June 4, 2020

REPORT #: E20-312

Market-Ready High-Performance Walls: Phase 2 Report

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Acknowledgements

The project team would like to thank the following construction professionals for sharing their many insights about building with an advanced wall assembly:

- Blake Bilyeu, Bilyeu Homes
- Carson Benner, Cellar Ridge Construction
- Stephen Smith, Design Build Portland
- Mike Ardeljan and Peter Grube, Dream Home Building and Design
- Anthony Maschmedt, Dwell Development
- Martha Rose, Martha Rose Construction
- Matt Daby, M.O. Daby Design
- Ben Walsh, New Energy Works
- Mike Frey, Noyes Development
- Mike Wille, Willamette West Habitat for Humanity

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Terminology

BIBS	Blown-in Blanket System insulation
CZ	Climate zone, as defined by the International Energy Conservation Code
CI	Continuous insulation
DSW	Double stud wall
EPS	Expanded polystyrene foam - a closed-cell insulation that is manufactured by “expanding” a polystyrene polymer
FG	Fiberglass batt insulation
IECC	International Energy Conservation Code
IRC	International Residential Code
ISO	Polyisocyanurate, also referred to as PIC, PIR, or polyiso, is a thermoset plastic typically produced as a foam and used as rigid thermal insulation
MC	Moisture content
MW	Mineral wool insulation
OSB	Oriented strand board—a manufactured wood panel made of laminated wood fibers, typically available in 4-ft. x 8-ft. sheets in various thicknesses
Perm	A unit of permeance or water vapor transmission given a certain differential in partial pressures on either side of a material or membrane
R-value	Quantitative measure of resistance to conductive heat flow ($[hr\cdot°F\cdot ft^2]/Btu$)
STC	Sound transmission class. A rating that indicates how well a wall assembly blocks airborne sound.
TBS	Thermal break shear (type of wall assembly)
U-value	Reciprocal of R-value - the rate of transfer of heat through a structure divided by the difference in temperature across that structure
Vapor barrier	Acts to restrict the migration of water vapor. A layer with a permeance rating of 0.1 perm or less.
Vapor retarder	Acts to limit the migration of water vapor. A layer with a permeance rating of greater than 0.1 perm.
VTT model	A mathematic-empirical model that predicts mold growth as a function of material, temperature, and relative humidity
WRB	Water-resistive barrier that protects the building envelope from liquid water while allowing the diffusion of water vapor back out
WUFI®	Wärme Und Feuchte Instationär—when translated means heat and moisture transiency. WUFI® is a family of software products that provides a realistic calculation of the moisture transport in walls.
XPS	Extruded polystyrene foam—a rigid insulation that’s also formed with polystyrene polymer, but manufactured using an extrusion process

Executive Summary

This report provides documentation of three different wall systems for new residential construction that provide substantial energy savings. These wall systems have the thermal properties that NEEA technical staff believe are representative of the best-case end-state efficiency requirement for northwest energy codes. NEEA commissioned this report to support its work in advancing residential best practices and removing barriers to adoption of high efficiency wall systems.

The three wall system archetypes show promise as approaches that can grow from niche high-performance custom and small-volume speculative builders to larger speculative builders:

1. *Thermal Break Shear (TBS) Wall*
2. *2x6 intermediate frame wall with continuous rigid insulation*
3. *2x4 double stud wall (DSW) with blown-in fibrous insulation*

The report contains detailed information on four topics for each wall system.

1. *Moisture Management*
2. *Benefits of the Advanced Wall Systems*
3. *Construction Best Practices*
4. *Code Compliance Resources*

Taken together, these sections provide a comprehensive package of supporting materials to inform builders and other construction industry professionals on the feasibility of integrating a new wall assembly approach into their standard home design and construction processes. NEEA intends to incorporate the information in builder training, utility program support, and code official training efforts.

Introduction

The construction of high-performance or “advanced” walls represents a significant energy efficiency opportunity for the Northwest new home construction sector. Three highly energy efficient wall system archetypes are showing promise as approaches that can grow from niche high-performance custom and small-volume speculative builders to larger speculative builders:

1) Thermal Break Shear (TBS) Wall
2) 2x6 intermediate frame wall with continuous rigid insulation (CI)[1]
3) 2x4 double stud wall (DSW) with blown-in fibrous insulation

While these three wall systems currently have limited exposure and acceptance by the broader regional new construction market, an initial analysis conducted by this project team in early 2019 documented the feasibility of these wall solutions. The Phase 1 analysis included confirmation that each wall assembly falls within acceptable cost bands. This report, which is the second phase of the Advanced Walls project, provides technical analyses and research documentation that can be used in support of potential future market transformation activities. Phase 3 of the Advanced Walls project, if pursued, will use the contents of this report as part of a Northwest Energy Efficiency Alliance (NEEA) Next Step Home Program market transformation initiative.

This Phase 2 report is organized into the following sections:

1. *Moisture Management:* This section includes a review of the moisture management performance of each wall assembly. When considering a new approach to wall design and construction, Northwest builders often reference moisture performance as one of their primary areas of uncertainty and therefore of concern. This section addresses moisture management performance based on both a review of existing building science research and the development of a WUFI® analysis for each wall assembly in three primary building environments in the Northwest.[2]
2. *Benefits of the Advanced Wall Systems:* This section documents additional quantifiable benefits of each wall assembly. Each of the documented benefits—noise attenuation, seismic resiliency, and energy efficiency—can be attributed to one, two, or all three of the wall assemblies.
3. *Construction Best Practices:* This section includes a best practices guide that will assist in accelerating the construction process for each wall assembly. Gleaned from direct interviews with Northwest builders experienced in each wall assembly, as well as from

[1] This assembly can also be constructed with advanced framing techniques, with the main benefit being the reduction in framing material use rather than reduced thermal bridging (which is mostly negated by the exterior continuous insulation).
[2] WUFI® is an acronym for Wärme Und Feuchte Instationär—which, translated from German, means heat and moisture transiency. WUFI® is a family of software products that provides a realistic calculation of the moisture transport in walls. The WUFI analyses were done for Boise, Idaho; Portland, Oregon; and Spokane, Washington.

published building industry guidance, this best practices section focuses on effective installation practices and risk mitigation strategies.

5. *Code Compliance Resources:* This section is designed to both support builders proposing one of the three advanced wall assemblies to a local building department and to serve as reference material for the building official reviewing the proposed approach. This section contains detailed drawings that address structural, air barrier, fire blocking, and other issues typically requested during the permitting processes.

Taken together, these sections provide a comprehensive package of supporting materials to inform builders and other construction industry professionals on the feasibility of integrating a new wall assembly approach into their standard home design and construction processes. The information contained in this report can also be used by building officials when reviewing permit submittals or in doing field inspections of homes using an advanced wall assembly approach.

Moisture Management

Introduction

In Phase 1 of this project, the project team noted some uncertainty among builders about the capacity of each of the advanced wall systems to adequately address moisture issues. For example, in early project research, the project team documented some builder perceptions that a disadvantage of both the TBS wall and 2x6 intermediate frame wall with exterior rigid insulation was the potential to trap moisture in the wall cavity due to the continuous layer of low-permeable foam (such as ISO foam). Similarly, the project team previously documented some builder concern that the thicker walls of a double stud wall could prevent heat transfer from the interior building temperature to the exterior sheathing, and that the colder temperatures of the exterior sheathing could lead to increased chances for condensation from air exfiltration. These concerns mirrored some builder responses documented by Earth Advantage in a 2013 cost analysis report for the Northwest Energy Efficiency Alliance (NEEA) and highlight a likely reason for builders' current hesitancy to modify their approach to wall design and construction (Earth Advantage, 2013).

To address some of these market perceptions, the project team prioritized the investigation into the relative moisture performance of the three wall systems in two ways: 1) a literature review of primary research from reputable building science sources, and 2) the project team's own quantitative moisture performance analyses of homes in different Northwest climates. Both the building science literature review and the project team's own moisture performance analyses conclude that not only are the three wall assemblies at no risk of moisture problems if best installation practices are followed, but the advanced wall assemblies actually perform better than a typical 2x6 wall assembly in climate zone 4C and are well within acceptable ranges in climate zone 5B.[3]

Evaluation of Existing Research and Case Studies

Thermal Break Shear Wall & 2x6 Intermediate Framed Wall with Continuous Rigid Insulation

The addition of insulation boards on the exterior of the assembly helps reduce the potential for wintertime condensation occurring in those wall assemblies. A Building Science Corp (BSC) analysis, using hygrothermal simulations of Northwest weather conditions, demonstrated that the 2x6 intermediate framed with continuous rigid insulation wall assembly lowers the wetting potential from interstitial moisture by keeping the wall studs and sheathing layer above the average dew point temperature (Smegal & Straube, 2010). Walls with exterior insulation were shown to have less simulated annual wetting hours compared to walls without. The exterior insulation protected these wall assemblies when moist air entered the wall cavities from the indoors due to poor interior air sealing. Home Innovation Research Labs™ conducted field investigations that reported similar results for walls with exterior rigid insulation (HI, 2015). 2x6 walls with continuous exterior rigid insulation were field-tested to evaluate interstitial moisture accumulation in the OSB sheathing. The project team believes the TBS wall assembly performs

[3] A typical wall assembly is defined as: 2x6 intermediate framed wall with OSB, Tyvek, and Hardi-Board cladding

similarly because the rigid insulation is acting as a vapor barrier that prevents indoor moisture from reaching the sheathing.

Building science literature also shows that exterior insulation, whether mineral wool, XPS, EPS, or ISO, manages moisture effectively with moisture levels below the 20% moisture content (MC) threshold.[4] In the Home Innovation Research Labs study, a wall with R-5 mineral wool rigid insulation experienced a peak moisture content in the OSB sheathing of 15%, the wall with R-5 XPS foam 18%, and the wall with R-5 EPS foam 19% (HI, 2015).[5] This illustrates that the semi-permeability of rigid insulation products provide good drying potential to the exterior while keeping the structure warm enough to prevent condensation. It should be noted that ISO with an impermeable foil covering experienced higher interstitial moisture levels, likely because of the low permeability, which limits drying potential to the exterior. The test wall with foil-faced ISO foam (0.03 perms) experienced 21% moisture levels in the OSB sheathing. All four wall assemblies dried out over time to below 15%; however, the ISO insulated wall took longer to dry out than the other walls, due to the low permeability of the ISO insulation. If using ISO foam insulation for this purpose, choosing a product with a fiberglass face material or perforated foil face is recommended to provide more permeability and better drying potential (further described in the Construction Best Practices section of this report).

As detailed in the Construction Best Practices section of this report, if enough rigid insulation is added to the exterior of the wall, then a vapor retarder on the interior is not necessary. Providing a wall assembly with the ability to dry out on at least one side is highly recommended. Since many insulation boards can be classified as vapor retarders, replacing the interior vapor barrier with an interior vapor retarder allows increased drying of the assembly to the interior and improves the overall performance of the wall.

2x4 Double Stud Wall with Blown-In Fibrous Insulation

A 2x4 double stud wall (DSW) with blown-in fibrous insulation can be susceptible to seasonal moisture fluctuations, indoor moisture intrusion, and potential wetting of structural members when the exterior surface temperatures are lower than the dew point temperature. However, when constructed with an effective air barrier, a class II vapor retarder installed to prevent moisture intrusion from the living space, and vapor-permeable exterior materials, this wall assembly has been shown to effectively manage moisture to achieve long-term durability.

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[4] 20% is deemed a conservative limit, especially in northern climates, where this threshold is typically exceeded during colder temperatures when the risk for mold and decay is at its lowest (Ueno & Lstiburek, 2014).

[5] While mineral wool performs well, because of its relatively high material and labor costs, it has not been included for analysis in this report.

A Building America study documented that under normal operating conditions with a functioning ventilation system and wintertime indoor relative humidity of 10%–30%, the double stud wall with blown cellulose insulation in climate zone 5 initially experiences moisture levels above 20% on the north-facing wall (Ueno, 2015).[6] However, the wall assembly dried out well during summer dry periods after the wintertime wetting. Despite higher-risk conditions experienced during the wetting periods, double stud walls with cellulose insulation showed no evidence of mold growth, staining, or liquid water accumulation. Use of a Class II vapor retarder, such as a variable permeability membrane or vapor retarder paint, will reduce moisture risks in the cellulose walls to acceptable levels (Ueno, 2015).

The US DOE Building America Solution Center guide to Double-Stud Wall Framing is in alignment with this recommendation for double stud wall assemblies:

"A Class II vapor retarder is recommended in cold climate zones (5 and higher). If one is installed, it should also be an air barrier/air control layer and it should be located on the exterior side of the interior wall. Care should be taken that insulation on both sides of this layer is fully aligned along the entire length of the wall." (BASC, 2016 (b))

WUFI Analysis

Description of WUFI

The project team undertook a WUFI® analysis to evaluate the long-term moisture durability and hygrothermal performance of the Thermal Break Shear (TBS) Wall, 2x6 intermediate frame with exterior rigid insulation wall, and 2x4 double stud with blown-in fibrous insulation wall.[7] These three high-performance wall assembly types were assessed in three different Northwest building geographies: Portland, OR; Boise, ID; and Spokane, WA. These sites are located in two primary Northwest climate zones (4C and 5B), each with differing weather patterns and moisture conditions. The results from the WUFI analysis were also compared alongside the results of a "base case" 2x6 wall assembly under the same conditions and in the same locations.

A hygrothermal analysis using WUFI is the current, state-of-the-art method for realistic simulations of moisture transport in walls. WUFI is a hygrothermal modeling tool that looks at the movement or accumulation of moisture and heat through an assembly over a period of time and is based on the latest knowledge in vapor diffusion and liquid transport in building materials. For boundary conditions, measured outdoor climates—including driving rain and solar radiation—are used. This allows for an analysis of multi-layer materials and component connections under realistic exposure to natural weather conditions. A summary of results is contained in the following section, with the full results and comprehensive report provided for reference in the Appendix B to this report.

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[6] In this study, a 12" double stud wall assembly was evaluated. The study was conducted in a production home located in Devens, Massachusetts (U.S. Department of Energy zone 5A). Both walls with blown cellulose insulation and wall sections with open-cell spray foam were included. The walls were monitored for moisture levels over three winters, 2011-2014.

[7] The Fraunhofer Institute in Germany originally created the WUFI software with involvement from Oak Ridge National Laboratory. https://web.ornl.gov/sci/buildings/tools/wufi/

The project team analyzed each component of each of the wall assemblies for moisture performance and for its impact on the entire system. Below is a list of the wall assembly component assumptions the project team used in the WUFI analysis. A more complete discussion of optimal wall assembly components is contained in the Construction Best Practices section of this report.

1. "Base case" 2x6 wall
    - Cement board siding
    - 14 perm water-resistive barrier (WRB)
    - ½" oriented strand board (OSB)
    - 5.5" blown-in fiberglass insulation for R-23 between 2x6 studs 16" OC
    - ½" drywall with Class II vapor retarder (PVA primer and latex paint)

2. TBS wall
    - Cement board siding
    - ⅜" drainage gap
    - 14 perm WRB
    - ½" OSB
    - 1" foil-faced polyisocyanurate (ISO)
    - 5.5" blown-in fiberglass insulation for R-23 between 2x6 studs 16" OC
    - ½" drywall with Class III vapor retarder (non-PVA latex primer and paint)

3. 2x6 intermediate frame wall with exterior rigid insulation
    - Cement board siding
    - 1" XPS insulation
    - 14 perm WRB
    - ½" OSB
    - 5.5" blown-in fiberglass insulation for R-23 between 2x6 studs 16" OC
    - ½" drywall with Class III vapor retarder (non-PVA latex primer and paint)

4. 2x4 double stud wall with blown-in fibrous insulation
    - Cement board siding
    - ⅜" drainage gap
    - 14 perm WRB
    - ½" OSB
    - 9.25" blown-in fiberglass insulation for R-39 inside and between two 2x4 staggered stud walls 16" OC, spaced 2.25" apart
    - ½" drywall with Class II vapor retarder (PVA primer and latex paint)

WUFI Analysis and Results

The WUFI analysis shows that each advanced wall assembly under consideration in this report was verified to be in compliance with the following acceptable moisture durability thresholds:

1. A simulated Moisture Content (MC) of no more than 20% by weight after the first year of simulation and no evidence of long-term moisture accumulation in 3 mm (≈1/8 in) OSB layers simulated on the inner and outer face of the exterior structural OSB sheathing.[8]
2. Predicted mold index of <3 based on the latest VTT model.[9]
3. Declining or time-stabilized moisture content of the entire assembly with no evidence of long-term moisture accumulation.

Figure 1, Figure 2, and Figure 3 on the following pages detail the MC percentage for each wall system on an annual basis in three locations within the two primary Northwest climate zones. In each case, the walls are well below the conservative MC limit of 20% during simulation years 2-5.[10] During the first year, some wall assemblies slightly exceed the 20% limit (21-24%) in certain locations, which is acceptable performance while new building materials are drying out. Additionally, in the first year, the wall assemblies never approached the critical 28%-30% fiber saturation level, which can lead to wood decay (Spray, 1985).

Ventilated rainscreens were added to the simulations for the TBS wall and the 2x4 DSW with blown-in fibrous insulation wall to evaluate the added drying potential of this feature. In all simulated climate zones, the ventilated rainscreen simulation demonstrated improved performance with less moisture accumulation during wintertime compared to the same wall without a rainscreen installed. The ventilated rainscreens not only improved the drying potential of the walls, they also reduced the risk of moisture intrusion through flaws in the WRB.

Controlling indoor humidity levels during winter with a ventilation system is an important best practice. Buildings with features that significantly increase indoor humidity, such as pools and spas, require additional moisture protection and cannot default to prescriptive code requirements for moisture control.

[8] 20% moisture content (MC) is a conservative limit, especially in northern climates, where this threshold is typically exceeded during colder temperatures when the risk for mold and decay is at its lowest (Ueno & Lstiburek, 2014).

[9] A description of the VTT modeling add-on can be found at https://wufi.de/en/2017/03/31/wufi-mould-index-vtt/..

[10] The WUFI analysis assumes primer and two coats of latex paint for the Thermal Break Shear wall and Continuous Rigid Insulation assemblies for Portland and Boise. The Spokane double stud wall assembly analysis assumes a 1 perm vapor retarder (vapor retarder primer).

