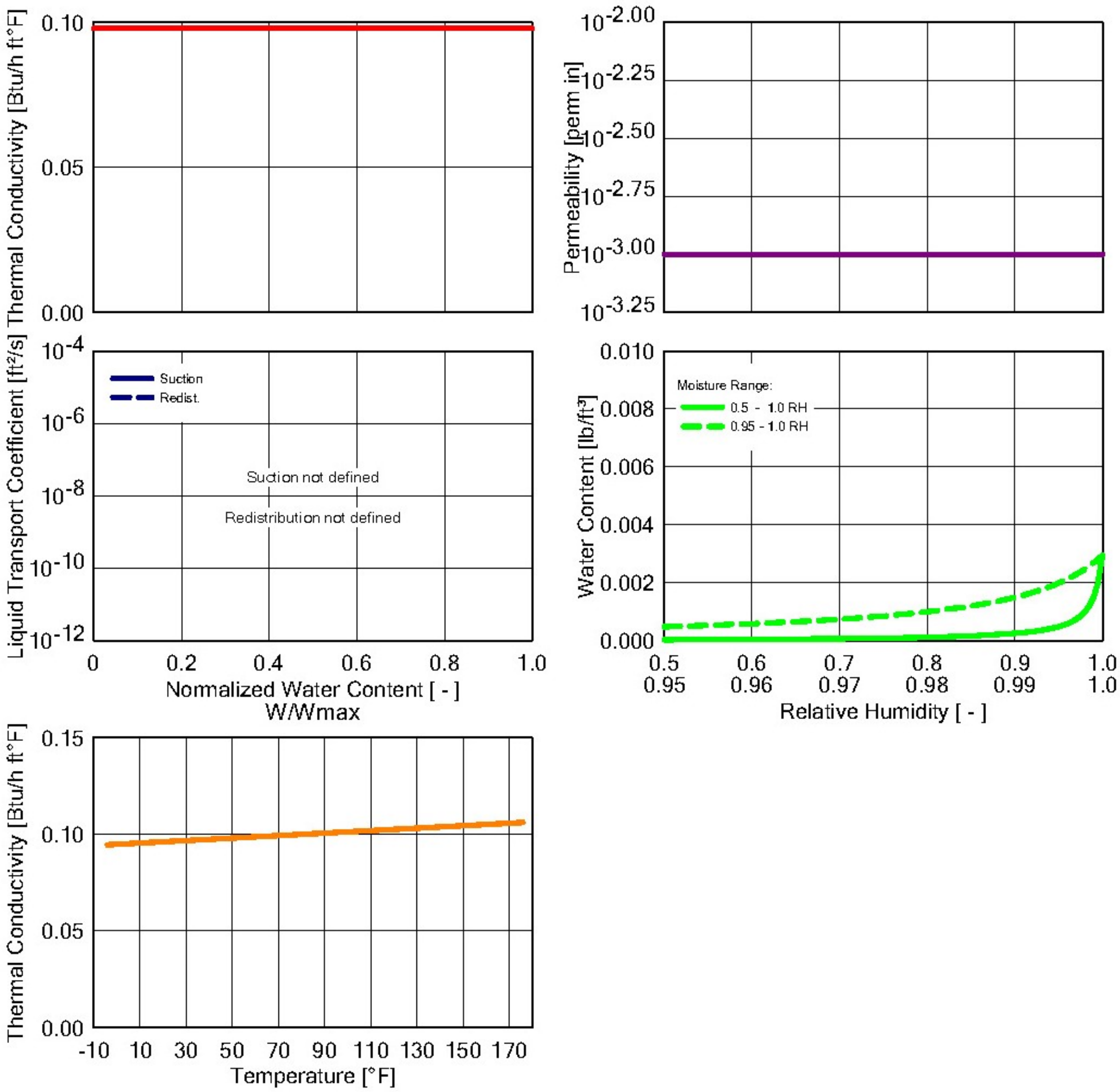
Property	Unit	Value
Bulk density	[lb/ft³]	31,214
Porosity	[ft³/ft³]	0,858
Specific Heat Capacity, Dry	[Btu/lb°F]	0,449
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0,069
Permeability	[perm in]	0,074
Reference Water Content	[lb/ft³]	3,883
Free Water Saturation	[lb/ft³]	18,728
Water Absorption Coefficient	[lb/in²s^0.5]	0.0000020
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000640



Material: *Vinyl Siding (no vapor perm)

Checking Input Data

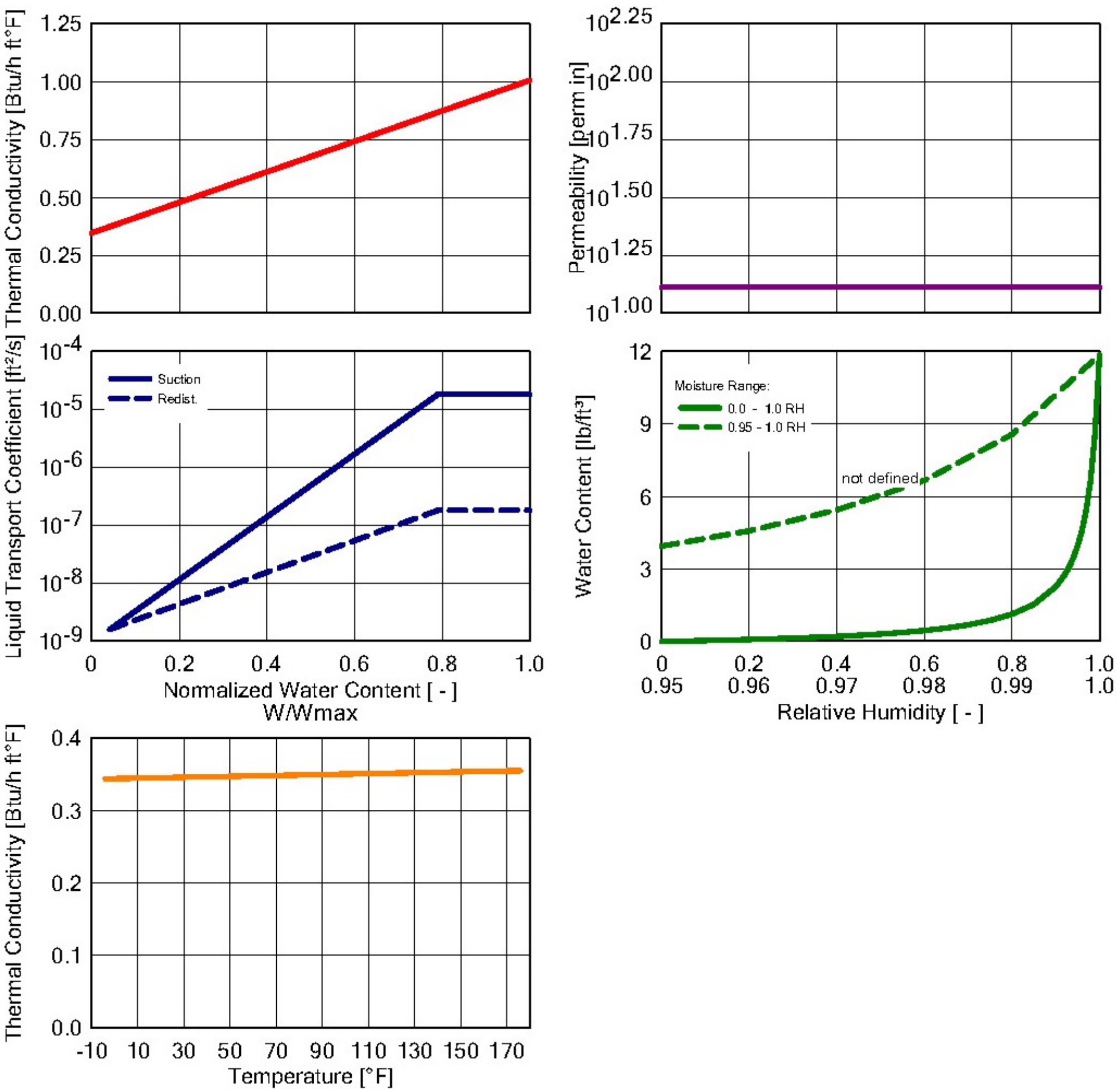
Property	Unit	Value
Bulk density	[lb/ft³]	51.753
Porosity	[ft³/ft³]	0.001
Specific Heat Capacity, Dry	[Btu/lb°F]	0.549
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.098
Permeability	[perm in]	0.001
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.000064