In Portland (climate zone 4C) the TBS wall and 2x6 with rigid insulation wall outperformed the conventional 2x6 wall for moisture management. Also observed in climate zone 4C (Portland), the 2x4 DSW with blown-in fibrous insulation wall without rainscreen performs at essentially the same level as the conventional 2x6 wall.

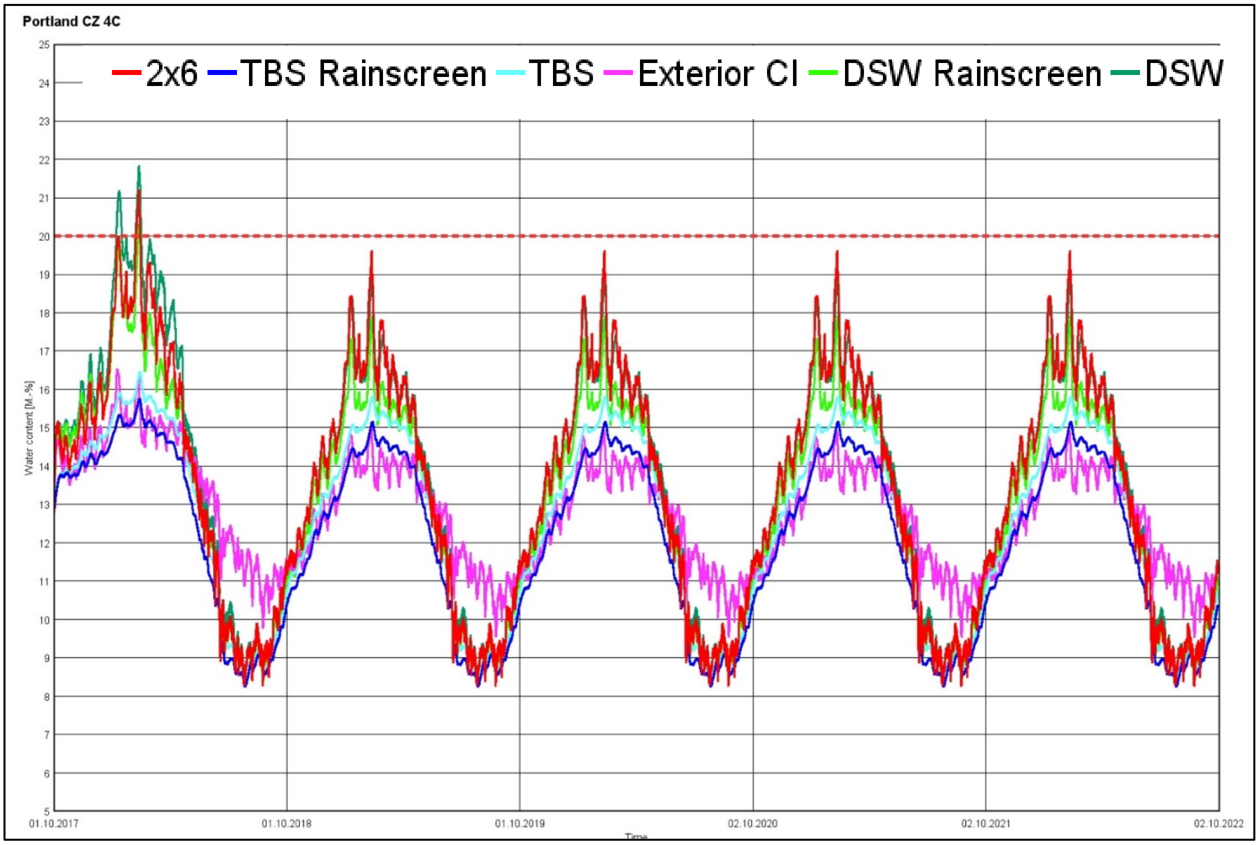

Figure 1. WUFI Results for Portland, OR in Climate Zone 4C

In Boise (climate zone 5B), the DSW without rainscreen performs at levels similar to the conventional 2x6 wall. When the rainscreen was added, the DSW outperforms the conventional 2x6 wall for homes in this location.

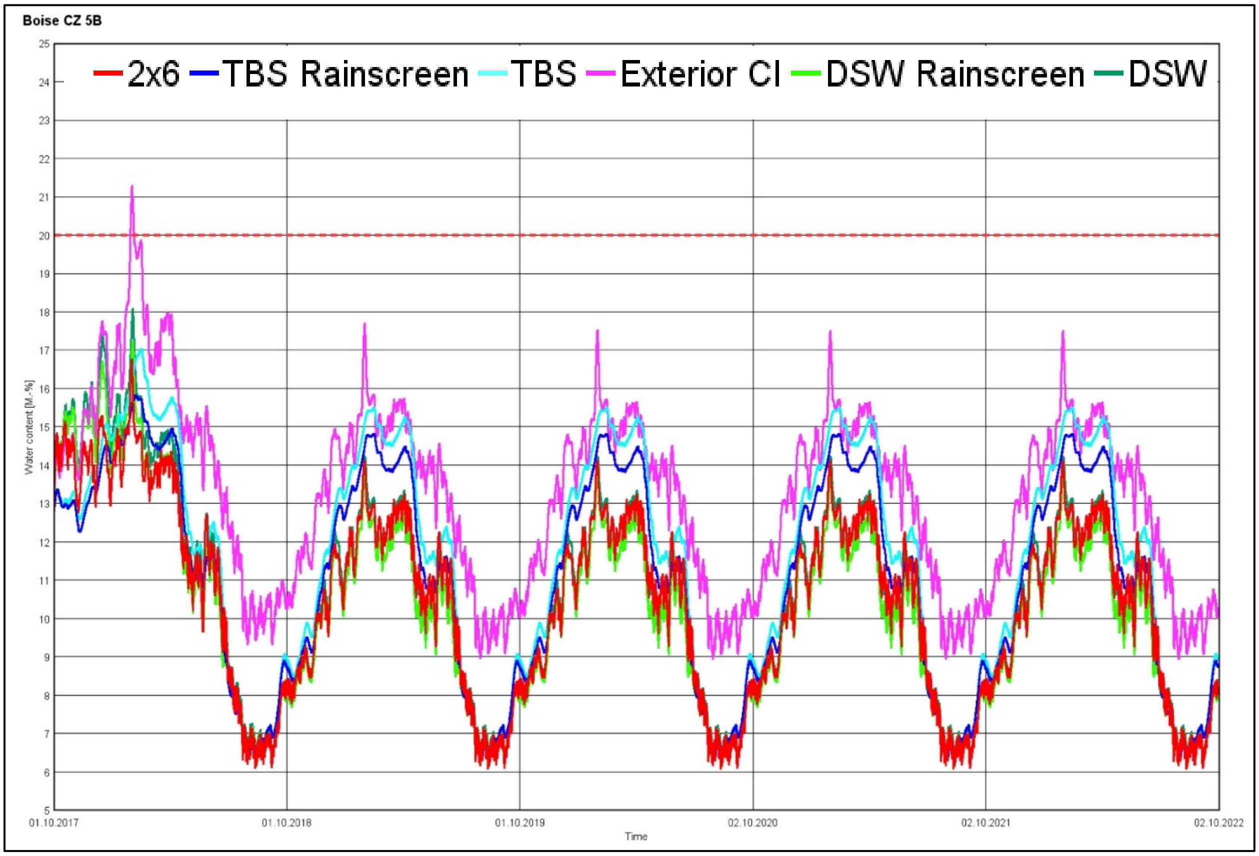

Figure 2. WUFI Results for Boise, ID in Climate Zone 5B

In Spokane (climate zone 5B), the DSW both with and without a rainscreen performs at levels similar levels to the conventional 2x6 wall. The conventional 2x6 wall slightly outperforms the TBS wall with rainscreen for homes in Spokane. Despite performing below conventional 2x6 wall levels, the TBS wall without rainscreen and the CI wall remain well within acceptable moisture performance ranges.

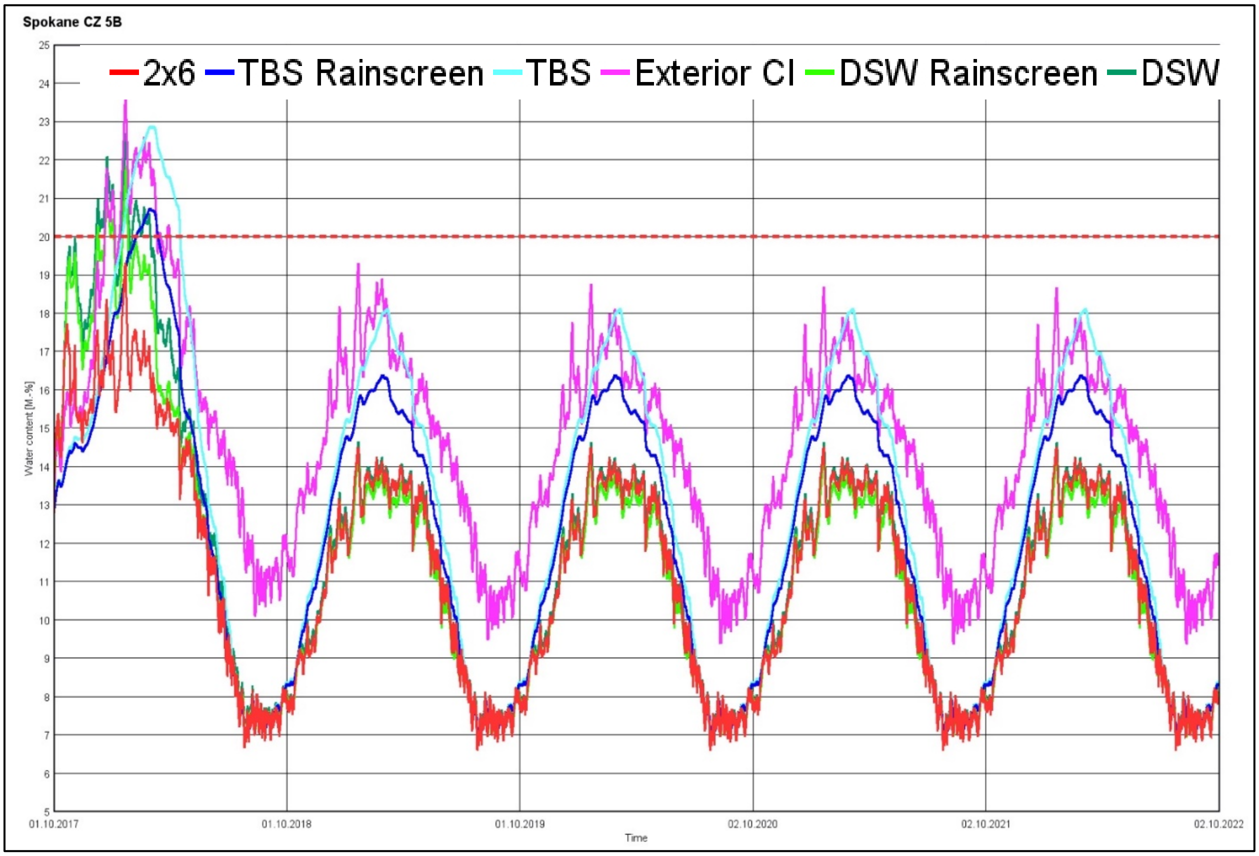

Figure 3. WUFI Results for Spokane, WA in Climate Zone 5B

Figure 4 below illustrates the comparative performance of the wall assemblies across each of the three building locations. As noted above, each of the wall assemblies performs within acceptable moisture content ranges across the region. However, when compared to current standard practices, location-specific impacts clearly exist. These analytical results should be considered when developing training and market engagement activities as part of any future market transformation efforts.

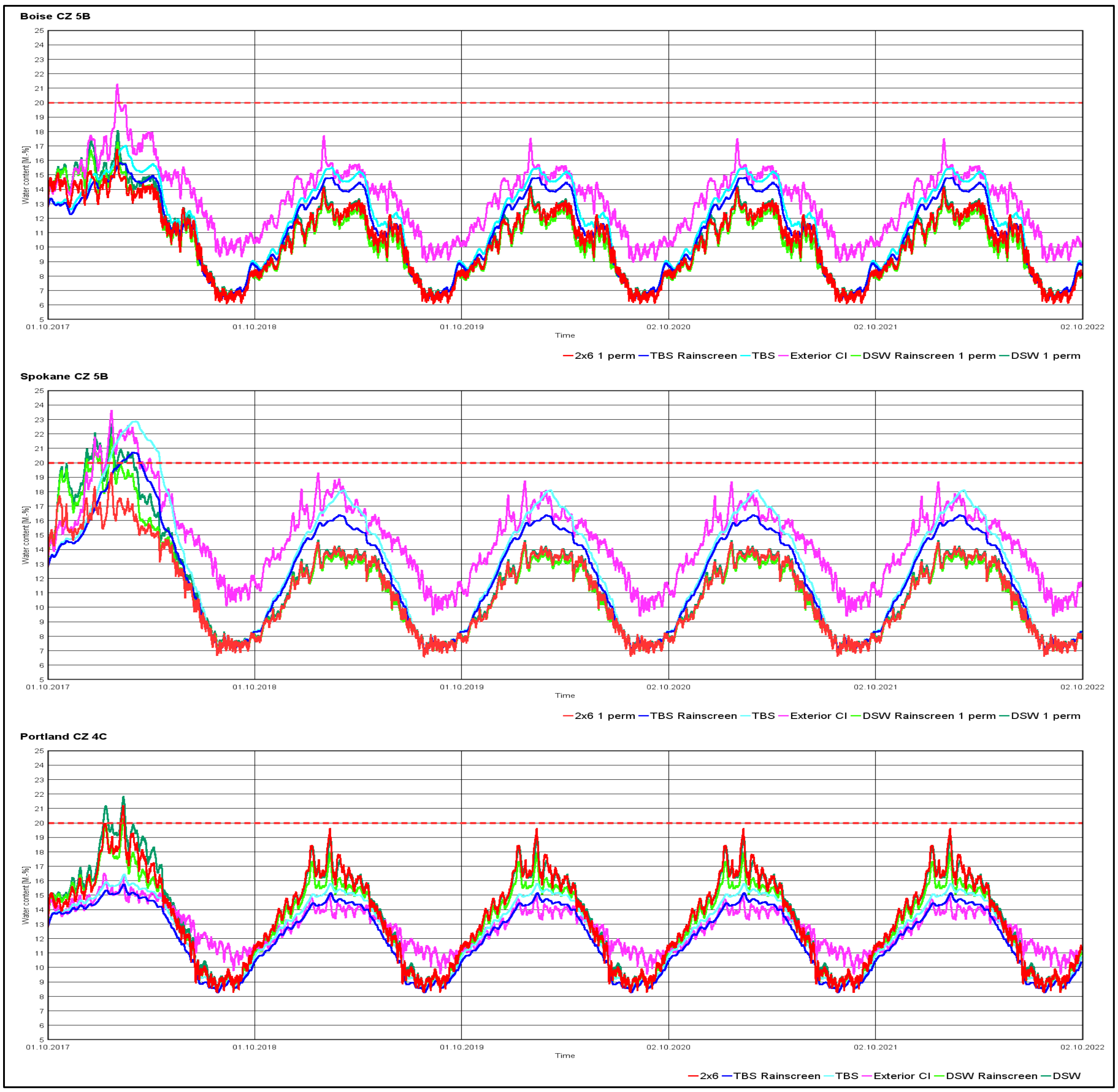

Figure 4. WUFI Results for Boise, ID and Spokane, WA in Climate Zone 5B and Portland, OR in Climate Zone 4C

Benefits of the Advanced Wall Systems

Introduction

In Phase 1 of the Advanced Walls project, the project team determined that not only do each of the three wall assemblies provide greater energy efficiency outcomes, they also generate other benefits for builders and their customers. The previous section of this Phase 2 report showed that contrary to some builder conjecture, in comparison to current industry practice, each of the advanced wall assemblies can actually provide additional moisture management benefit in most Northwest locations. This section of the report includes quantifiable confirmation of the varying energy performance improvements provided by each wall assembly, as well as quantifiable and documented evidence of other enhancements to the overall performance of the home. These other enhancements include documented noise mitigation attributes of each of the three wall assemblies and proven seismic resiliency benefits from the TBS wall.

Energy Savings

Energy savings constitute one of the clear benefits of each of the three advanced wall assemblies. Specific energy savings calculations for each wall assembly are included in Table 1 below and were calculated through REM/Rate modeling of the total mmBTU for heating and cooling of a standard home.

As Table 1 indicates, the different wall assemblies yield a range of energy efficiency benefits, and further variations exist based on the selected insulation components of each assembly (see Table 2). The calculated energy savings for the heating and cooling load over standard practice were determined using a baseline conventional wall system of 2x6 intermediate framing with R-21 fiberglass batt insulation.

The baseline home was configured in the following way:

- House size: 2,386 sq ft
- Stories: 2
- Bedrooms: 3
- Window glazing amt: 405.5 sq ft
- Window glazing %: 17%
- 95 Average Fuel Utilization Efficiency (AFUE)
- 13 Seasonal Energy Efficiency Ratio (SEER)
- Air leakage: 3.0 ACH@50pa
- Attic insulation: R-49
- Floor insulation: R-38
- Windows: U = .30 / Solar Heat Gain Coefficient (SHGC) = .30

Table 1. Energy Savings by % of Heating and Cooling Load

% savings vs. conventional wall	TBS Wall			Exterior Rigid					Double Wall 8”	Double Wall 8”	Double Wall 10”	Double Wall 10”
	ISO	EPS	XPS	1” EPS	1” XPS	2” EPS	2” XPS	2” ISO	FG	Cell	FG	Cell
Portland	5.8%	4.6%	5.2%	4.6%	5.2%	6.7%	7.6%	8.2%	7.3%	6.1%	9.6%	9.0%
Spokane	7.0%	5.6%	6.3%	5.6%	6.3%	8.1%	9.1%	9.9%	9.0%	7.3%	11.5%	10.3%
Boise	6.5%	5.1%	5.9%	5.1%	5.9%	7.5%	8.4%	9.2%	8.3%	7.5%	10.7%	9.5%

Table 2. U-Values of Each Wall Assembly/Components

Wall Assembly	Nominal U-Value	Total Wall U-Value
Baseline wall assembly	0.048	.055
Exterior Rigid 1” XPS	0.037	0.041
Exterior Rigid 1” EPS	0.036	0.039
Exterior Rigid 1” ISO	0.035	0.037
Exterior Rigid 2” XPS	0.032	0.035
Exterior Rigid 2” EPS	0.03	0.032
Exterior Rigid 2” ISO	0.028	0.03
DW 8" BIBS	0.03	0.033
DW 8" Cellulose	0.035	0.037
DW 10” BIBS	0.024	0.026
DW 10" Cellulose	0.028	0.03

Noise Attenuation

Sound can be attenuated in a number of ways: through the decoupling of solid materials to create a vibration break, by placing sound absorption materials into the wall assembly, and by using denser materials such as concrete or extra layers of gypsum sheathing. As noted in the Phase 1 report, noise attenuation is a potential non-energy benefit of building with each of the three advanced wall assemblies. With housing density becoming a more regular consideration in new home construction, and homebuyers more frequently working from their homes than in the past, noise attenuation is likely to become increasingly important to a growing proportion of homebuyers, and therefore an increasingly compelling selling point for builders.[11]

2x4 Double Stud with Blown-In Fibrous Insulation

In Phase 1 of the Advanced Walls project, the 2x4 double stud with blown-in fibrous insulation was specifically identified through builder interviews as having the potential to dampen exterior sound transmission through the wall assemblies due to decoupling of the vertical structural studs and through sound absorption of the fibrous insulation layer. The 2x4 double wall both decouples the structural studs with the gap between the inner and outer wall and includes a significant amount of sound absorption material with the insulation in the cavities.

To confirm actual noise attenuation characteristics, wall assemblies are laboratory-tested to determine their Sound Transmission Class (STC) ratings. An STC rating indicates how well a wall assembly blocks airborne sound; the higher the STC rating, the more the assembly reduces sound transmission.[12] Table 3 describes several STC-rated assemblies' abilities to attenuate loud speech (Bliss, 2005).

Table 3. STC Rating Levels

STC Rating	Speech Heard Through Wall or Floor	Noise Control Levels
30	Loud speech can be understood fairly well	Poor
35	Loud speech audible but not intelligible	Marginal
42	Loud speech audible as a murmur	Moderate
45	Loud speech barely audible	Good
48	Hearing strained to hear loud speech	Good
50	Loud speech barely audible	Very Good
55+	Loud speech not audible	Excellent

While most of the documented laboratory STC testing was performed on partition walls to evaluate sound attenuation potential for assemblies in multifamily housing, schools, or other shared spaces with varied internal noise levels, the results are illustrative of the overall performance of different wall assemblies in exterior contexts. For example, an uninsulated, 2x4

[11] 24% of working Americans worked from their homes some or all the time in 2015 (BLS, 2016). People with advanced degrees are more likely to work from home than persons with lower levels of educational attainment—42% of those with an advanced degree performed some work at home on days worked, compared with 12 percent of those with a high school diploma and no college (BLS 2019). Homeownership rates are higher for Americans with advanced degrees.

[12] Johns Manville Insulation, Acoustical Performance Advantages https://www.jm.com/content/dam/jm/global/en/building-insulation/Files/BI%20Toolbox/Acoustical-Assemblies-STC-Rating-Reference-Guide.pdf

partition wall has an STC rating of 35 and provides only marginal sound attenuation (DuPree, 1980). By contrast, a fiberglass batt insulated 2x4 wall has an STC rating of 41, providing moderate sound attenuation across partition walls. This type of wall is commonly used in single-family residential construction for internal sound attenuation.

The 2018 International Building Code, Section 1206.2 (Airborne Sound) requires that “Walls, partitions and floor-ceiling assemblies separating dwelling units and sleeping units from each other or from public or service areas shall have a sound transmission class of not less than 50, or not less than 45 if field-tested, for airborne noise when tested in accordance with ASTM E90.”[13] As Table 4 describes, an 8”, 2x4 double stud partition wall insulated with fiberglass batts significantly reduces sound transmission with an STC rating of 54-59 depending on the thickness of the gypsum board. A 2x4 DSW with blown-in fibrous insulation should attenuate sound similarly to the 8”, 2x4 double stud partition wall insulated with fiberglass batts. The actual STC rating of the exterior wall would likely vary from the partition wall ratings due to the wooden exterior sheathing layer replacing the gypsum board in the laboratory-tested assemblies. A thicker 10”-12” DSW should have a higher STC rating due to the additional amount insulation.

Table 4. STC Ratings for Each Wall Assembly

STC Ratings for Each Wall Assembly		
Wall Type	**Estimated STC Rating**	**Noise Control Levels**
Conventional 2x6 wall	40*	Marginal / Moderate
Thermal Break Shear Wall (TBS)	51-55[14]	Very good / Excellent
2x6 Intermediate frame with continuous rigid insulation (CI)	51-55[15]	Very good / Excellent
2x4 double stud wall (DSW) with blown-in fibrous insulation	54-59	Excellent

**Owens Corning (no date) p. 28.*

[13] International Code Council, August 2017, 2018 International Building Code

[14] Estimated STC ratings based on builder interviews and building industry documentation. See https://basc.pnnl.gov/building-science-measures/exterior-insulation-sheathing, https://www.jm.com/content/dam/jm/global/en/building-insulation/Files/BI%20Toolbox/Acoustical-Assemblies-STC-Rating-Reference-Guide.pdf and https://bettersoundproofing.com/best-soundproofing-insulation/

[15] Ibid

Structural Resilience

Thermal Break Shear Wall

A 2016 analysis by NEEA documented the seismic resiliency benefits of the Thermal Break Shear (TBS) wall (Miter Construction, 2016). In 2009, when a Washington County (OR) Code Official required proof from builder Ben Walsh[16] that a proposed shear wall assembly would be capable of resisting code-level seismic forces, the builder contracted with Oregon State University to perform destructive seismic testing. Earthquake testing conducted at Oregon State University's Knudson Wood Engineering Laboratory has documented that the Thermal Break Shear wall assemblies used in new construction meet shear strength requirements and deliver a much higher lateral load capacity than do conventional new construction wall assemblies.[17] The TBS wall assembly tested was engineer-designed with an advanced nailing pattern of 3” o.c. at the panel edge and 12” o.c. in the panel field.

From the 2016 NEEA report, “The graph below compares hysteresis loops, force curves, from the tests of a conventional wall, and a [TBS] wall. The curves describe wall panels bolted into a test rack, being pushed and pulled increasingly out-of-square by a test cylinder. The blue line shows a conventional assembly reaching its capacity at about 1-3/4” of deflection, under a 5,600-lb load, and suffering catastrophic failure. The green line shows a [TBS] wall continuing to resist deflection with increasing strength as the test reaches its protocol maximum deflection of 5”.” (Miter Construction, 2016)

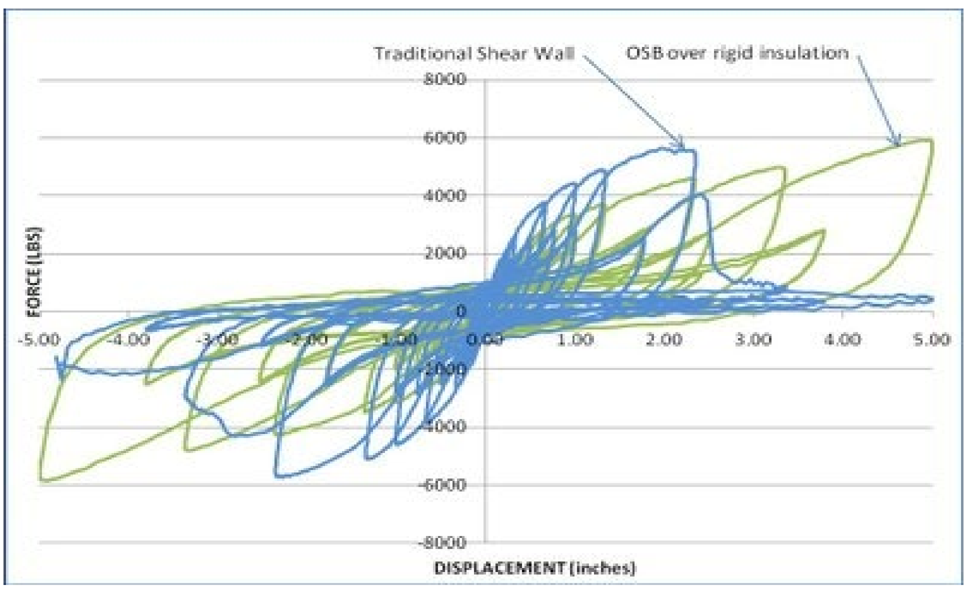

Figure 5. Wall Displacement - Standard Wall vs. TBS

[16] The project team would like to thank Ben Walsh for his time and insights into the permit submittal process he undertook to gain approval for the Thermal Break Shear wall in Washington County and later, on a separate project, with the City of Portland.

[17] Dr. Rakesh Gupta of Oregon State University performed ASTM-E72/CUREE-style cyclic lateral load testing (i.e., commercial code standard) in conformance with ICC Evaluation Service Approval Criterion 130. See https://vimeo.com/156026994 and https://vimeo.com/156038124.

The increased flexibility of this wall assembly delivered a higher lateral load capacity than does a conventional wall assembly, and also made the wall much more resilient in the face of the rocking motion typical of seismic events.

Summary of Wall Benefits

Table 5 below summarizes key considerations for each wall system. The project team has identified industry research that documents the benefit of the wall assembly or has conducted an analysis quantifying the benefits of the wall. These cases are identified by a (D) in the table.

In other cases, the project team documented field evidence from builder interviews to suggest that additional benefits exist, although quantified research results are not available. These attributes are identified by an (F) in the table. For example, based on builder interviews, customers responded very favorably to the deeper sills created by the double stud wall. Homebuyers claimed they provided the home a sense of being “more solid” and “more comfortable,” as well as providing informal seating or decoration options. Also, those builders interviewed who are building consistently with their chosen wall assembly did not find the approach overly burdensome and claimed it did not require much additional coordination with trades.

The project team’s Phase 1 analysis included an estimated incremental cost for each assembly, which is provided in the table below for the purpose of comparison.

Table 5. Summary of Wall Benefits

Wall Type	**Ease of Assembly**	**Aesthetic Benefits** (deeper sills)	**Less Thermal Bridging**	**Seismic Resiliency**	**Noise Attenuation**	**Moisture Manage-Ment**	**Estimated Incremental Cost at scale**
Thermal Break Shear (TBS) Wall	F		D	D	D	D	$.48/sq ft
Continuous Rigid Insulation (CI)	F		D		D	D	$1.03/sq ft
Double Stud Wall (DSW)	F	F	D		D	D	$.79/sq ft

D = Documented through research
F = Field evidence

The incremental cost estimates were developed in Phase 1 of this project. These cost estimates assume production builder economies of scale.

Construction Best Practices

Introduction

The three advanced wall systems detailed in this report significantly reduce or eliminate thermal bridging, which is the movement of heat through a solid object that is more conductive than the materials around it. By effectively eliminating thermal bridging, these wall systems establish a thermal break between the wooden structural building components and the exterior environment, or the wooden structural building components and the interior environment. Whether building a thicker wall or introducing rigid continuous insulation into the wall assembly, the purpose of this section of the Phase 2 report is to provide up-to-date and field-tested recommendations that help ensure time-effective installation, minimize additional costs, and maximize overall performance. These construction best practice recommendations address proper detailing to account for the effects of additional insulation on moisture movement through the overall assembly.[18]

All the wall systems described below involve some modification to current standard single-family residential construction practices to add insulation to a code-built wall assembly. With the TBS wall, the framers will install the insulation, whereas the siding installers will typically install exterior rigid insulation when it is outboard of the sheathing. With a staggered or double stud wall, the framers' work scope is modified and the insulators install additional insulation inside the wall cavity with a slightly modified installation process. The subcontractors impacted may affect the decision of which assembly to build based on the availability of and confidence in local subcontractors who are either familiar with these wall systems and/or are willing to try something new. This factor is important as it may affect the cost and construction schedule.
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[18] Manufacturer installation instructions, applicable jurisdictional building codes, and architectural construction drawings and specifications should take precedence over the details in this section.

Thermal Break Shear Wall (TBS)

The TBS wall is an assembly in which a continuous layer of rigid foam insulation is sandwiched between the structural sheathing and standard framing to create a "thermal break shear wall" for significantly increased energy efficiency. The TBS wall can be either field assembled with standard construction materials, such as plywood or oriented strand board (OSB) and rigid foam insulation panels, or by using factory-assembled insulated sheathing panel systems, such as ZIP System® R-Sheathing made by Huber. The factory-assembled structural insulated sheathing panels consist of a layer of OSB structural sheathing with ½" to 2" of rigid insulation glued to the interior side and a fluid-applied water-resistive barrier (WRB) applied to the exterior. The pre-assembled panels carry a cost premium. When field-assembled, the rigid foam used in this assembly can be expanded polystyrene (EPS), extruded polystyrene (XPS), or polyisocyanurate (ISO), but is most commonly fiberglass-faced ISO.[19] The wall achieves laboratory-verified seismic resiliency benefits when built with an increased nailing pattern. The rigid insulation panels are typically installed by the framer.

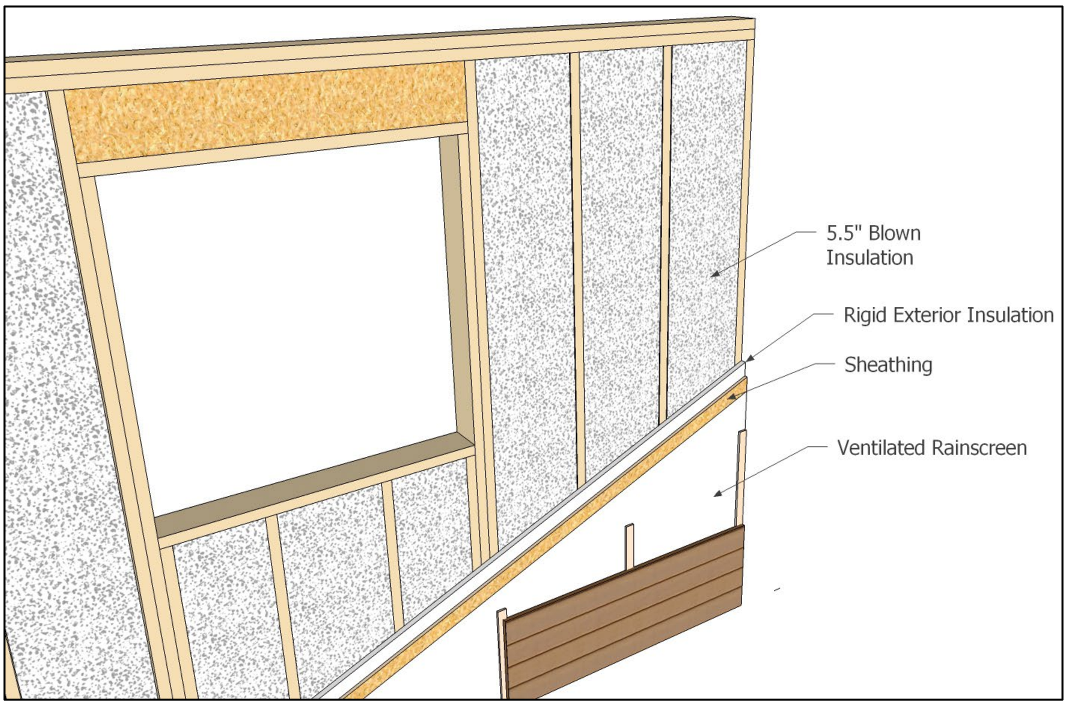

Figure 6. TBS Wall

Effective Installation

- For factory-assembled structural insulated sheathing panels such as ZIP System® R-Sheathing: Seams and nail holes are either caulked or taped to complete the pre-applied WRB.

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[19] Graphite polystyrene (GPS), a relatively new product, is a potential alternative to these other rigid insulation options. GPS is similar to EPS but is made from graphite-infused polystyrene beads. It shows promise as an outboard insulation material given its higher R-value per inch than EPS and its greater compressive strength. GPS is typically unfaced and has relatively high vapor permeability to allow substantial drying to the exterior, and is roughly in the middle of the other insulation options in terms of price per sheet.

- The panel must be dry for the seams to be effectively taped to complete the WRB.
- ZIP System® R-Sheathing requires an increased nailing schedule at the edges with longer fasteners: 4” edge spacing rather than 6” and 1½” stud penetration rather than 1”.
- Some rigid insulation panel types can be ordered pre-scored at 16”, 24”, and 32”, which can reduce installation labor for field-assembled walls.

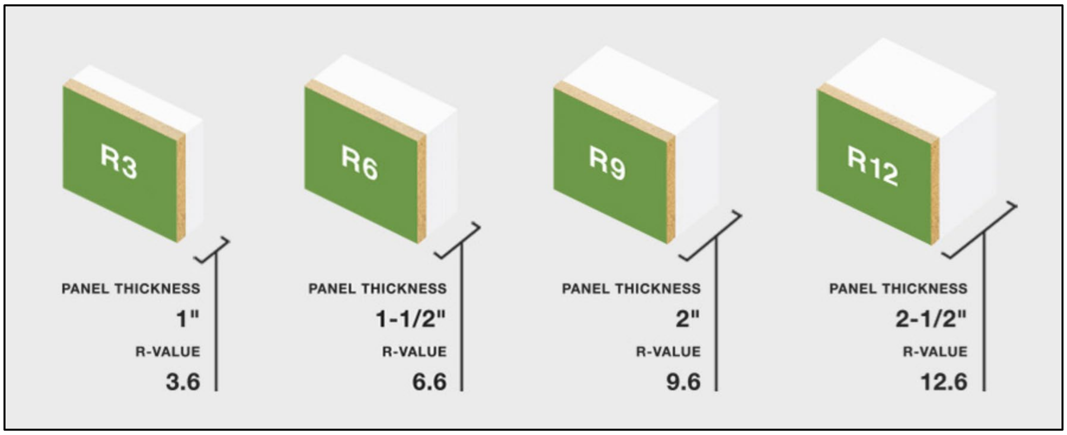

Figure 7. Huber ZIP System® R-Sheathing

- For field-assembled walls: After typical wall stud and plate framing is completed on the floor, the foam board is installed over the wall by nailing only at the corners to temporarily keep it in place. This is followed by fully nailing the sheathing over the rigid insulation.
- Stagger the foam panels relative to the sheathing to minimize seam alignment (as illustrated in Figure 8).