Material: Solid Brick Masonry

Checking Input Data

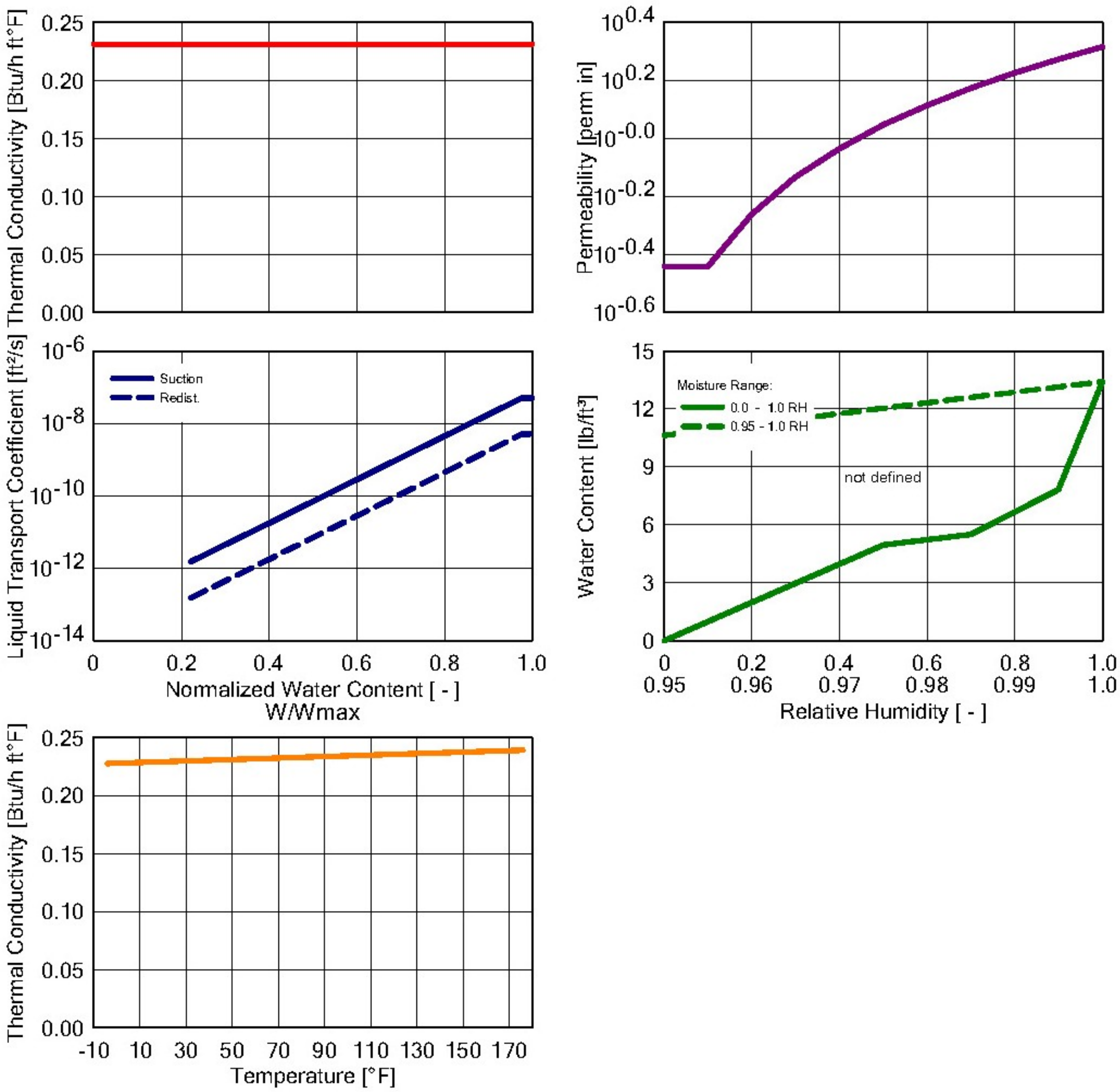
Property	Unit	Value
Bulk density	[lb/ft³]	118.613
Porosity	[ft³/ft³]	0.24
Specific Heat Capacity, Dry	[Btu/lb°F]	0.203
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.347
Permeability	[perm in]	12.88
Reference Water Content	[lb/ft³]	1.124
Free Water Saturation	[lb/ft³]	11.861
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	15.0
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.000064



Material: Regular Portland Stucco

Checking Input Data

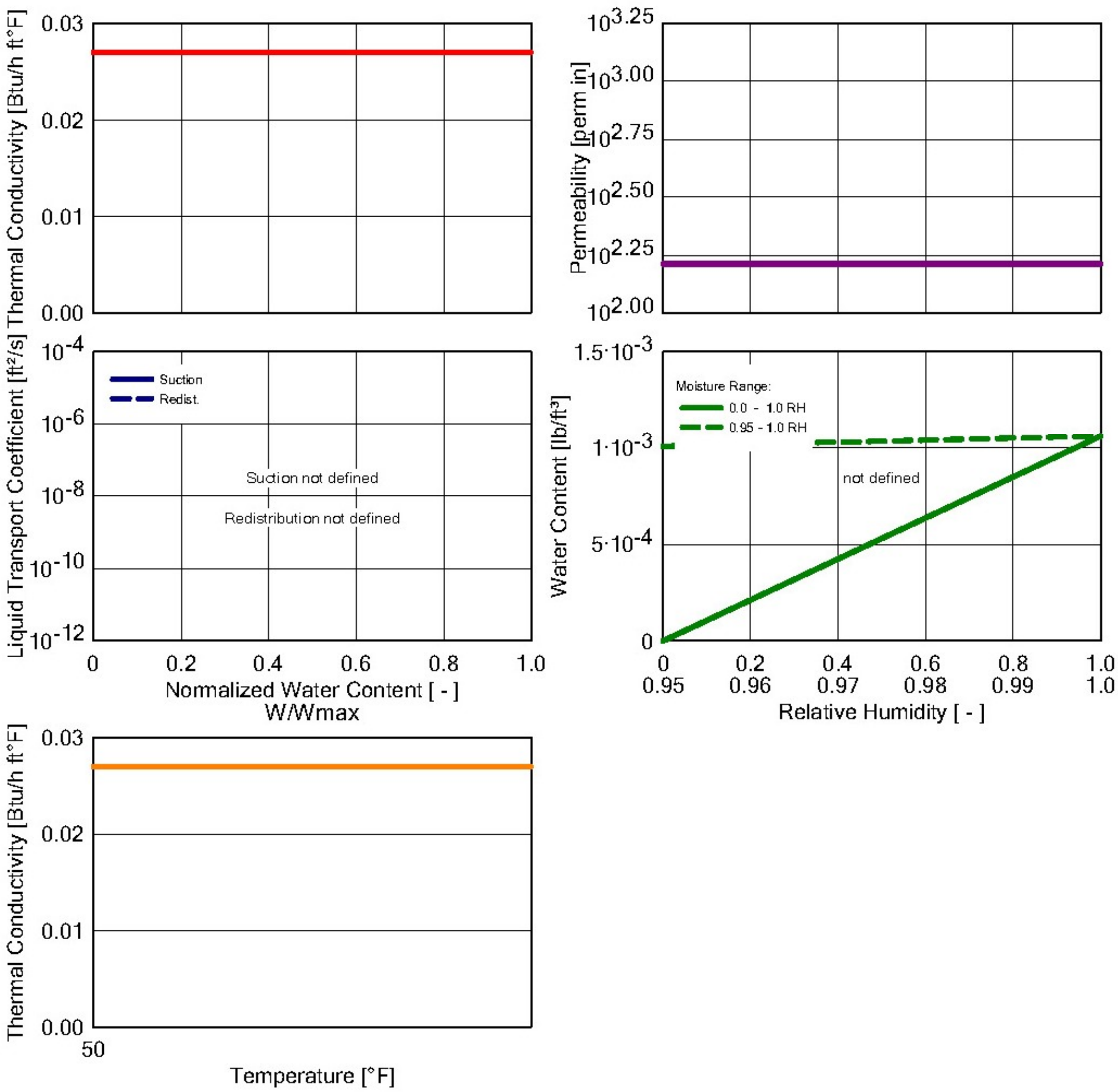
Property	Unit	Value
Bulk density	[lb/ft³]	122.078
Porosity	[ft³/ft³]	0.225
Specific Heat Capacity, Dry	[Btu/lb°F]	0.201
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.231
Permeability	[perm in]	0.362
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.000064