Figure 8. Exterior View of Staggered Layers to Minimize Seam Alignment. Courtesy of Home Innovation Research Labs (Gunderson & Kochkin, 2018)

- Place the sheathing on top of the foam and attach to the studs with 8d galvanized box nails following a nailing schedule of 6” at the edge and every 12” in the field when using the prescriptive approach per ICC ESR 2586 (ICC-ES 2019). See Figure 10 for a detailed description.

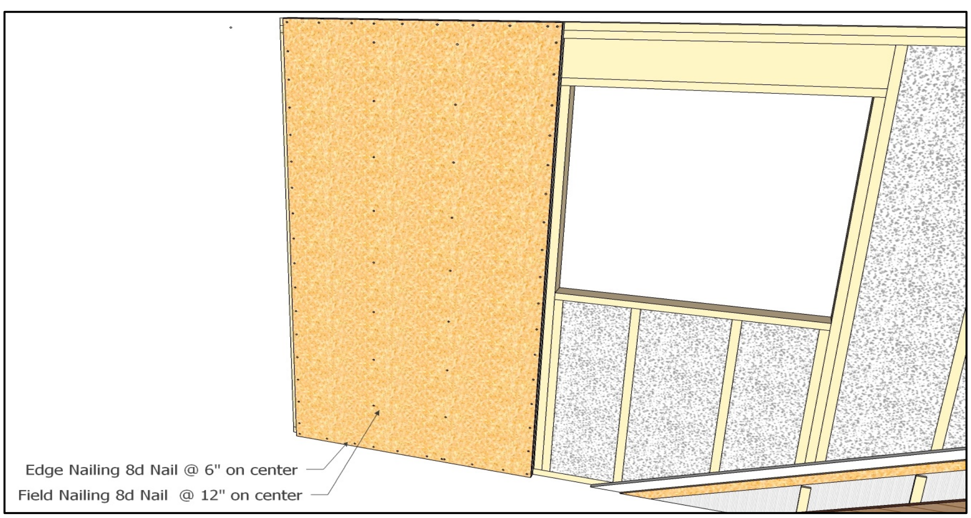

Figure 9. TBS Wall Nailing Pattern

APA Rated Siding Panels Over Rigid Foam Insulation Sheathing

Excerpts from ICC-ES Evaluation Report ESR-2586

4.4.2 Panel Siding: Panel siding must be fastened directly to framing in accordance with wood structural panel provisions of the code. When siding ½ inch (12.7 mm) or less in thickness is installed over foam plastic Insulation up to 1 inch (25.4 mm) in thickness, the siding must be fastened with 8d galvanized box nails.

Panel sizing applied directly to studs, spaced in Accordance with the span rating and fastened with 6d Galvanized box nails or equivalent, spaced 6 inches (152 mm) on center at panel edges and 12 inches (305mm) on center at intermediate studs, is an alternative To the wood structural panel sheathing construction Specified in the code for wall bracing (2018, 2015, and 2012 IRC Table R602.10.4, Method WSP, and 2009 IRC Table R602. 10.2, Method WSP).

Shear values for all-veneer panel siding must be as given in the applicable code for siding applied directly to Studs of over ½ or ⅝ inch (12.7 mm or 15.88 mm) Gypsum sheathing. Thickness at point of nailing at panel Edges determines applicable values.

Figure 10. ICC ESR-2586

- To increase the shear capacity of the wall assembly and to attain the lab-verified seismic resiliency, the fastener schedule is increased to every 3”-4” at the edges with 12d nails to achieve 1½” penetration into the stud.
- The ZIP System® R-Sheathing nailing schedule for increased shear capacity is indicative of the additional capacity provided by the increased nailing schedule with this assembly (see Figure 11).
- Note that while an advanced nailing schedule is recommended in seismic hazard zones, it increases the thermal bridging through the fasteners and is therefore counter-recommended where seismic and wind loads do not warrant it.

	Framing[4]		Fasteners			Shear Values	
ZIP System® R-sheathing Type[5]	Nominal Stud Spacing (min.)	Maximum Stud Spacing (in.)	Fastener Specifications[6]	Edge/Field Spacing (in.)	Minimum Penetration into Framing (in.)	Allowable Seismic Controlled Shear Values[7, 9, 10] (plf)	Allowable Wind Controlled Shear Values[2, 7, 9] (plf)
R-3	2-by-4	24	0.131" shank nails	4/12	1.5	245	343
R-3	2-by-4	24	0.131" shank nails	3/12	1.5	280	393
R-3	2-by-4	16	16ga staples, 7/16" crown, 2" length	3/6	1	210	294
R-6	2-by-4	24	0.131" shank nails	4/12	1.5	230	322
R-6	2-by-4	24	15ga staples, 7/16" crown, 2.5" length	3/6	1	NA[8]	NA
R-6	2-by-4	24	0.131" shank nails	3/12	1.5	255	357
R-9	2-by-4	24	0.131" shank nails	3/12	1.5	240	336
R-12	2-by-4	24	0.131" shank nails	3/12	1.5	215	301

For SI: Inch = 25.4mm; 1 pound per foot (ppf) = 14.59 N/m.
1 Prescriptive bracing requirements with Douglas Fir-Larch Framing under the 2015, 2012 and 2009 IRC.
2 Not approved for use as prescriptive wall bracing where the design wind speed is greater than 110mph.
3 Engineered shear wall requirements with Douglas Fir-Larch Framing under the 2015, 2012, and 2009 IBC.
4 For framing with other than Douglas Fir-Larch, the shear value above must be multiplied by the Specific Gravity Adjustment Factor = [1 - (0.50 - SG)], where SG=Specific Gravity of the framing lumber in accordance with the ANSI/AWC NDS. This adjustment factor must not be greater than 1.
5 Type R-3 R-sheathing panels have a foam plastic insulation thickness of .5". Type R-6 R-sheathing panels have a foam plastic insulation thickness of 1". R-9 R-sheathing panels have a foam plastic insulation thickness of 1.5". Type R-12 R-sheathing panels have a foam plastic insulation thickness of 2".
6 Fasteners must be common nails or equivalent, or staples, of a type generally used to attach wood sheathing.
7 The shear walls must have a maximum height-to-width aspect ratio of 2:1.
8 This panel and fastening configuration is only applicable to the prescriptive bracing requirements under the 2015 IRC.
9. All panel edges must be backed by framing
10. ZIP System R-sheathing used as the lateral resistance system in seismic zones C, D_0, D_1, D_2 and E should be designed in accordance to ER-482.

Figure 11. Nailing Schedule for ZIP System® R-Sheathing in Seismic Controlled Regions (Huber, 2019)

- Use a panel pilot router bit with self-driving guide tip and minimum 1¾” cutting depth to cut out window and door openings.
- Install tie-down straps/hardware on the inside. The transference shear strapping commonly used to vertically connect walls across an intervening floor assembly will not accommodate the foam; the conventional flat shear strapping must be replaced with hold-downs and bolts inside the wall cavity.

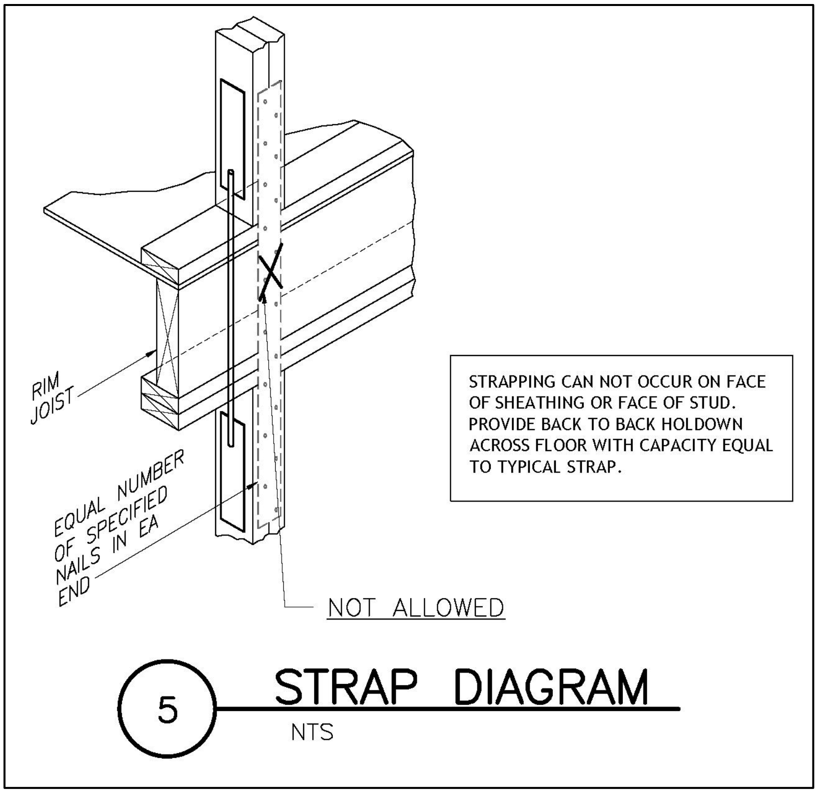

Figure 12. TBS Strap Diagram

Optional, if applicable: Install double roofing truss at gable end (also called a rake) when adjacent to unconditioned attic space to eliminate unnecessary rigid insulation in this otherwise uninsulated section of wall, while keeping the sheathing surface plumb and increasing the end truss bearing on the wall top plate.

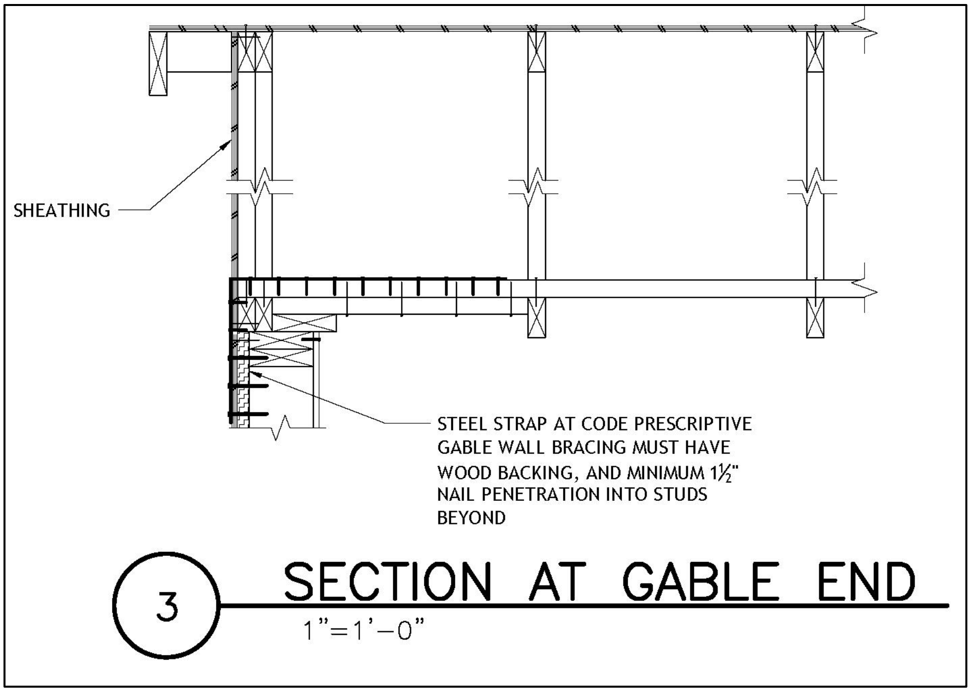

Figure 13. TBS Section at Gable End

Best Practices for Siding Installers

- When installing rainscreen furring strips, fasteners should penetrate into the studs at least 1½".
- Cladding attachment may follow an alternate schedule when forgoing the rainscreen furring strips.
- Attach siding weighing 3 psf or less (most fiber cement siding qualifies) directly to wood structural sheathing per table R703.3.2 (see Figure 14 below).
- Alternatively, siding or other types of exterior finishes may use nails or screws of sufficient length to attach through both the wood structural sheathing and the 2-in. foam layer to the studs with penetration to the depth required by 2012 International Residential Code (IRC) Section R703.3.3, at the prescribed frequency.

Table 9. Fastening Exterior Finishes *the IRC provides an alternate schedule for fastening directly to structural sheathing.*

	Adapted from 2015 IRC TABLE R703.3.2 OPTIONAL SIDING ATTACHMENT SCHEDULE FOR FASTENERS WHERE NO STUD PENETRATION NECESSARY	
Exterior wall covering (weighing 3 psf or less) attachment to wood structural panel sheathing, either direct or over foam sheathing a maximum of 2 in. thick.[a] Note: Does not apply to vertical siding.	**NUMBER AND TYPE OF FASTENER**	**SPACING OF FASTENERS[b]**
	Ring shank roofing nail (0.120" min dia.)	12 in. o.c.
	Ring shank nail (0.148" min dia.)	15 in. o.c.
	#6 screw (0.138" min dia.)	12 in. o.c.
	#8 screw (0.164" min dia.)	16 in. o.c.

a. Fastener length shall be sufficient to penetrate back side of the wood structural panel sheathing by at least 1/4 in. The wood structural panel sheathing shall be not less than 7/16 in. in thickness.

b. Spacing of fasteners is per 12 in. of siding width. For other siding widths, multiply "Spacing of Fasteners" above by a factor of 12/s, where "s" is the siding width in inches. Faster spacing shall never be greater that the manufacturer's minimum recommendations.

Figure 14. Courtesy Home Innovation Research Labs (Gunderson & Kochkin, 2018)

- Install Z flashing under the WRB and beneath the bottom row of cladding to cover and protect the bottom edge of the sheathing and foam (see Figure 15).

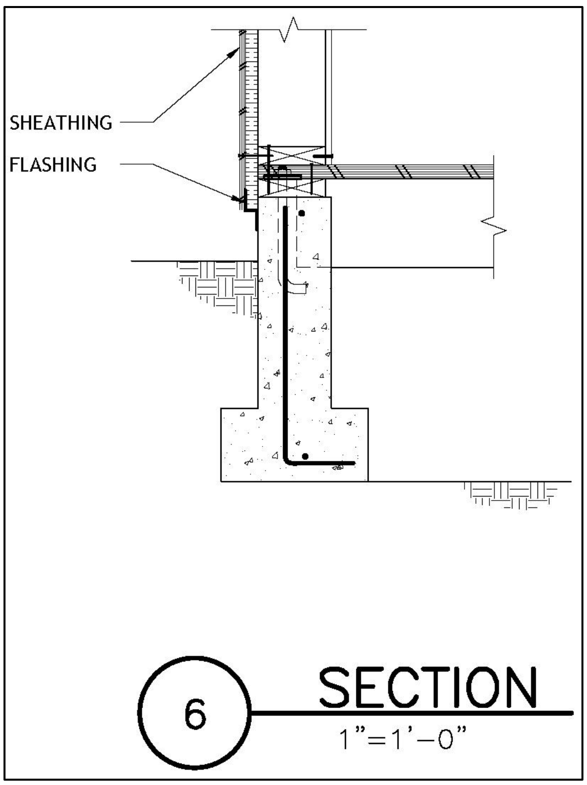

Figure 15. TBS Wall Section

Best Practices for Drywall Installers and/or Millwork Installers

- Install 1" wider drywall return at window jambs and sills.
- Exterior door jambs and thresholds must be 1" wider.
- Install drywall using the airtight drywall approach (Building Science, 2009).

Risk Reduction

To mitigate risk to the wall assembly:

- Use a Class III vapor retarder on the interior side of the wall in climate zone 4C to allow the exterior wall cavity more drying potential to the inside.
    - Non-PVA latex primer and paint on ½" gypsum board is a typical assembly to achieve a Class III vapor retarder.[20]
- Use a Class II vapor retarder on the interior side of the wall in climate zones 5 and 6.
    - PVA vapor retarder primer and paint on ½" gypsum board can achieve a Class II vapor retarder.
    - Alternatively, install a membrane behind the gypsum board with smart vapor retarder characteristics. Smart vapor retarders have variable perm ratings. They increase their permeability during dry periods, allowing moisture to diffuse toward the interior conditioned space in order to dry the wall assembly.
- If using a faced EPS, XPS, or ISO product, install a Class III vapor retarder on the interior surface to increase the drying potential of the wall assembly to the inside to address the decreased drying potential to the outside.
- When using unfaced EPS insulation panels, which are vapor semi-permeable, the wall has sufficient drying potential though the outside when a Class I vapor barrier is installed inside.
- In general, vapor-permeable exterior insulation in combination with an interior vapor barrier typically provides a lower-risk wall assembly than does an assembly using vapor-impermeable exterior insulation.

[20] See IRC Table R702.7.1 for requirements and details. https://codes.iccsafe.org/content/IRC2018/chapter-7-wall-covering

R702.7.1 Class III vapor retarders.

Class III vapor retarders shall be permitted where any one of the conditions in Table R702.7.1 is met.

TABLE R702.7.1
CLASS III VAPOR RETARDERS

CLIMATE ZONE	CLASS III VAPOR RETARDERS PERMITTED FOR:[a]
Marine 4	Vented cladding over wood structural panels. Vented cladding over fiberboard. Vented cladding over gypsum. Continuous insulation with *R*-value ≥ 2.5 over 2 × 4 wall. Continuous insulation with *R*-value ≥ 3.75 over 2 × 6 wall.
5	Vented cladding over wood structural panels. Vented cladding over fiberboard. Vented cladding over gypsum. Continuous insulation with *R*-value ≥ 5 over 2 × 4 wall. Continuous insulation with *R*-value ≥ 7.5 over 2 × 6 wall.
6	Vented cladding over fiberboard. Vented cladding over gypsum. Continuous insulation with *R*-value ≥ 7.5 over 2 × 4 wall. Continuous insulation with *R*-value ≥ 11.25 over 2 × 6 wall.
7 and 8	Continuous insulation with *R*-value ≥ 10 over 2 × 4 wall. Continuous insulation with *R*-value ≥ 15 over 2 × 6 wall.

For SI: 1 pound per cubic foot = 16 kg/m^3.

a. Spray foam with a maximum permeance of 1.5 perms at the installed thickness, applied to the interior cavity side of wood structural panels, fiberboard, insulating sheathing or gypsum is deemed to meet the continuous insulation requirement where the spray foam *R*-value meets or exceeds the specified continuous insulation *R*-value.

Figure 16. IRC Table R702.7.1 Class III Vapor Retarders

Per IRC Table 702.7.1 - A Class III vapor retarder is only permitted in CZ 4C if there's continuous exterior insulation with R value greater than or equal to 3.75 over 2X6 wall. One inch of exterior rigid, which is the recommended thickness for the TBS wall, will get an R value of roughly 4-6 depending on material used.

In CZ's 5 and higher, at least R7.5 is required over a 2X6 wall in order to use a Class III vapor retarder, which is thicker than one inch and would require different detailing for the TBS wall that we don't cover and wasn't tested/modeled.

The use of continuous rigid insulation in a TBS wall assembly provides an effective solution to thermal bridging. There are three primary types of rigid insulation that can be applied in a TBS wall: expanded polystyrene (EPS), extruded polystyrene (XPS), or polyisocyanurate (ISO). These same rigid foam options apply in the 2x6 Intermediate Frame with Continuous Exterior Rigid Insulation wall assembly discussed in the following section.

Table 6. Exterior Insulation Types: Summarized Comparisons

Exterior Insulation Types: Summarized Comparisons (Gunderson & Kochkin, 2018, p. 12)		
EPS	**XPS**	**ISO**
The most versatile of the three rigid insulation options	Falls in the middle of the three types of rigid foam insulation in both cost and R-value	More expensive than the other two rigid insulation options
Highest average R-value per dollar	Comes unfaced and considered semipermeable	Highest R-value per inch that degrades only slightly over time
Does not retain water over the long term	Considered a vapor retarder, not a vapor barrier	All ISO panels are faced, and different facings affect the performance of the panel in both durability and perm rating
Available faced or unfaced – faced products are considered vapor retarders	R-value might degrade over time	Foil-faced panels are considered impermeable and should not be used with an interior vapor barrier
R-value does not degrade over time	The manufacturing process is considered environmentally-unfriendly	

EPS and XPS are thermoplastics, which are non-cross-linked polymers, making them susceptible to deterioration in high temperatures.[21] ISO is a thermoset and made up of cross-linked polymers, so it has a much higher melting temperature. XPS and ISO tend to be higher density, higher R-value, and lower permeance than EPS

Table 7. Pros and Cons of Rigid Insulation Options

Exterior Insulation Types: Pros and Cons		
Insulation Type	**Pros**	**Cons**
EPS	Lower Cost Permeable	Lower R-value
XPS	Higher R Value Semi-Impermeable	Higher Cost
ISO	Higher R Value Permeable (fiber faced)	Higher Cost Impermeable (foil faced)

[21]See BSC 2007

Table 8. Quantitative Comparison of Various Insulation Options

Exterior Insulation Types: Quantitative Comparison					
Insulation Type	**Per in. R-value**	**Min. Density (pcf)**	**Per in. Perm Ratings**	**ASTM Standard**	**Compressive Strength, psi**
EPS Type II	4.0	1.35	2-4	ASTM C 578	15
EPS Type IX	4.2	1.80	2-4	ASTM C 578	25
XPS Type X	5.0	1.30	0.8	ASTM C 578	15
XPS Type IV	5.0	1.55	0.8	ASTM C 578	25
ISO	6.0	1.70	0.1 foil faced 4-8 fiber faced	ASTM C 1289	16

From Kochkin & Wiehagen, 2017

2x6 Intermediate Frame with Continuous Exterior Rigid Insulation

The 2x6 intermediate frame with exterior rigid insulation wall is an assembly in which a standard code compliant wall has continuous exterior rigid insulation installed to help reduce thermal bridging through wood structural members. Continuous rigid insulation is a construction solution that provides a thermally efficient building enclosure. Rigid insulation panels are available in several thicknesses and R-values; 1-inch and 2-inch thicknesses are common. In addition to providing thermal protection, rigid insulation can also serve as an additional air and moisture barrier. As detailed above, expanded polystyrene (EPS), extruded polystyrene (XPS), and polyisocyanurate (ISO) rigid insulation options each offer slightly different performance, cost, and installation considerations.[22]

The assembly described in this section is a standard, code 2x6 intermediate framed wall with exterior rigid insulation. The walls are framed and tilted up with standard construction practices. The siding installer is the subcontractor whose work scope is most affected in the construction of this assembly, as their scope typically includes installing the WRB, windows, rainscreen, flashing, trim, and cladding.

[22] See the tables in the Thermal Break Shear Wall (TBS) section above for comparison among the various rigid insulation options.

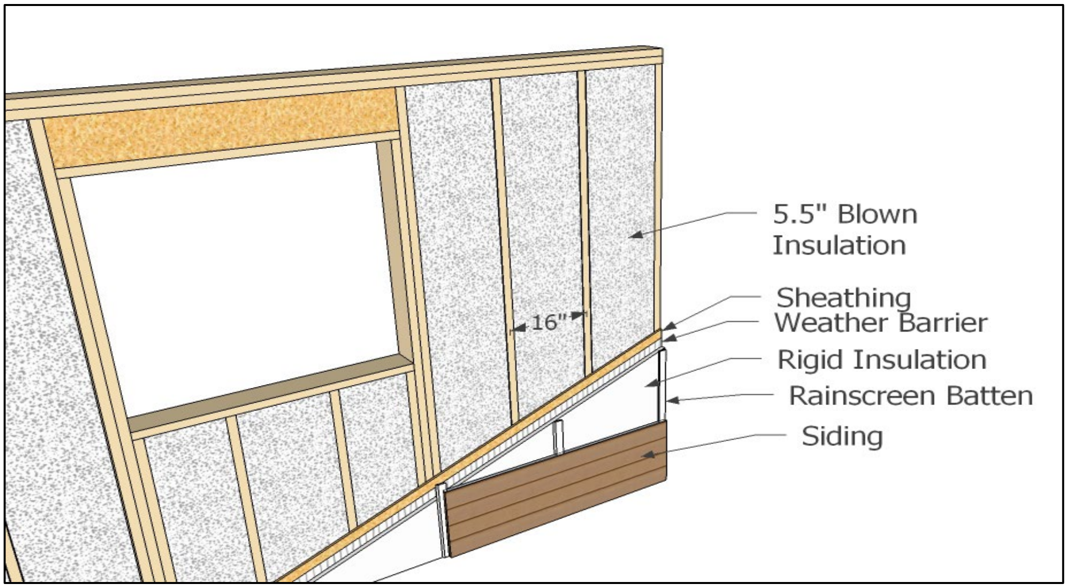

Figure 17. Diagram of Continuous Exterior Rigid Insulation with Rainscreen Cladding

Effective Installation

- The main differences in construction details for this assembly, compared to standard construction practices, are in the window flashing and WRB integration.
- The WRB can be installed directly to the sheathing, outside the rigid insulation, or in many cases the rigid insulation product can even be used as the WRB with proper detailing per the manufacturer – typically by sealing edges and seams with tape.
- Where shear wall inspections are required by the local jurisdiction, the rigid insulation panels and WRB must be installed after the shear wall inspection.

Best Practices for Siding Installers

The building community has no consensus on the best choice for WRB placement in this assembly; however, each strategy has best practices to follow, as exemplified in Figure 18 on the following page.

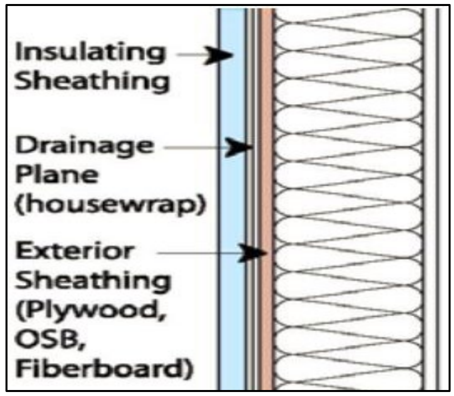

Figure 18. Example of WRB Placement (Image from BASC 2016(a)[23])

WRB Installed on the Sheathing

- The WRB, windows and doors, and flashing are installed at the sheathing following standard construction practices; a complete drainage plane is provided prior to installing the exterior rigid insulating sheathing.
- Insulating sheathing is then added over the drainage plane, followed by the cladding.
- Installation of a ventilated rainscreen or a house wrap product with enhanced draining channels is recommended, to enable water shedding in the space between the foam sheathing and the WRB.
- Various commercially-available house wrap products have built-in features (e.g., bumps, grooves, wrinkles) to create a small air gap to promote drainage in these types of applications.

When the WRB is installed directly against the sheathing, with 1” exterior insulation and a ½” rainscreen, install wood strapping around window rough openings for additional support, as follows:

- Wrap the window exterior rough openings with 2x4 to be plumb with cladding after 1” continuous insulation and ½” rainscreen furring strips are installed.
- Dimensional 1x3, or the same width as the exterior insulation, can be used if forgoing a rainscreen.
- Use 9” (rather than typical 5” or 6”) flex wrap tape to integrate window openings to the WRB during window installation.
- Use flashing tape to seal the WRB and the rigid insulation panel around any pipes or vents that penetrate through. Exterior outlets are frequently blocked out with wood strapping the same width as the rigid insulation, as shown in Figure 19.
- Tape is applied in an overlapping shingle fashion.
- Use tape or another flashing product that is compatible with the foam.
- Fastening the foam panels: the primary role of the attachment is to hold the material in place until the permanent cladding or furring is installed and fastened to the structural framing and/or sheathing members.

[23] For additional details, see Hammer & Hand (no date).

Figure 19. Wood Strapping Installation around Exterior Outlets (Image courtesy of Design Build PDX)

- Installation guidelines for fastening requirements vary among foam sheathing manufacturers.
- Building codes do not provide a required fastening schedule for this application as it is a construction process consideration rather than an integral structural feature of the wall.
- Typical fasteners for this application are cap-head nails or one-inch crown staples with minimum ¾” penetration into the wood substrate.

When installing rainscreen furring:

- Install the first layer of rigid insulation with a limited number of nails or staples.
- Optional: install a second layer of rigid insulation, staggering the seams, with a limited number of nails or staples.
- Fasten the furring with screws; spacing and fastener size are to be determined by weight of siding material and spacing of furring.

Figure 20. A completed rainscreen over exterior rigid insulation Courtesy of Design Build PDX of a

WRB Installed on the Foam

- Using a separate WRB provides a drainage surface that relies on shingled, overlapped, taped joints to divert any water that gets behind the cladding to the outside.
- Fenestration installed after the house wrap is followed by standard flashing detailing (see Figure 21).

Figure 21. Windows Installed after House Wrap. Courtesy of Home Innovation Research Labs (Kochkin & Wiehagen, 2017)

When installing with the continuous insulation functioning as the WRB:

- Only approved foam insulation products with all joints sealed using an approved tape can be used as a WRB surface.
- Follow the product manufacturer's specific instructions for installations of foam sheathing as a WRB.
- Using foam insulation as a WRB is advantageous because the foam serves multiple functions. It provides insulation, acts as a drainage plane, contributes to the air barrier, and provides backing for the cladding. In addition, the foam sheathing fasteners, when placed into studs, provide markers for the location of siding fasteners.
- The effectiveness of the foam sheathing acting as a WRB relies on the taped joints. Therefore, only tape products specifically approved for this application can be used. In addition, the tape must be installed using a J-roller to eliminate "fish-mouthing," or gaps in the taped joint.
- Siding systems (wood, vinyl, and fiber cement) and masonry veneers require virtually no change from standard recommended practice for cladding attachment details. One of the only differences is that all fasteners must be installed through to the studs, as insulating sheathing does not have adequate structural capacity in either shear or pull-out strength. Alternatively, attach cladding per IRC Table 702.7.1, as shown earlier in Figure 16, for optional siding attachment schedule for fasteners where no stud penetration is necessary.

- A rainscreen system with wood furring strips between the rigid insulation and cladding can provide adequate structural capacity to negate the need for longer fasteners to attach the cladding, while improving drying potential. This is especially true with a vapor semi-permeable rigid insulation. A rainscreen also reduces the risk of moisture intrusion through flaws in the water control layer.

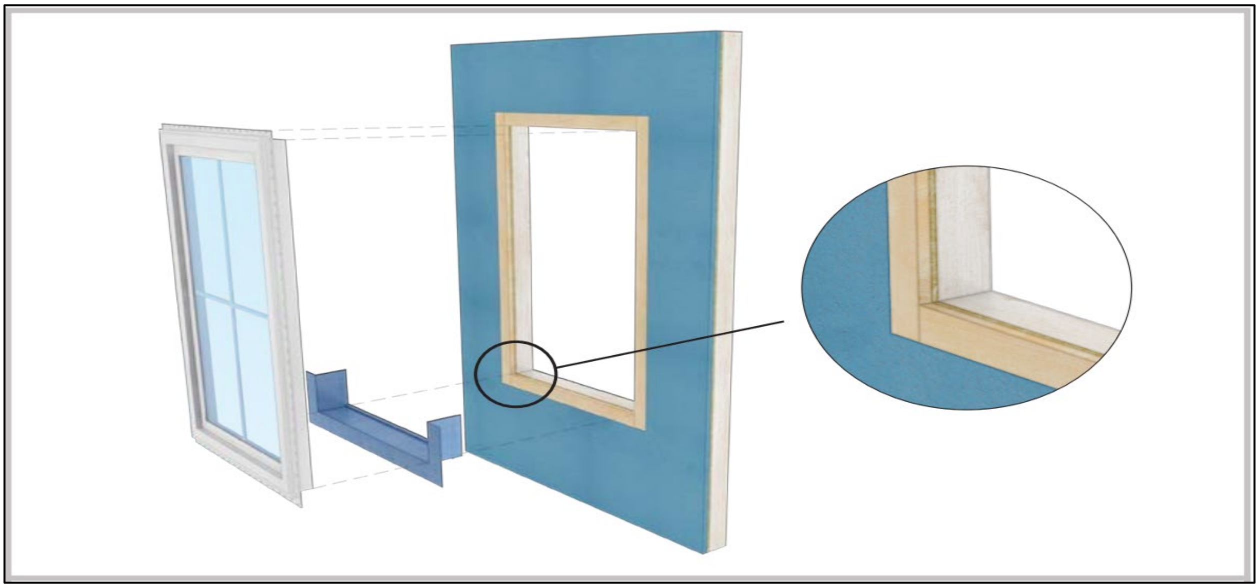

Figure 22. Wood Strapping around Windows for Attaching Window and Sill Flashing. Courtesy of Home Innovation Research Labs (Kochkin & Wiehagen, 2017).

Best Practices for Drywall Installers and/or Millwork Installers

- Install a wider drywall return at window jambs and sills for a deeper wall assembly.
- Exterior door jambs and thresholds must be 1” wider and may require jamb and threshold extensions.
- Install drywall using the airtight drywall approach.

Risk Reduction

Adding exterior insulation triggers a change in moisture management strategy and requires different vapor control methods and flashing details. Exterior insulation keeps the exterior sheathing and wall cavity warmer in the winter, reducing the risk of condensation inside the wall. While walls that have only cavity insulation rely on interior vapor retarders as the primary mechanism for condensation control, walls with exterior insulation should use a more permeable interior vapor retarder. The primary drying path for any incidental moisture in the walls with most types of exterior continuous insulation is to the inside of the building. In general, vapor-permeable exterior insulation in combination with an interior vapor barrier typically provides a lower-risk wall assembly than does an assembly using impermeable exterior insulation.

- Use a Class III vapor retarder on the interior side of the wall in climate zone 4C, allowing the exterior wall cavity more drying potential to the inside. In climate zones 5 and 6, a

Class III vapor retarder may be used if one or more of the conditions in Table R702.7.1 are met (see Figure 16).
  - Non-PVA latex primer and paint on ½" gypsum board is a typical assembly to achieve Class III vapor retarding levels.
- Use a Class II vapor retarder on the interior side of the wall in climate zones 5 and 6.
  - A PVA vapor retarder primer and paint on ½" gypsum board is a typical assembly to achieve a Class II vapor retarder. Alternatively, install a membrane behind the gypsum board with smart vapor retarder characteristics. Smart vapor retarders have variable perm ratings. A smart vapor retarder increases its permeability during dry periods, allowing moisture to diffuse toward the interior conditioned space in order to dry the wall assembly.
- A minimum of 1" exterior rigid insulation is recommended for climate zones 4C, 5, and 6. Optionally, install 2" or 3" exterior rigid insulation for higher assembly R-value and overall performance of the building.
- Air-sealed drywall is recommended.
- Use of a Class I vapor retarder on the interior side of the wall assembly is discouraged.

2x4 Double Stud with Blown-In Fibrous Insulation

Double stud wall construction consists of an exterior 2x4 stud-framed structural wall and a second 2x4 non-structural wall built to the inside with a gap in between. For one-story homes, the outer 2x4 wall is constructed as normal except with 2x4 rather than 2x6 lumber. This second wall can be constructed when interior framing begins with 2x4 or 2x3 framing at 16" or 24" on center. For two-story homes, the outer wall is constructed with 2x6 lumber, with a 2x3 or 2x4 inner wall. Framed openings for windows and doors are usually aligned square with the openings in the exterior walls for simplicity and best thermal performance, although 45° side and top returns are also feasible for aesthetic purposes. The studs in each wall can be aligned or staggered, although research has shown only minor improvement (<R-1) when staggering the studs.

Best practice includes an air gap of 1"-3" between the inner and outer walls to eliminate thermal bridging between the studs, with sheathing installed above the double top plates to span the gap of the 8"-10" double wall. A common variation is a staggered stud wall consisting of 2x8 top and bottom plates with staggered 2x4 studs that are used to create a 7.5" wall cavity. The assembly is insulated with blown-in fiberglass or cellulose. The exterior wall studs and sheathing will experience colder temperatures in the winter; therefore, a ventilated rainscreen is highly recommended to provide robust drying potential to the exterior to help prevent any moisture vapor intrusion from accumulating within the assembly.