Material: *Air Layer 5 mm; without additional moisture capacity

Checking Input Data

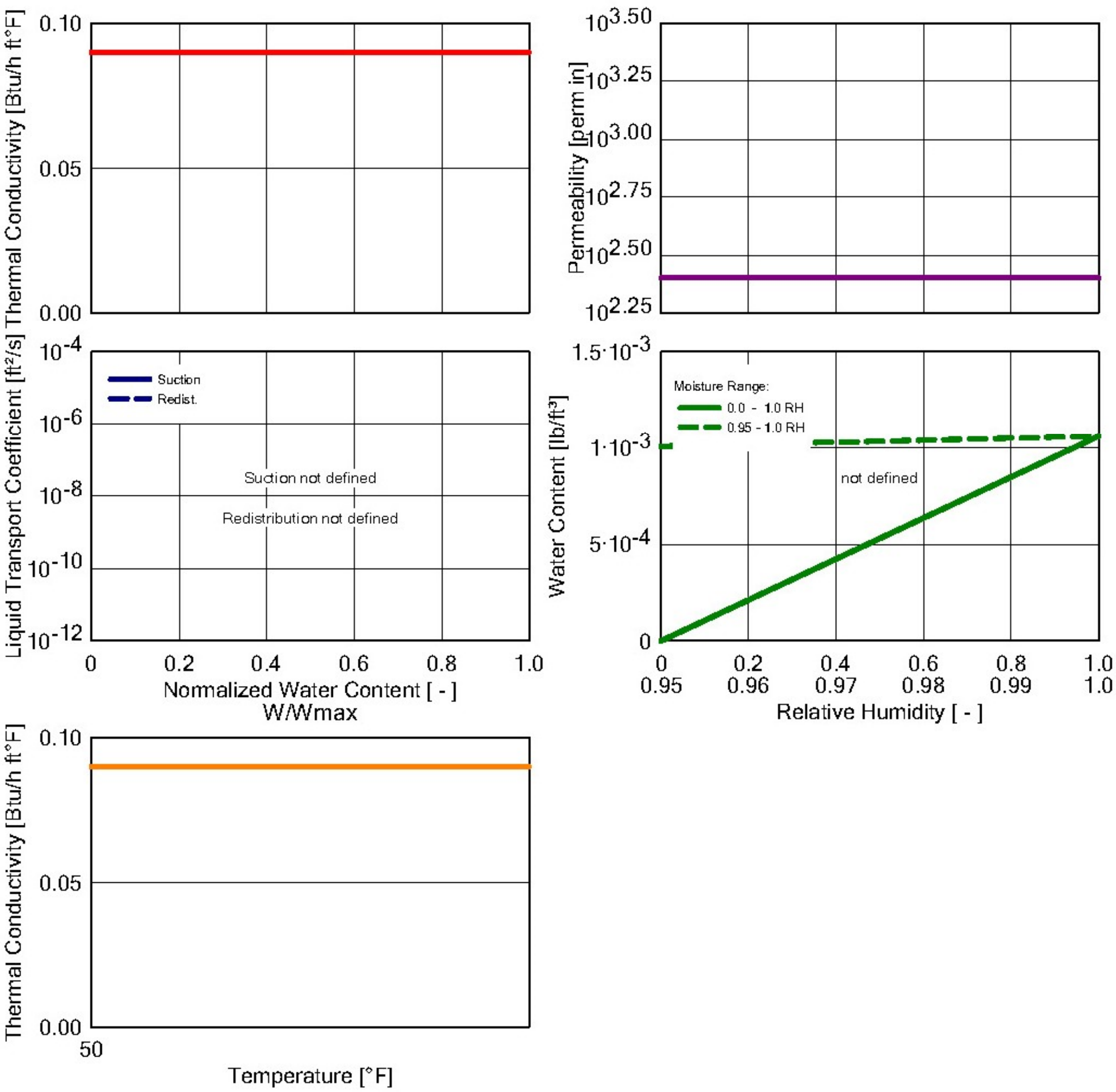
Property	Unit	Value
Bulk density	[lb/ft³]	0,081
Porosity	[ft³/ft³]	0,999
Specific Heat Capacity, Dry	[Btu/lb°F]	0,239
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0,027
Permeability	[perm in]	163,038



Material: Air Layer 25 mm; without additional moisture capacity

Checking Input Data

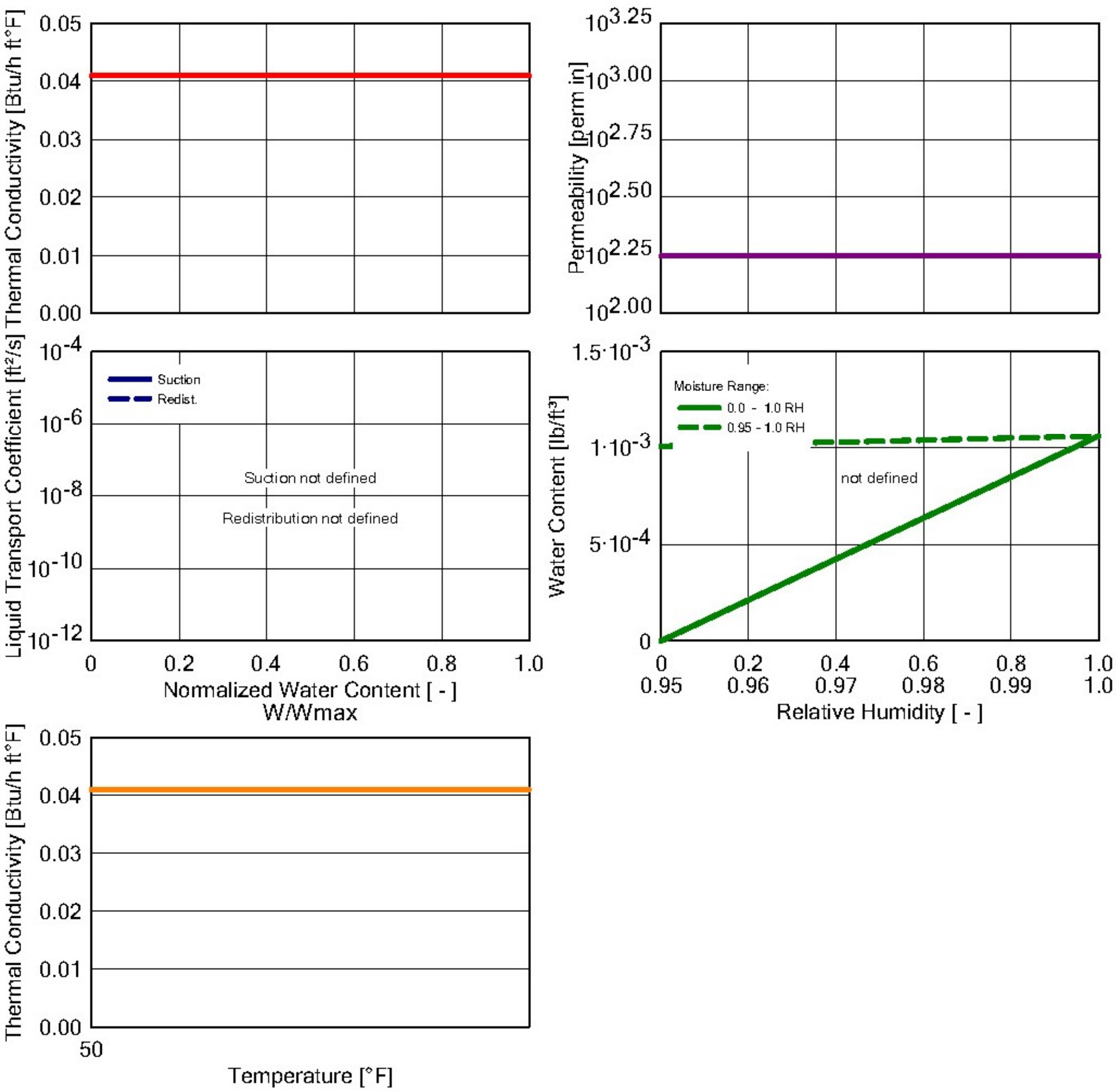
Property	Unit	Value
Bulk density	[lb/ft³]	0.081
Porosity	[ft³/ft³]	0.999
Specific Heat Capacity, Dry	[Btu/lb°F]	0.239
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.09
Permeability	[perm in]	252.549