This assembly requires some additional framing material and labor. Framing the interior wall can sometimes take more time than the exterior framing, as the openings must be in alignment. The method of blowing insulation is somewhat different than that for single frame construction. Because the wall is not divided into discrete stud bays, the exterior walls for each story basically include one large insulation cavity. Rough-in work is substantially less labor-intensive since wiring and supply pipes can run through the gap between the studs in exterior walls, eliminating the need for much of the drilling typically involved. Aside from this, no major changes to conventional practices are necessary.

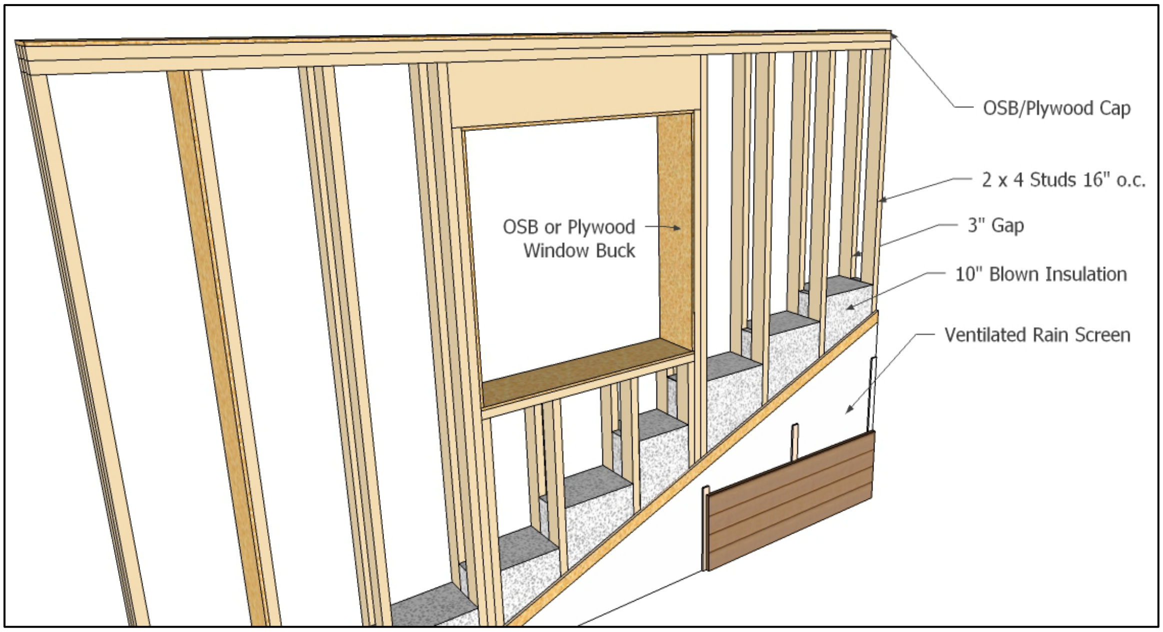

Figure 23. DSW with Ventilated Rainscreen

Effective Installation

- Include an air gap of 1”-3” between the inner and outer walls to eliminate thermal bridging between the studs, with sheathing above the double top plates to span the gap of the 8”-10” double wall.
- Window attachment, WRB and flashing integration details, and exterior cladding installation, are the same as for typical construction with vented rainscreen.

Best Practices for Framers

- With the inner 2x4 wall, the inner frame wall must be carefully aligned with windows and doors. Frame rough openings for windows and doors one inch larger than typical and install 7/16” plywood or OSB buck boxes to span all sides of the rough openings.
- As the inner wall is not load-bearing, framing spacing can be reduced to 24” on center to save on time and materials.
- On the inner wall, double top plates and jack studs are often unnecessary (although jack studs may still be used for more consistent alignment of window openings).
- Two-stud corners are very simple to implement in both the outer and inner framed walls, as no drywall is attached to the outer wall and no exterior sheathing is attached to the inner wall.
- Install plywood or OSB across top plates to connect the inside and outside walls and air-seal the assembly.
- Install fire blocking with solid sheet materials (OSB, plywood, sheetrock, etc.) across the stud bay every 10 ft horizontally if required by the authority having jurisdiction. This fire blocking can consist of cut-offs from the sheathing.

- Many building officials allow the use of blown-in fibrous insulation to meet the fire blocking requirement.

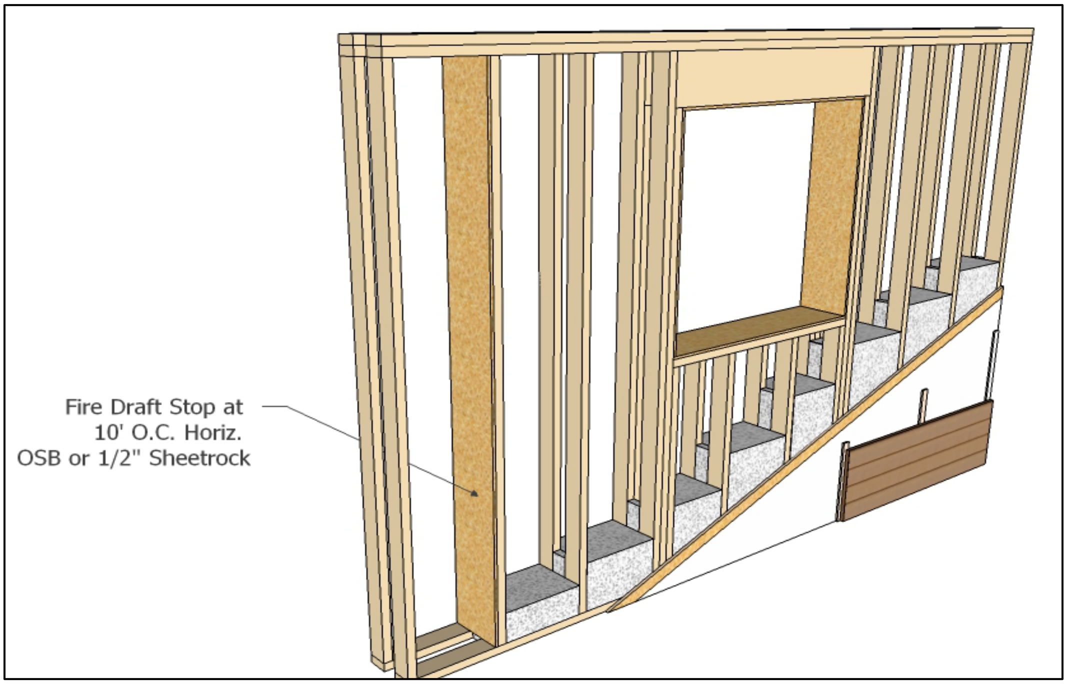

Figure 24. DSW Fire Blocking Details

- Window and door installations are typical, except all exterior doors require jamb extensions.
- Window sills must be wider, and if using window trim (instead of a drywall wrap), the trim must also be wider.

Best Practices for Insulators

- When using dry, dense-blown insulation, insulators typically fill this cavity by moving around the home in a circular pattern; each section of the wall is partially filled.
- After the walls are nearly completely filled, the insulator makes one more circuit around the home blowing through each interior stud bay until the insulation reaches the desired density.
- Because of the single insulation cavity (there are not discrete stud bays filled with insulation), some builders have chosen to install insulation netting on the studs surrounding critical wall penetrations.
- If a vent pipe or similar must be accessed or repaired in the future, insulation in the entire wall will not compromised and only the insulation around the penetration must be replaced.

Best Practices for Drywall Installer and/or Millwork Installer

- The responsible party depends on the type of interior window trim used (drywall or wood).
- Install wider drywall return at window jambs and sills.

- Exterior door jambs and thresholds must be wider.
- Install drywall using the airtight drywall approach.[24]

Staggered Stud Wall on 8" Plate

- A common installation variation for double stud wall is a "staggered stud wall" which consists of a 2x8 top and bottom plates with 2x4 studs staggered inboard and outboard every 12 inches thus creating a 7.5" wall cavity without any continuous stud heat transfer paths through the assembly.
- The assembly is insulated with blown-in fiberglass or cellulose.
- In this case, the exterior walls are framed on the floor with 2x4 studs and 2x8 plates.
- Use 4" wood blocks to temporarily hold the outside studs flush with the edge of the plates when framing walls on the floor.
- This version of the assembly creates a thicker wall cavity with additional insulation, which keeps the exterior sheathing colder during the heating season.
- Air leakage from the inside can carry moisture into the wall assembly, where the water vapor can condense on the cold sheathing. Therefore, both an exterior rainscreen and an effective air barrier seal at the interior wall surface are critical.
- Use either a Class I or Class II vapor retarder on the inside surface to reduce moisture migration from the inside. Unlike the other two wall types described in this guide, the primary drying path for any incidental moisture in the double wall is through the outside of the assembly.

Risk Reduction

To mitigate risk to the wall assembly:

- Use the airtight drywall approach to create an interior air barrier and reduce the potential for warm indoor air to exfiltrate into the wall assembly where it could cause condensation on the cold exterior sheathing.
- Use a Class II vapor retarder on the interior side of the wall for all climate zones in the Pacific Northwest, per 2012 International Residential Code (Section 702.7).[25]
  - PVA vapor retarder primer and paint on ½" gypsum board is a typical assembly to achieve a Class II vapor retarder. Alternatively, install a membrane behind the gypsum board with smart vapor retarder characteristics. Smart vapor retarders have variable perm ratings. A smart vapor retarder increases its permeability during dry periods, allowing moisture to diffuse toward the interior conditioned space in order to dry the wall assembly.
- Install a minimum ⅜" rainscreen with furring strips to increase the ability of the sheathing to dry to the exterior. The exterior wall studs and sheathing will experience colder temperatures in the winter. Therefore, a ventilated rainscreen is highly recommended for additional resiliency to increase drying potential to the exterior to help prevent any moisture vapor intrusion from accumulating within the assembly.[26]

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[24] See Building America's Solution Center https://www1.eere.energy.gov/buildings/publications/pdfs/building_america/airtight_drywall_approach.pdf

[25] See ICC Table R702.7.1 for specific requirements and details

[26] Note that WUFI modeling demonstrates that this wall assembly also meets moisture performance standards without the ventilated rainscreen. However, use of a ventilated rainscreen is a highly recommended best practice.

- The quality of the insulation installation is critical to limiting convective looping within the increased wall assembly depth, which can reduce the effectiveness of the insulation and also contribute to moisture accumulation within the assembly. Continuity of the air barrier and installation of an interior vapor barrier are fundamental to the performance of this assembly, as the slightly-decreased exterior sheathing temperature (as compared to standard construction) increases the risk of condensation and related damage.
- Install a heat recovery ventilation system to control indoor humidity levels.

Code Compliance Resources

Introduction

The three advanced wall systems that are the focus of this project are currently used by a number of the Northwest's leading high-performance custom and small-volume speculative builders. However, the wall systems have limited exposure and acceptance by the broader regional new construction market and are often unfamiliar to local building code officials. To assist builders in proposing a relatively new wall assembly approach to the authority having jurisdiction, the project team has compiled supporting materials that can help expedite the permit process. This section is designed to assist builders in gaining permit approval through a prescriptive path rather than requiring a builder to pursue the engineered design permit pathway, through which commercial code standards sometimes apply for residential projects. Ideally, a builder would be able to bring the supporting documentation from this section to the permitting authority early in the process to help satisfy the initial uncertainty or concerns of the building official.

Thermal Break Shear Wall (TBS)

Description of Assembly

The TBS wall is an assembly in which a continuous layer of rigid foam insulation is sandwiched between the structural sheathing and standard framing to create a "thermal break shear wall" for significantly increased energy efficiency and a nailing pattern that creates laboratory-verified seismic resiliency benefits. The greater Portland and Seattle metro areas offer several project examples (Building Innovations, 2018(a) and 2018(b)).

The TBS wall can be either field-assembled with standard construction materials, such as plywood or OSB and rigid foam insulation panels, or it can use factory-assembled insulated sheathing panel systems. The exterior flashing details are the same as in standard stud-framed construction practice. An optional best practice is to install a ventilated rainscreen behind the cladding to provide added protection from bulk water intrusion and increase the drying potential to the exterior.

Detailed drawings of the assembly can be found in Appendix A1 – Detailed Drawings of Thermal Break Shear Wall (TBS).

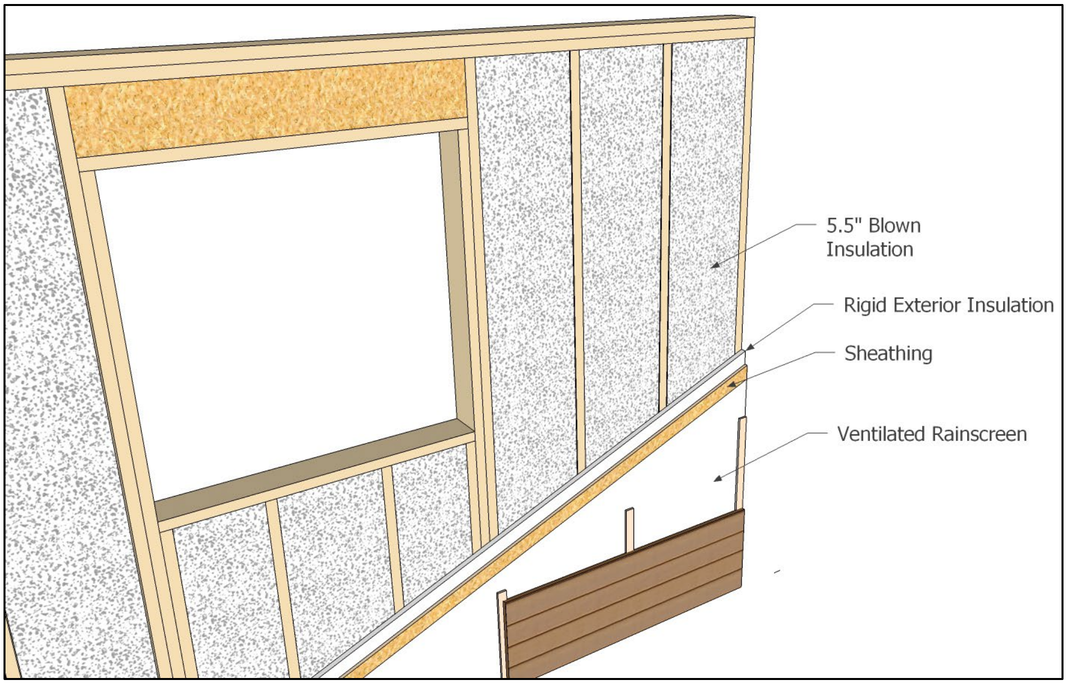

Figure 25. TBS Wall

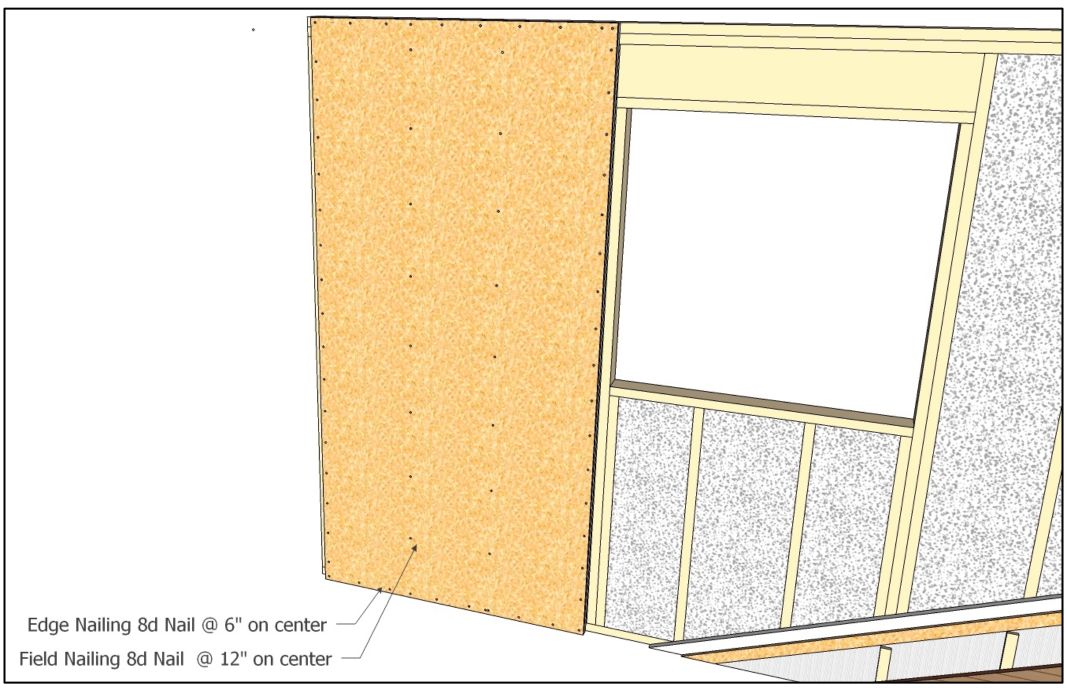

Figure 26. TBS Wall Nailing Pattern for Prescriptive Path

For Building Officials – Key Considerations

Permit Review[27]

- Refer to The International Code Council Evaluation Services (ICC-ES) Evaluation Services Report 2586 originally published in 2013 (ICC-ES, 2019).
    - Since 2015, building officials at the City of Portland have acknowledged that ICC-ESR 2586 establishes that a TBS wall assembly with up to 1" of foam meets requirements for lateral bracing under International Residential Code (IRC) Table 602.10.2, Method WSP, and confers prescriptive approval on such an assembly with no engineering required (Building Innovations, 2018(a)).
- Refer to detailed drawings (provided in Appendix A1 – Detailed Drawings of Thermal Break Shear Wall (TBS)) for review guidance of submitted plans.

Field Verification

Confirm each of the following:

- Nailing pattern meets or exceeds ICC-ESR 2586 of 6" o.c. at edge and 12" o.c. in field.
- Vapor retarder (if applicable) is properly installed on the interior (warm-in-winter) side of the exterior wall and in compliance with the locally applicable building code (e.g., only required in mixed or colder climate zones).
- Air barrier is properly installed on the interior or exterior (or both sides) of the exterior wall, or in the cavity if using an air-impermeable insulation product.
- All seams, gaps, holes, and the sill plate are properly air sealed.
- The junctions of the top plate and top of exterior walls are sealed.
- Corners and headers are insulated.
- The exterior thermal envelope insulation for framed walls is installed with substantial contact with the entire wall cavity and in continuous alignment with the air barrier.