Material: Air Layer 10 mm; without additional moisture capacity

Checking Input Data

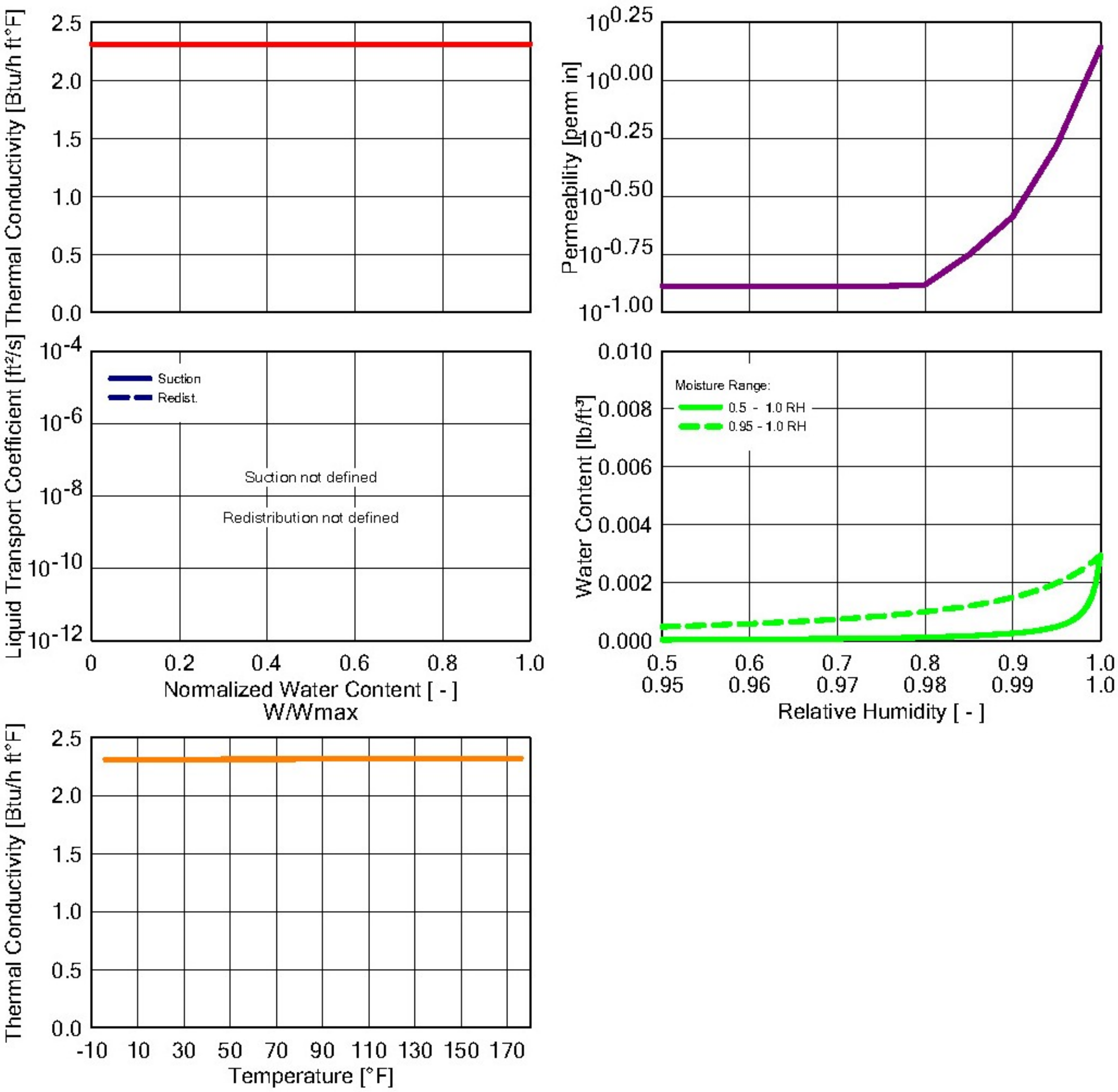
Property	Unit	Value
Bulk density	[lb/ft³]	0.081
Porosity	[ft³/ft³]	0.999
Specific Heat Capacity, Dry	[Btu/lb°F]	0.239
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.041
Permeability	[perm in]	176.438



Material: *Bituminous Paper (#15 Felt)

Checking Input Data

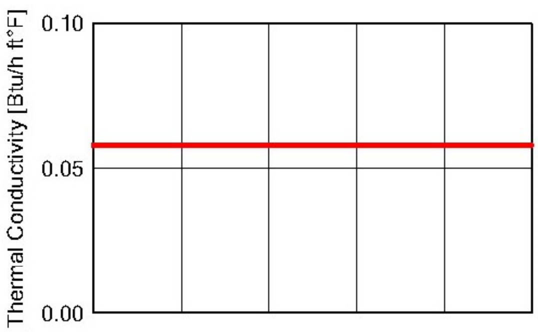
Property	Unit	Value
Bulk density	[lb/ft³]	44,636
Porosity	[ft³/ft³]	0,001
Specific Heat Capacity, Dry	[Btu/lb°F]	0,358
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	2,311
Permeability	[perm in]	0,13
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000640

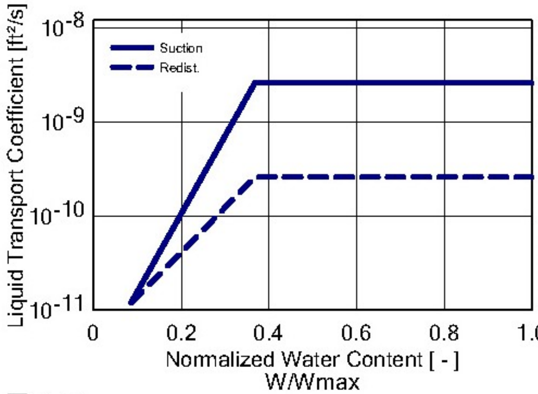


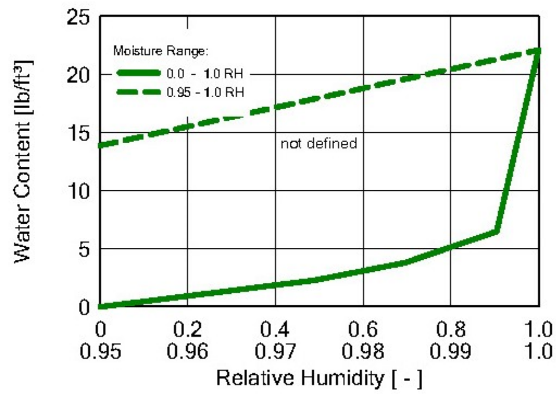
Material: Plywood high

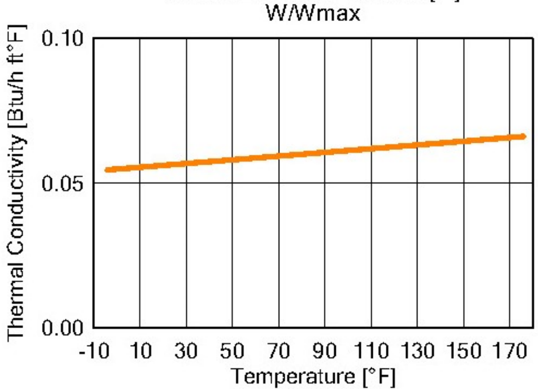
Checking Input Data

Property	Unit	Value
Bulk density	[lb/ft³]	37.457
Porosity	[ft³/ft³]	0.96
Specific Heat Capacity, Dry	[Btu/lb°F]	0.449
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.058
Permeability	[perm in]	0.336
Reference Water Content	[lb/ft³]	5.132
Free Water Saturation	[lb/ft³]	22.1
Water Absorption Coefficient	[lb/in²s^0.5]	0.000004
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.000064





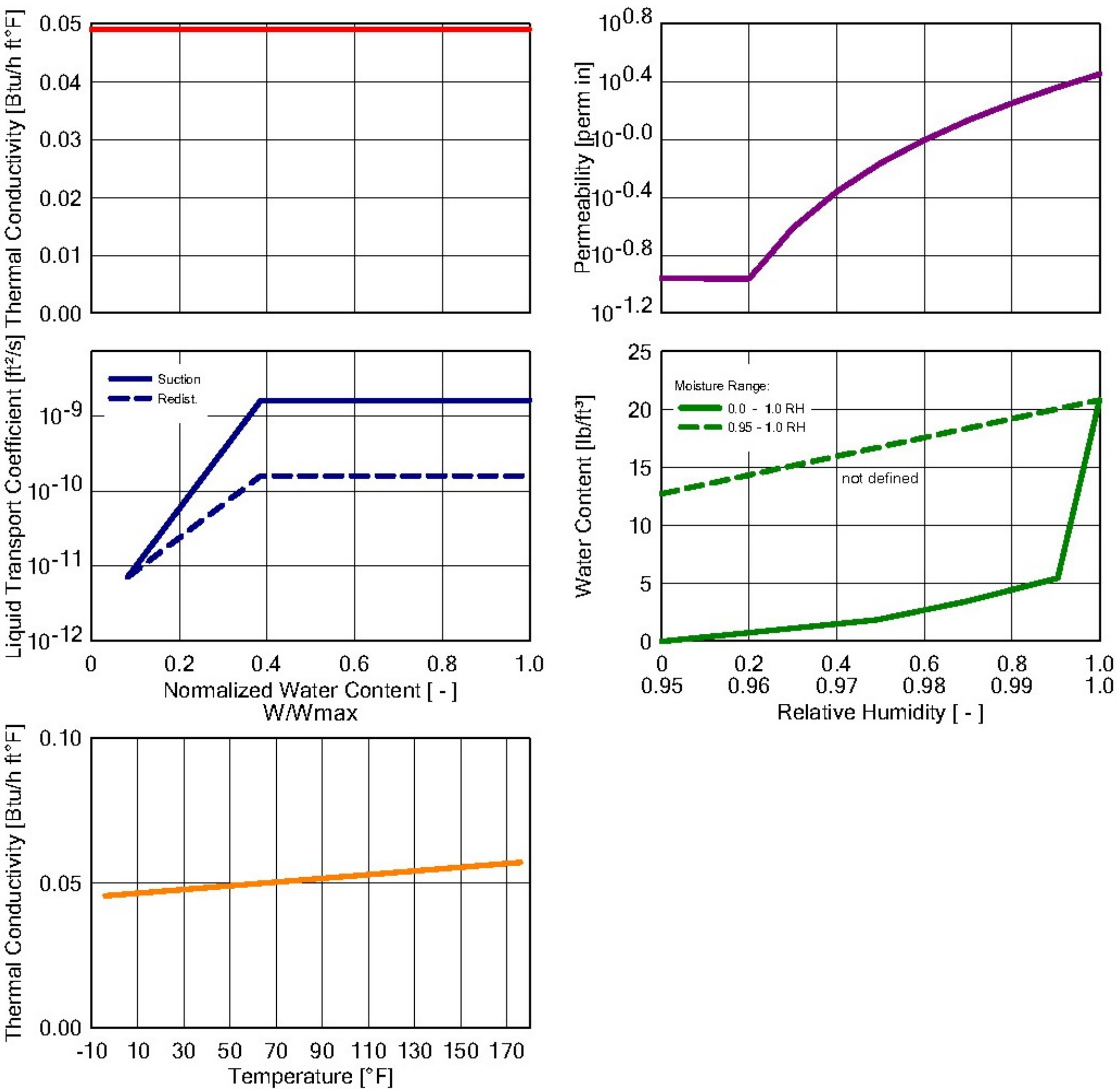




Material: Oriented Strand Board low

Checking Input Data

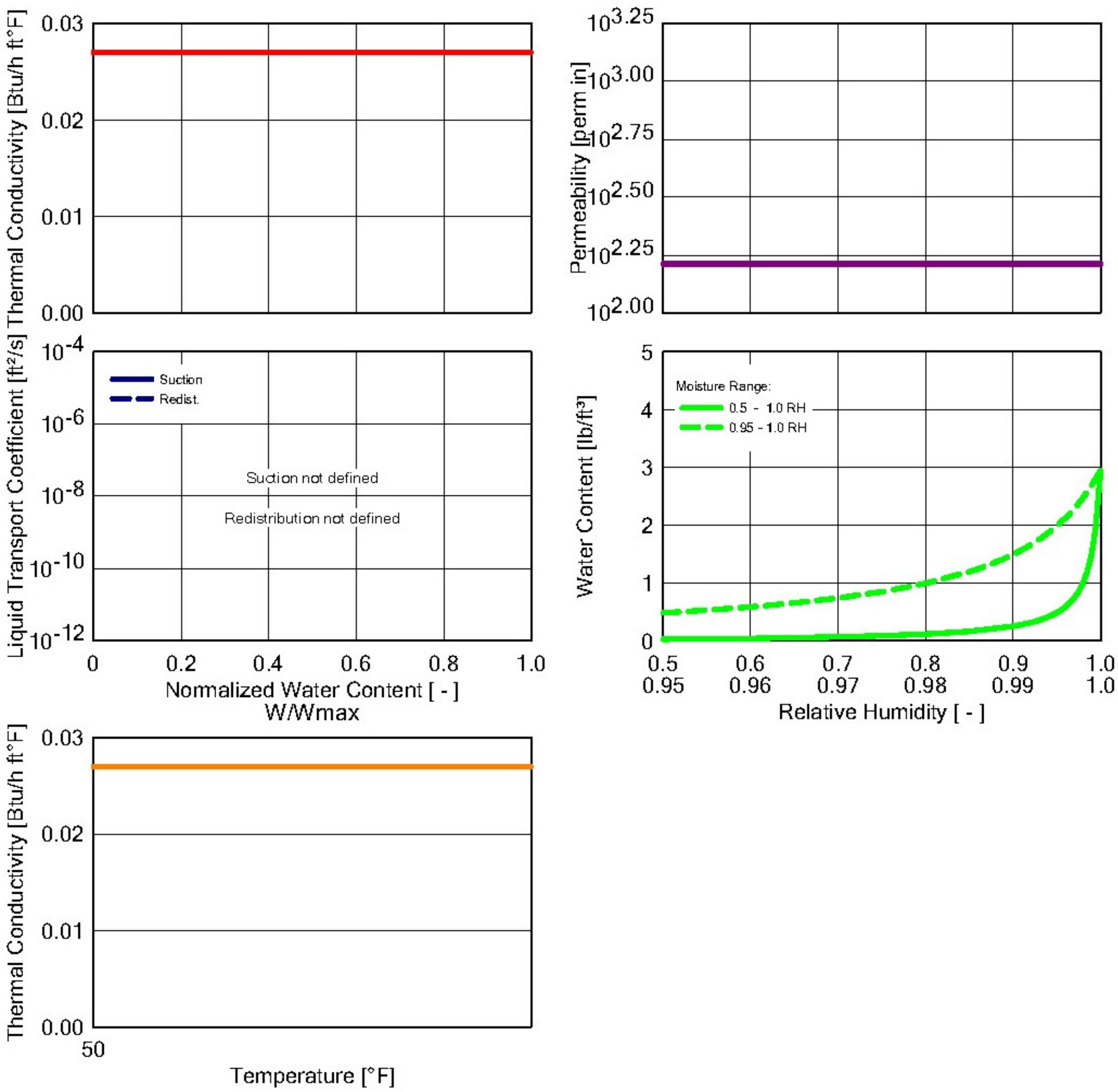
Property	Unit	Value
Bulk density	[lb/ft³]	35.896
Porosity	[ft³/ft³]	0.8625
Specific Heat Capacity, Dry	[Btu/lb°F]	0.449
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.049
Permeability	[perm in]	0.109
Reference Water Content	[lb/ft³]	4.451
Free Water Saturation	[lb/ft³]	20.82
Water Absorption Coefficient	[lb/in²s^0.5]	0.000003
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.000064