2x6 Intermediate Frame with Continuous Exterior Rigid Insulation

Description of Assembly

The 2x6 intermediate frame with continuous exterior rigid insulation (CI) wall is an assembly in which a standard code compliant wall has continuous exterior rigid insulation to help reduce thermal bridging through wood structural members (see Figure 27). Continuous rigid insulation is a construction solution that provides a thermally efficient building enclosure and can also serve as an air and weather resistive barrier. Rigid insulation boards are available in several thicknesses and R-values; 1-inch and 2-inch thicknesses are common.

[27] The City of Seattle recently adopted Director's Rule 2019-4, which is a different way of measuring setbacks that would allow for more exterior insulation on high-performance buildings. Under this Director's Rule, setbacks are measured to the foundation wall rather than siding, and up to 6" is allowed beyond the foundation wall for exterior insulation and siding.

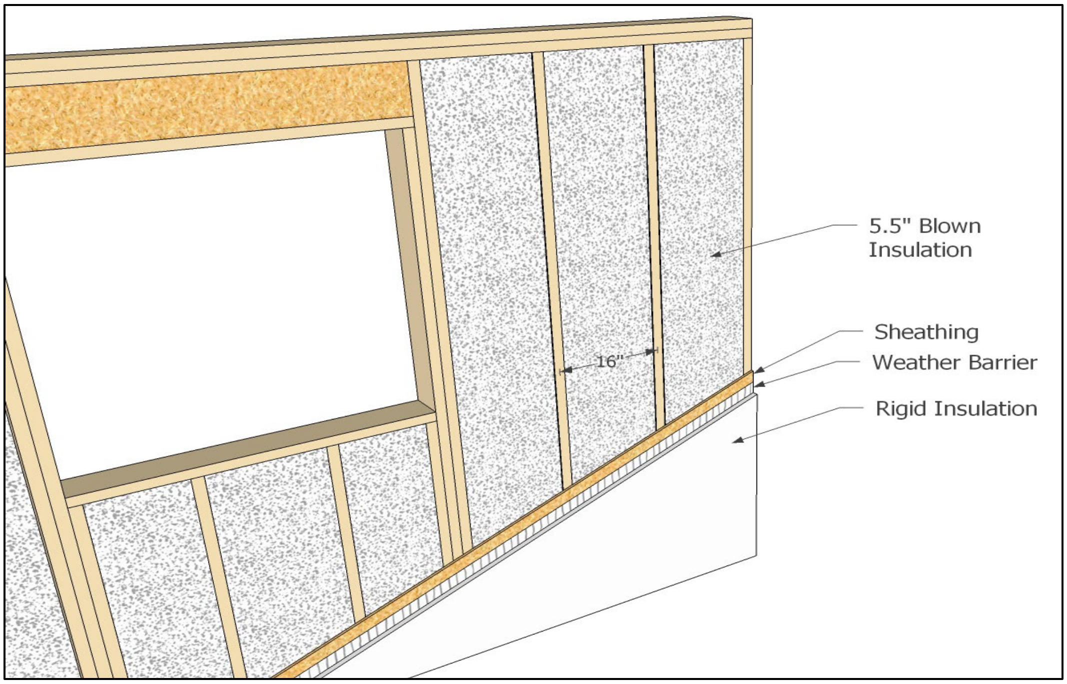

Figure 27. 2x6 Intermediate Frame with Exterior Rigid Insulation Wall

For climate zone 4 Marine, 1” of exterior rigid insulation is installed on top of the water resistive barrier (WRB) using cap nails. For window installation, 1x4 or 1x3 wood furring strips are used to wrap the perimeter of the window. Extended window wrap is used to flash the rough opening and tie it to the WRB. Window installation proceeds as usual and siding is nailed directly through the foam.

For climate zone 5, the WRB is also installed directly on the sheathing. Two layers of 1” EPS foam are attached on the outside with offset seams. The first layer is secured with long staples, then a screw with a Wind-lock plastic washer is used to secure the second layer. 1x4 furring strips are secured in the field on top of the foam at the studs to act as siding nailers. 1x6 strips are used at the corners. 6” structural lags secure the furring strips every 18-24 vertical inches. An insect barrier, such as Cor-A-Vent, is installed at the top and bottom of the rainscreen. Thermal bucks are installed in the window rough openings to allow window attachment without thermal bridging through a typical plywood buck box.

For climate zone 4 Marine and climate zone 5, when installing with the continuous insulation to function as the WRB, use only approved foam insulation products with all joints sealed using an approved tape. Follow the product manufacturer’s specific instructions for installations of foam sheathing as a WRB. The tape must be installed using a J-roller to eliminate “fish-mouthing.”

Detailed drawings of the assembly can be found in Appendix A2 – Detailed Drawings of 2x6 Intermediate Frame with Continuous Exterior Rigid Insulation.

For Building Officials – Key Considerations

Permit Review

- Refer to detailed drawings (provided in Appendix A2 – Detailed Drawings of 2x6 Intermediate Frame with Continuous Exterior Rigid Insulation) for review guidance for submitted plans.

Field Verification

Confirm each of the following:

- Cavity insulation completely fills the cavity with no compression or gaps, the manufacturer's R-value mark is readily available, and the insulation meets the approved R-value per plans.
- Continuous insulation is installed in accordance with manufacturer's installation instructions, the manufacturer's R-value mark is readily available, and the insulation meets the approved R-value per plans.
- Joints, seams, and penetrations in the CI are caulked, gasketed, weatherstripped, or otherwise sealed.
- Vapor retarder (if applicable) is properly installed on the interior (warm-in-winter) side of the exterior wall and in compliance with the locally applicable building code (e.g., only required in mixed or colder climate zones).
- Air barrier is properly installed on the interior or exterior (or both sides) of the exterior wall, or in the cavity if using an air-impermeable insulation product.
- All seams, gaps, holes, and the sill plate are properly air sealed.
- The junctions of the top plate and top of exterior walls are sealed.
- Corners and headers are insulated.
- The exterior thermal envelope insulation for framed walls is installed with substantial contact and continuous alignment with the air barrier.

2x4 Double Stud with Blown-In Fibrous Insulation

Description of Assembly

Double stud wall (DSW) construction consists of an exterior 2x4 stud-framed structural wall and a second 2x4 non-structural wall built to the inside with a gap in between. This second wall can be constructed when interior framing begins with 2x4 or 2x3 framing at 16" or 24" on center. Framed openings for windows and doors are aligned square with the openings in the exterior walls for simplicity and best thermal performance, although 45° side and top returns are also possible for aesthetic purposes. The studs in each wall can be aligned or staggered, although research has shown only minor improvement (<R-1) when staggering the studs.

Best practice includes an air gap of 1"-3" between the 2x4 walls to eliminate thermal bridging between the studs, with sheathing above the double top plates to span the gap of the 8"-10" double wall. A common variation is a staggered stud wall consisting of 2x8 top and bottom plates with staggered 2x4 studs that are used to create a 7.5" wall cavity. The assembly is insulated with blown-in fiberglass or cellulose. The exterior wall studs and sheathing will experience colder temperatures in the winter; therefore, a ventilated rainscreen is highly recommended to provide robust drying potential to the exterior to help prevent any moisture vapor intrusion from accumulating within the assembly (see Figure 28).

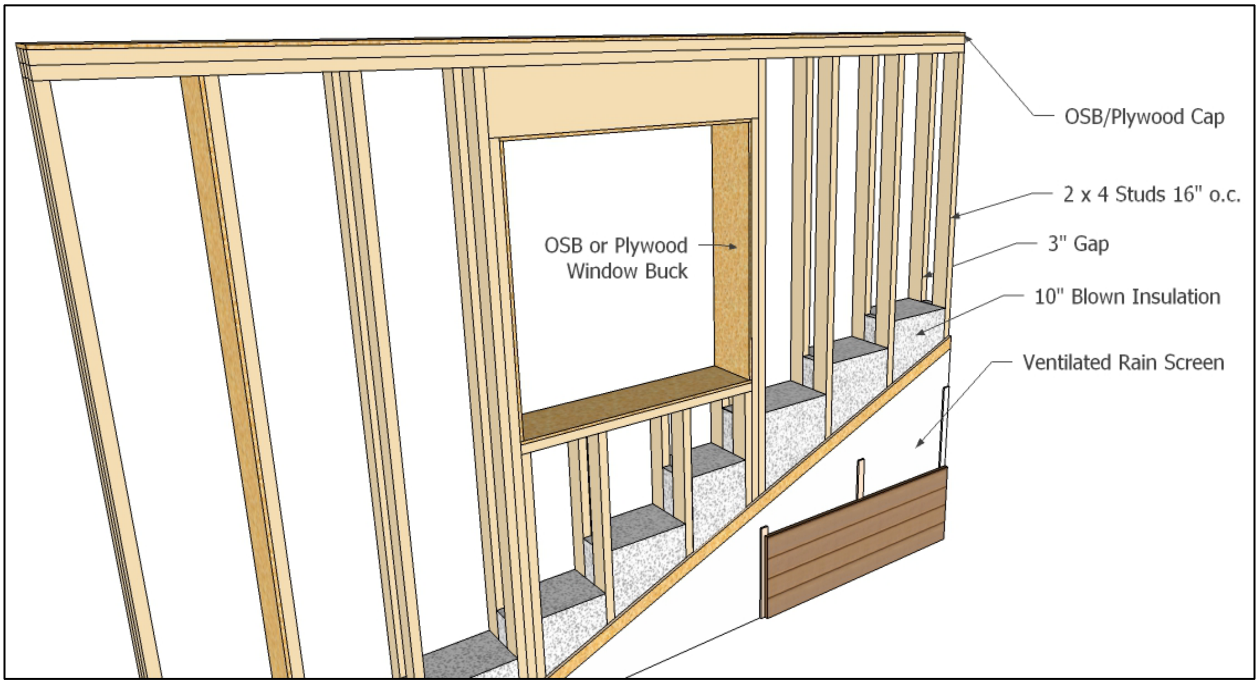

Figure 28. 2x4 Double Stud with Blown-In Fibrous Insulation

Detailed drawings of the assembly can be found in Appendix A3 – Detailed Drawings of 2x4 Double Stud with Blown-In Fibrous Insulation.

For Building Officials – Key Considerations

Permit Review

- Refer to detailed drawings (provided in Appendix A3 – Detailed Drawings of 2x4 Double Stud with Blown-In Fibrous Insulation) for review guidance of submitted plans.
- 2012 International Residential Code (IRC) Table N1102.4.1.1 and IECC Table R402.4.1.1 require that a continuous air barrier be installed.

Field Verification

Confirm each of the following:

- Insulation should completely fill the cavity with no compression or gaps.
- All seams, gaps, and holes must be sealed properly.
- Corners and headers are insulated and the junction of the foundation and sill plate is sealed.
- The junction of the top plate and top of exterior walls should be sealed.
- The exterior thermal envelope insulation for framed walls is installed in substantial contact and continuous alignment with the air barrier (BASC, no date (b)).

- Vapor retarder (if applicable) is properly installed on the interior (warm-in-winter) side of the exterior wall and in compliance with the locally applicable building code (e.g., only required in mixed or colder climate zones).
- Air barrier is properly installed on the interior or exterior (or both sides) of the exterior wall, or in the cavity if using an air-impermeable insulation product.
- Fire blocking requirement may be met with blown in fibrous insulation or by installation of rigid sheet materials (gypsum board, OSB, plywood) at every 10 feet horizontally (see Figure 29).

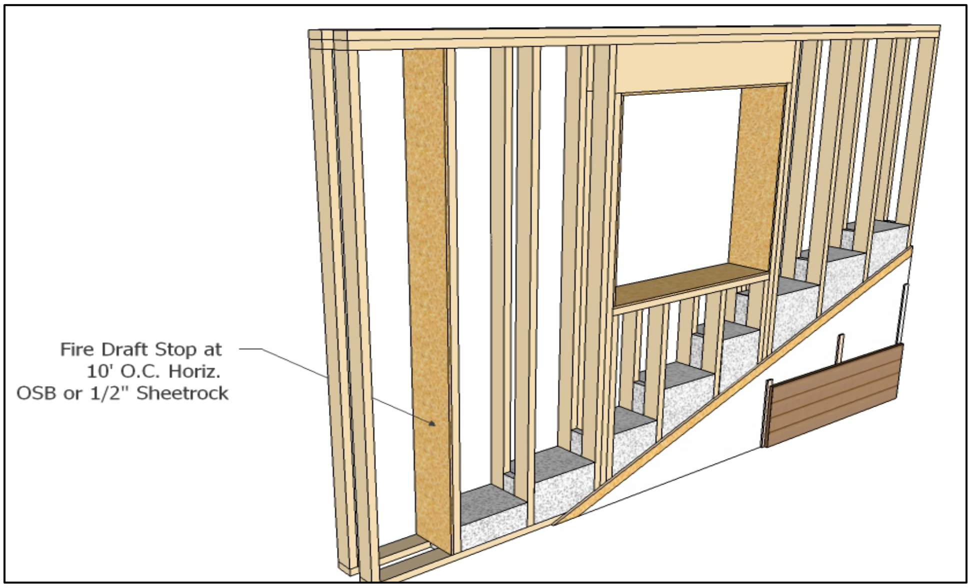

Figure 29. DSW Fire Blocking Details

Summary

In the Phase 1 Advanced Walls report, the project team identified several gaps in the available information about the relative performance of each of the three wall assemblies in the Northwest. This Phase 2 report provides documented evidence that demonstrates both energy and non-energy benefits of each of the three wall assemblies and addresses builder concerns about perceived deficiencies with the wall assemblies. The project team's analysis confirmed the following:

1. **Energy efficiency benefits**: Documented that the wall assemblies, depending on climate zone and insulation type, provide 4.6% to 11.5% better energy performance than conventional walls.
2. **Moisture management performance**: Industry research and the project's own detailed analysis shows that each of the advanced wall assemblies performs better than a typical 2x6 wall assembly in climate zone 4C and are well within acceptable ranges in climate zone 5B.
3. **Noise attenuation benefits**: Industry research confirmed that each of the three wall assemblies considerably impacts soundproofing and improves noise control from the "moderate" level for a conventional 2x6 wall to "very good or excellent."
4. **Seismic resiliency benefit**: Documented the additional seismic resiliency benefit of the TBS wall.

Discussion

Taken together, the results detailed in this report suggest that with adequate strategic market interventions, advanced wall strategies can become a more prevalent feature of Northwest homebuilding. If Phase 3 of this project is undertaken, strategic market interventions could be implemented with the following considerations:

- *Provide synthesized information:* Include a dedicated page on the BetterBuilt Northwest (BBNW) website that includes summarized and condensed technical content taken from this report, short technical briefs, and case studies that include detailed project photo documentation and testimonials from builders and trades.
- *Deliver information in accessible formats:* Develop advanced wall training modules that can be offered through the BetterBuilt Northwest (BBNW). Introductory live webinars hosted by BBNW could serve as initial lead-up and introduction to these more in-depth training modules. Advanced wall concepts could also initially be introduced to local building communities through in-person builder networking events where builders can dialogue directly with other builders about their approaches to wall assembly design and construction. Information on advanced walls should also be synthesized into template presentation slides and provided to BBNW partners to leverage and use in their own trainings and resource libraries.
- *Ensure information is provided by credible evangelists:* The Phase 1 report highlighted that a credible messenger, as much as the information being delivered, is an important factor in motivating builders to transition to one of the three high-performance wall systems. Training courses delivered by reputable and successful builders have proven to be strong drivers in encouraging other builders to accept the risk of embarking on a new approach.