Material: *Air Layer 5 mm

Checking Input Data

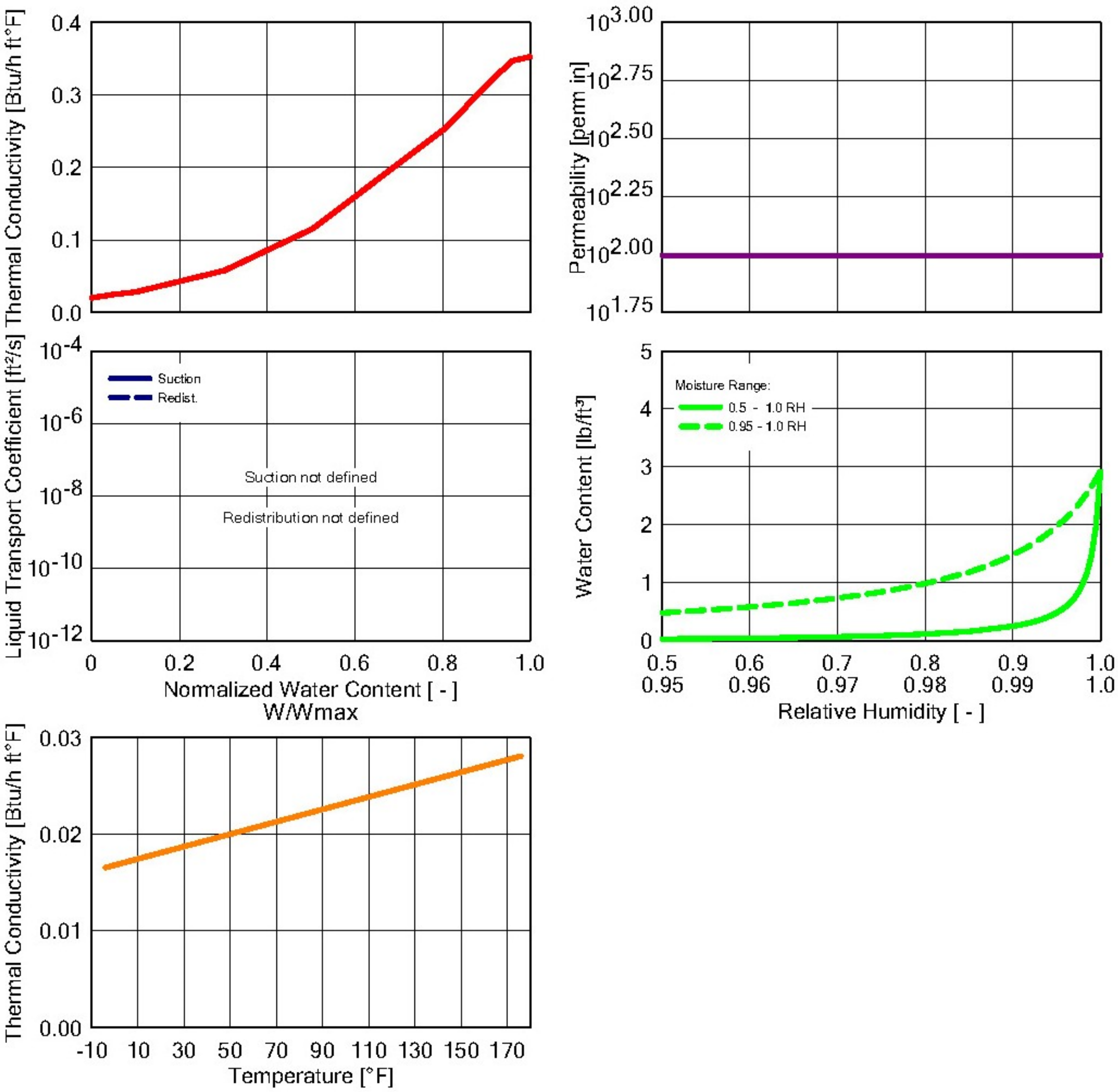
Property	Unit	Value
Bulk density	[lb/ft³]	0,081
Porosity	[ft³/ft³]	0,999
Specific Heat Capacity, Dry	[Btu/lb°F]	0,239
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0,027
Permeability	[perm in]	163,038



Material: *Fibre Glass (unlocked)

Checking Input Data

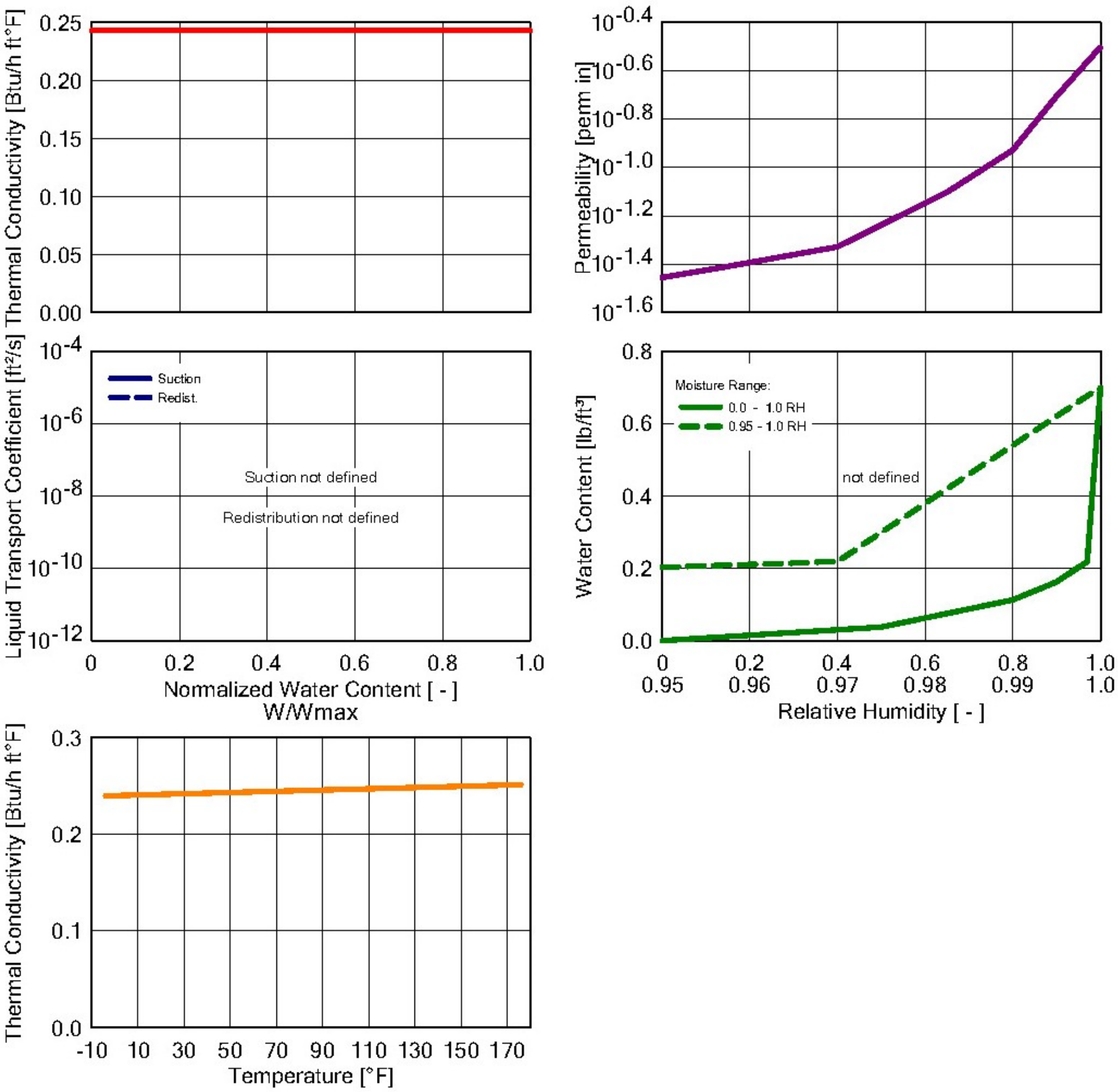
Property	Unit	Value
Bulk density	[lb/ft³]	1,2
Porosity	[ft³/ft³]	0,99
Specific Heat Capacity, Dry	[Btu/lb°F]	0,201
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0,02
Permeability	[perm in]	99,0769
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000640



Material: *(BSC) Kraft Paper

Checking Input Data

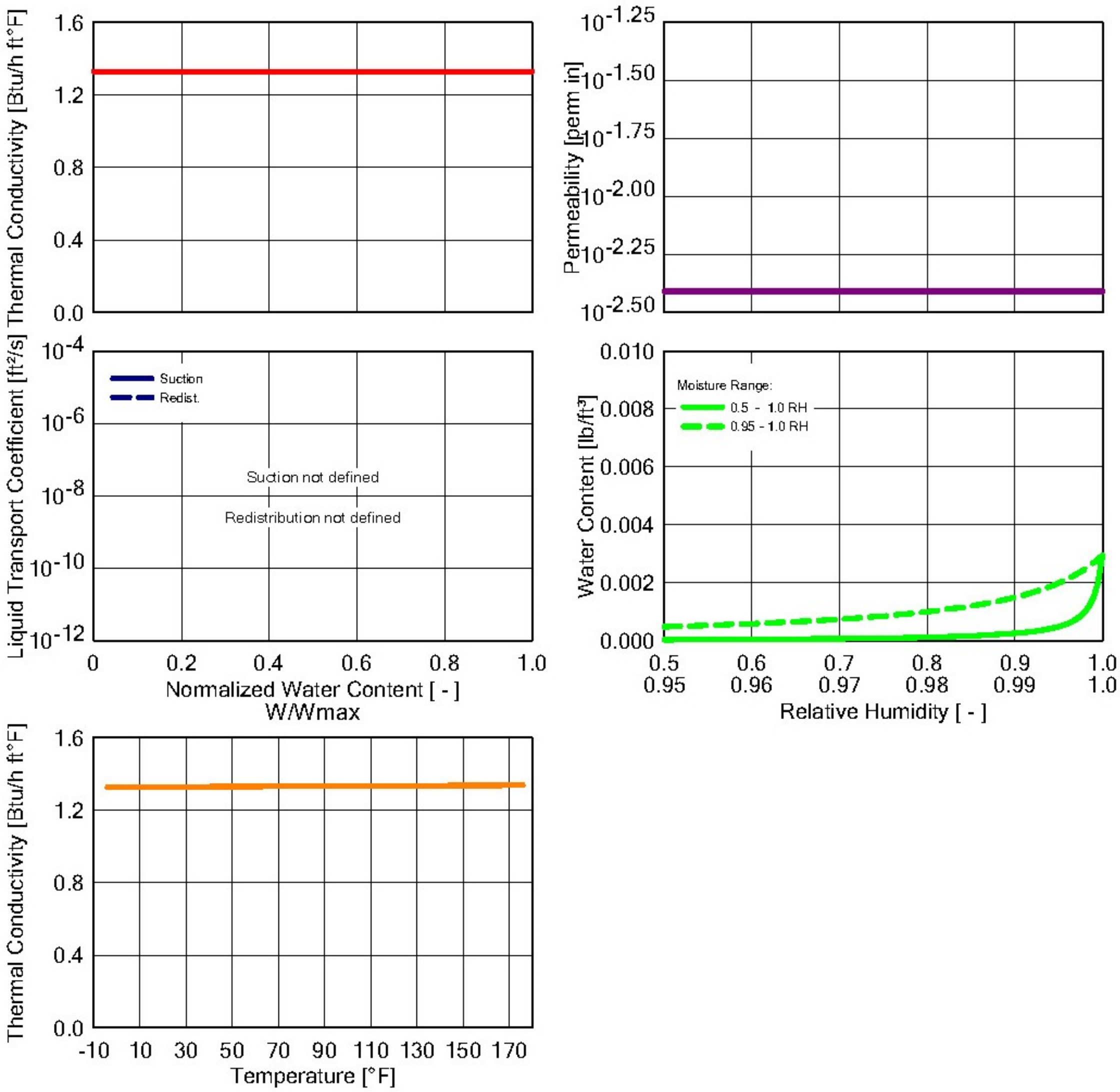
Property	Unit	Value
Bulk density	[lb/ft^3]	7,491
Porosity	[ft^3/ft^3]	0,6
Specific Heat Capacity, Dry	[Btu/lb°F]	0,358
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0,243
Permeability	[perm in]	0,035
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F^2]	0.0000640



Material: vapor retarder (0.1perm)

Checking Input Data

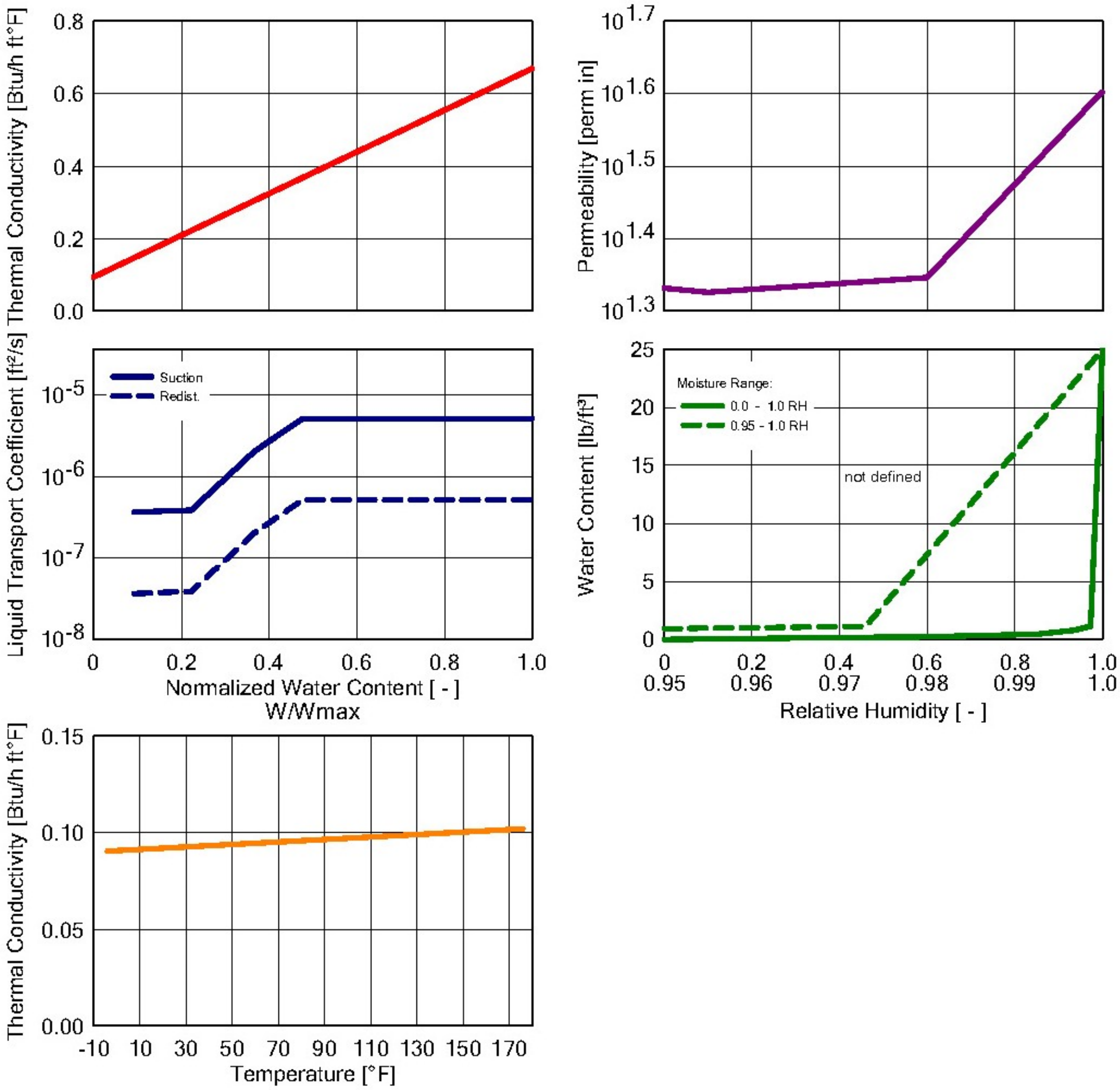
Property	Unit	Value
Bulk density	[lb/ft³]	8.1156
Porosity	[ft³/ft³]	0.001
Specific Heat Capacity, Dry	[Btu/lb°F]	0.5493
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	1.3289
Permeability	[perm in]	0.0039
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642



Material: *Gypsum Board (USA)

Checking Input Data

Property	Unit	Value
Bulk density	[lb/ft³]	53,064
Porosity	[ft³/ft³]	0,65
Specific Heat Capacity, Dry	[Btu/lb°F]	0,208
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0,094
Permeability	[perm in]	21,467
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8,0
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000640



Appendix C: WUFI Surface Transfer Coefficients

Exterior (Left Side)

Name	Description	Unit	Value
Heat Resistance - includes long-wave radiation	External Wall	[h ft² °F/Btu]	0,3339 yes
Permeance	No coating	[perm]	----
Short-Wave Radiation Absorptivity	Stucco, dark (aged)	[-]	0.6
Long-Wave Radiation Emissivity	Stucco, dark (aged)	[-]	0.9
Adhering Fraction of Rain	According to inclination and construction type	[-]	0.7
Explicit Radiation Balance			no

Interior (Right Side)

Name	Description	Unit	Value
Heat Resistance	External Wall	[h ft² °F/Btu]	0,7098
Permeance		[perm]	10,0

Appendix D: WUFI Source, Sinks

Wall 1 (Wood Siding-Ply)

***Southern Yellow Pine**

Name	Type		
Rain Leak @ back of cladding	*Moisture Source*		
	Depth in Layer	[in]	0,1181
	Cut-Off at Free Water Saturation	[lb/ft³]	18,728
	Fraction of Driving Rain	[%]	1

***Air Layer 5 mm; without additional moisture capacity**

Name	Type		
Ventilation	*Air Change Source*		
	Whole Layer		
	mix with air from left-hand side		
	Air Changes	[1/h]	20

Plywood high

Name	Type		
Rain Leak @ Shthg	*Moisture Source*		
	Depth in Layer	[in]	0,0118
	Cut-Off at Free Water Saturation	[lb/ft³]	22.1
	Fraction of Driving Rain	[%]	0.01

***Air Layer 5 mm**

Name	Type		
Stud Space Ventilation	*Air Change Source*		
	Whole Layer		
	mix with air from left-hand side		
	Air Changes	[1/h]	10

***Air Layer 5 mm**

Name	Type		
Air Leak	*Air Change Source*		
	Whole Layer		
	mix with air from right-hand side		
	Air Changes	[1/h]	10

Wall 2 (Vinyl Siding-Ply)

Air Layer 5 mm; without additional moisture capacity

Name	Type		
Rain Leak @ back of cladding	*Moisture Source*		
	Whole Layer		
	Cut-Off at Free Water Saturation	[lb/ft³]	
	Fraction of Driving Rain	[%]	1

*Air Layer 5 mm; without additional moisture capacity

Name	Type		
Ventilation	*Air Change Source*		
	Whole Layer		
	mix with air from left-hand side		
	Air Changes	[1/h]	200

Plywood high

Name	Type		
Rain Leak @ Shthg	*Moisture Source*		
	Depth in Layer	[in]	0,0118
	Cut-Off at Free Water Saturation	[lb/ft³]	22.1
	Fraction of Driving Rain	[%]	0.01

*Air Layer 5 mm

Name	Type		
Stud Space Ventilation	*Air Change Source*		
	Whole Layer		
	mix with air from left-hand side		
	Air Changes	[1/h]	10

*Air Layer 5 mm

Name	Type		
Air Leak	*Air Change Source*		
	Whole Layer		
	mix with air from right-hand side		
	Air Changes	[1/h]	10

Wall 3 (Vinyl-OSB)

Air Layer 5 mm; without additional moisture capacity

Name	Type		
Rain Leak @ back of cladding	*Moisture Source*		
	Whole Layer		
	Cut-Off at Free Water Saturation	[lb/ft³]	
	Fraction of Driving Rain	[%]	1

***Air Layer 5 mm; without additional moisture capacity**

Name	Type		
Ventilation	*Air Change Source*		
	Whole Layer		
	mix with air from left-hand side		
	Air Changes	[1/h]	200

Oriented Strand Board low

Name	Type		
Rain Leak @ Shthg	*Moisture Source*		
	Depth in Layer	[in]	0,0118
	Cut-Off at Free Water Saturation	[lb/ft³]	20.82
	Fraction of Driving Rain	[%]	0.01

***Air Layer 5 mm**

Name	Type		
Stud Space Ventilation	*Air Change Source*		
	Whole Layer		
	mix with air from left-hand side		
	Air Changes	[1/h]	10

***Air Layer 5 mm**

Name	Type		
Air Leak	*Air Change Source*		
	Whole Layer		
	mix with air from right-hand side		
	Air Changes	[1/h]	10

Wall 4 (Brick-OSB)

Solid Brick Masonry

Name	Type		
Rain Leak @ back of cladding	*Moisture Source*		
	Start Depth in Layer	[in]	3
	End Depth in Layer	[in]	3.5
	Cut-Off at Free Water Saturation	[lb/ft³]	11.861
	Fraction of Driving Rain	[%]	1

Air Layer 25 mm; without additional moisture capacity

Name	Type		
Ventilation	*Air Change Source*		
	Whole Layer		
	mix with air from left-hand side		
	Air Changes	[1/h]	10

Oriented Strand Board low

Name	Type		
Rain Leak @ Shthg	*Moisture Source*		
	Depth in Layer	[in]	0,0118
	Cut-Off at Free Water Saturation	[lb/ft³]	20.82
	Fraction of Driving Rain	[%]	0.01

*Air Layer 5 mm

Name	Type		
Stud Space Ventilation	*Air Change Source*		
	Whole Layer		
	mix with air from left-hand side		
	Air Changes	[1/h]	10

*Air Layer 5 mm

Name	Type		
Air Leak	*Air Change Source*		
	Whole Layer		
	mix with air from right-hand side		
	Air Changes	[1/h]	10

Wall 5 (Stucco-OSB)

Regular Portland Stucco

Name	Type		
Rain Leak @ back of cladding	*Moisture Source*		
	Start Depth in Layer	[in]	0.5
	End Depth in Layer	[in]	0.75
	Cut-Off at Free Water Saturation	[lb/ft³]	
	Fraction of Driving Rain	[%]	1

Oriented Strand Board low

Name	Type		
Rain Leak @ Shthg	*Moisture Source*		
	Depth in Layer	[in]	0,0118
	Cut-Off at Free Water Saturation	[lb/ft³]	20.82
	Fraction of Driving Rain	[%]	0.01

*Air Layer 5 mm

Name	Type		
Stud Space Ventilation	*Air Change Source*		
	Whole Layer		
	mix with air from left-hand side		
	Air Changes	[1/h]	10

*Air Layer 5 mm

Name	Type		
Air Leak	*Air Change Source*		
	Whole Layer		
	mix with air from right-hand side		
	Air Changes	[1/h]	10

Wall 6 (Vented Stucco-OSB)

Regular Portland Stucco

Name	Type		
Rain Leak @ back of cladding	*Moisture Source*		
	Start Depth in Layer	[in]	0.5
	End Depth in Layer	[in]	0.75
	Cut-Off at Free Water Saturation	[lb/ft³]	
	Fraction of Driving Rain	[%]	1

Air Layer 10 mm; without additional moisture capacity

Name	Type		
Ventilation	*Air Change Source*		
	Whole Layer		
	mix with air from left-hand side		
	Air Changes	[1/h]	10

Oriented Strand Board low

Name	Type		
Rain Leak @ Shthg	*Moisture Source*		
	Depth in Layer	[in]	0,0118
	Cut-Off at Free Water Saturation	[lb/ft³]	20.82
	Fraction of Driving Rain	[%]	0.01

*Air Layer 5 mm

Name	Type		
Stud Space Ventilation	*Air Change Source*		
	Whole Layer		
	mix with air from left-hand side		
	Air Changes	[1/h]	10

*Air Layer 5 mm

Name	Type		
Air Leak	*Air Change Source*		
	Whole Layer		
	mix with air from right-hand side		
	Air Changes	[1/h]	10

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This report was prepared with the cooperation of the U.S. Department of Energy's Building America Program.

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