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Appendix A: Detailed Drawings of Wall System Archetypes

Appendix A1 – Detailed Drawings of Thermal Break Shear (TBS) Wall

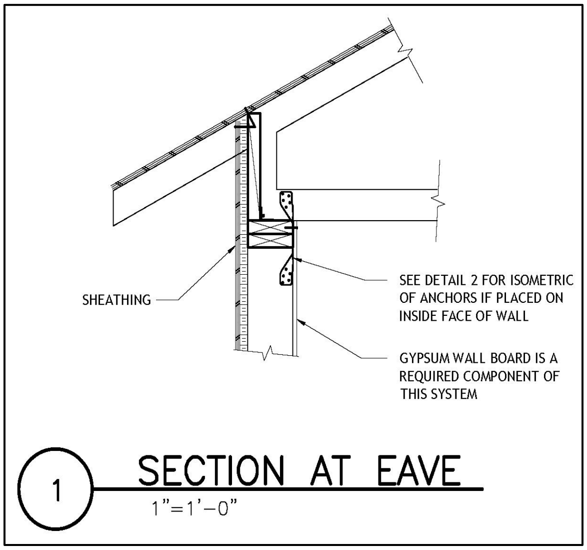


Figure 30. TBS Wall: Section at Eave

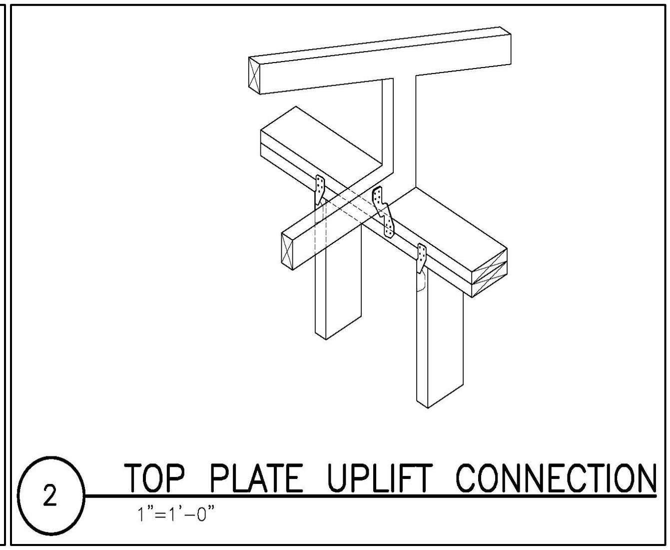


Figure 31. TBS Wall: Top Plate Uplift Connection

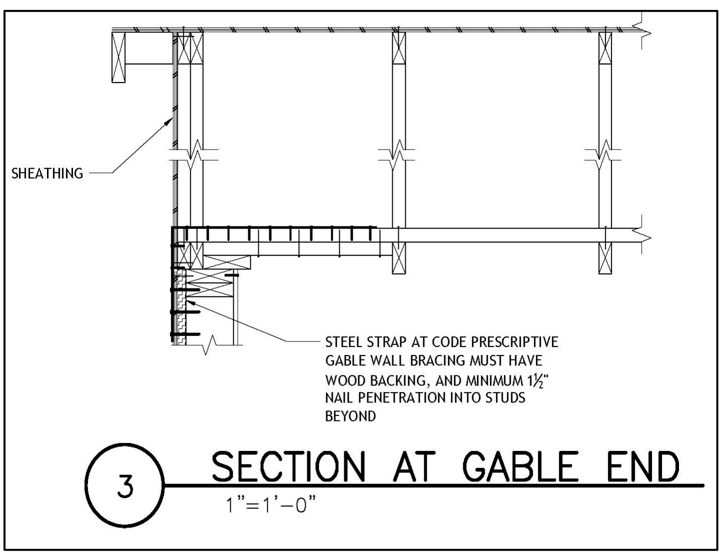


Figure 32. TBS Wall: Section at Gable End

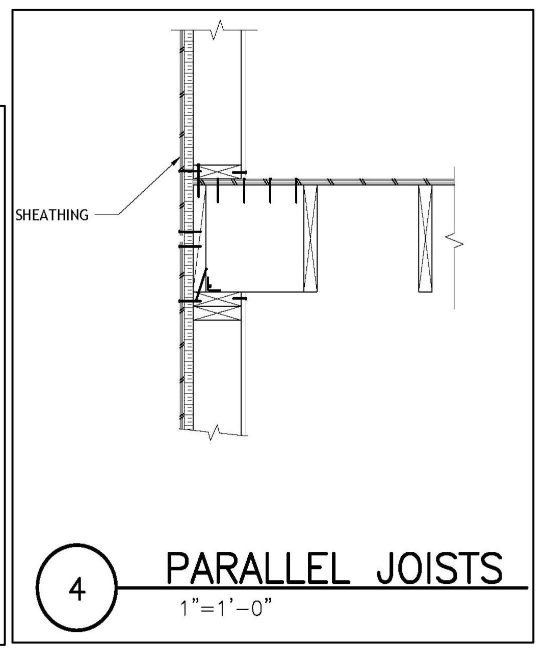


Figure 33. TBS Wall: Parallel Joists

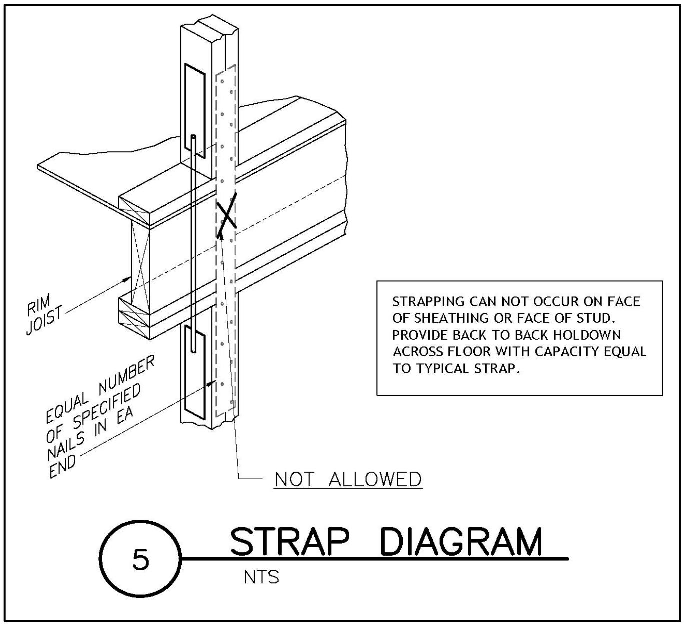


Figure 34. TBS Wall: Strap Diagram

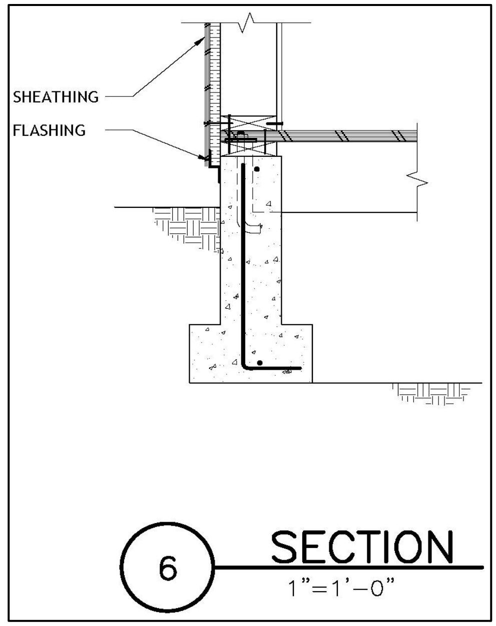


Figure 35. TBS Wall: Section Diagram 1

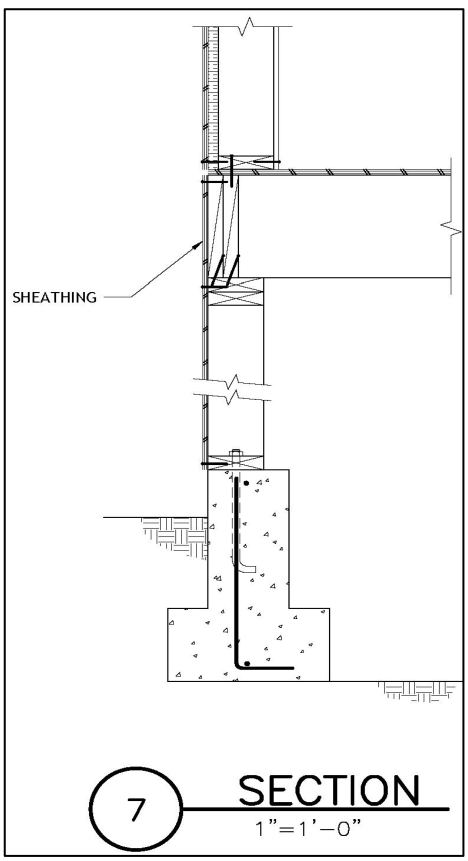


Figure 36. TBS Wall: Section Diagram 2

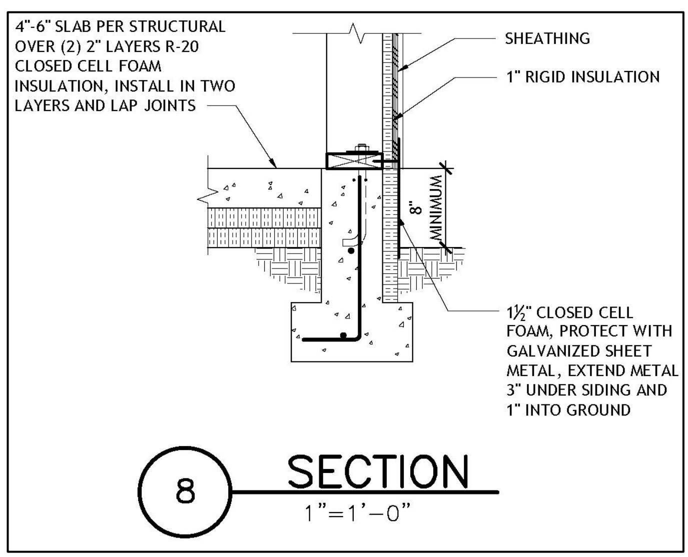


Figure 37. TBS Wall: Section Diagram 3

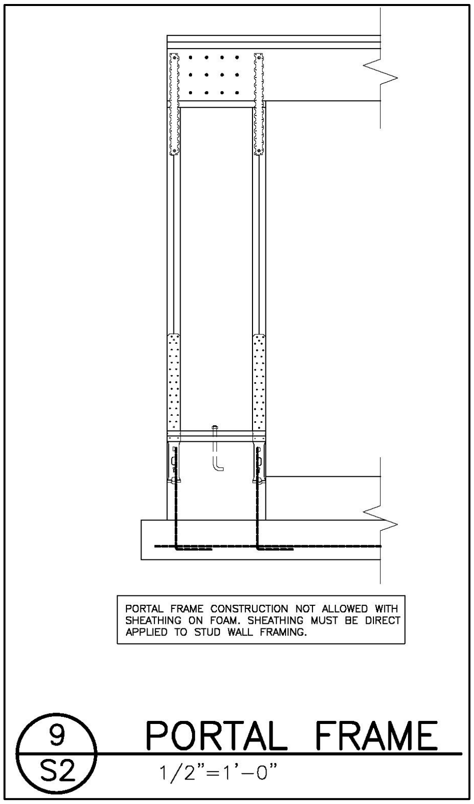


Figure 38. TBS Wall Portal Frame

APA Rated Siding Panels Over Rigid Foam Insulation Sheathing

Excerpts from ICC-ES Evaluation Report ESR-2586

4.4.2 Panel Siding: Panel siding must be fastened directly to framing in accordance with wood structural panel provisions of the code. When siding ½ inch (12.7 mm) or less in thickness is installed over foam plastic Insulation up to 1 inch (25.4 mm) in thickness, the siding must be fastened with 8d galvanized box nails.

Panel sizing applied directly to studs, spaced in Accordance with the span rating and fastened with 6d Galvanized box nails or equivalent, spaced 6 inches (152 mm) on center at panel edges and 12 inches (305mm) on center at intermediate studs, is an alternative To the wood structural panel sheathing construction Specified in the code for wall bracing (2018, 2015, and 2012 IRC Table R602.10.4, Method WSP, and 2009 IRC Table R602. 10.2, Method WSP).

Shear values for all-veneer panel siding must be as given in the applicable code for siding applied directly to Studs of over ½ or ⅝ inch (12.7 mm or 15.88 mm) Gypsum sheathing. Thickness at point of nailing at panel Edges determines applicable values.

Figure 39. Description of APA Rated Siding Panels

Appendix A2 – Detailed Drawings of 2x6 Intermediate Frame with Continuous Exterior Rigid Insulation

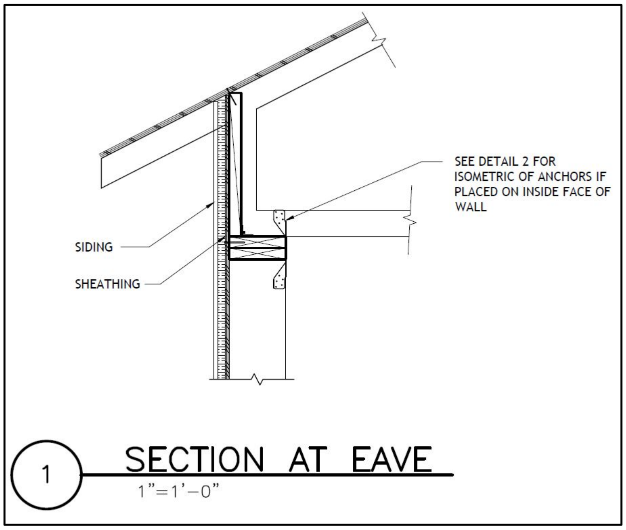


Figure 40. CI Wall: Section at Eave Diagram 1

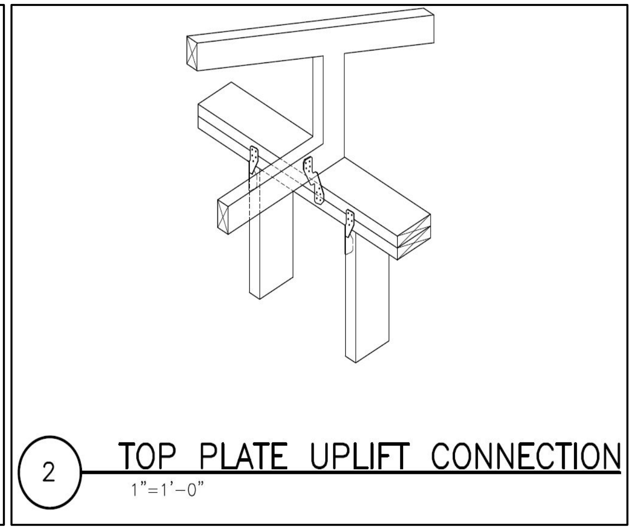


Figure 41. CI Wall: Top Plate Uplift Connection

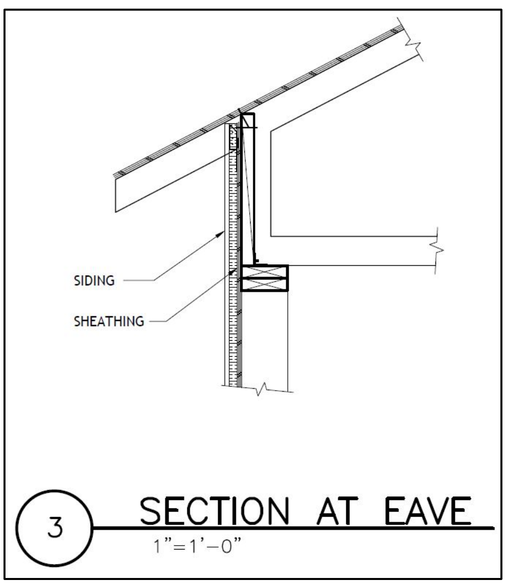


Figure 42. CI Wall: Section at Eave Diagram 2

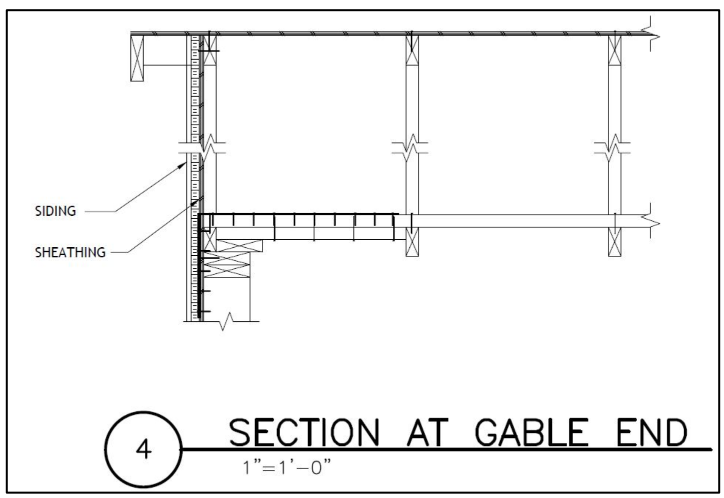


Figure 43. CI Wall: Section at Gable End

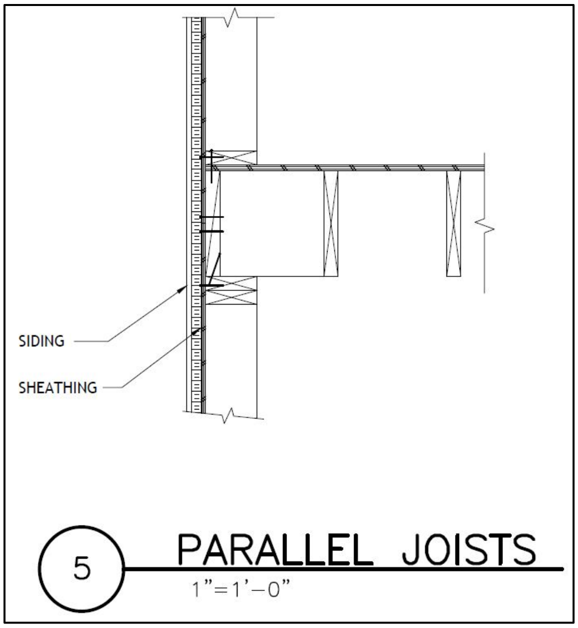


Figure 44. CI Wall: Parallel Joists

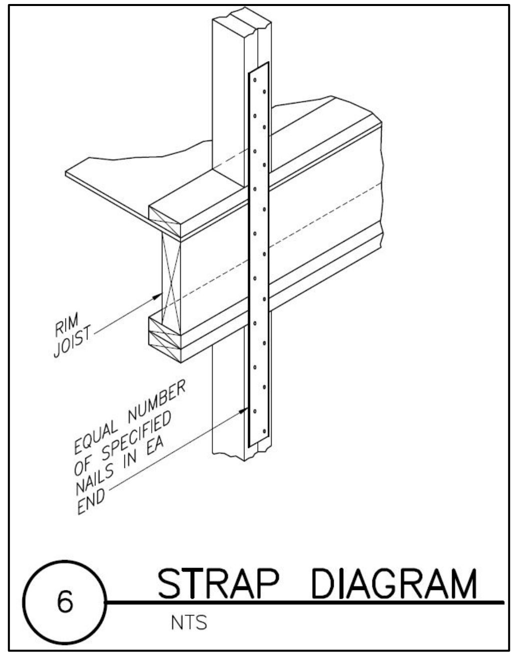


Figure 45. CI Wall: Strap Diagram

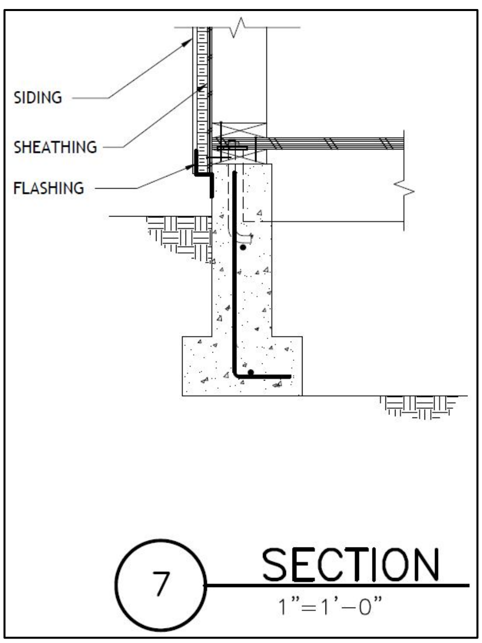


Figure 46. CI Wall: Section Diagram 1

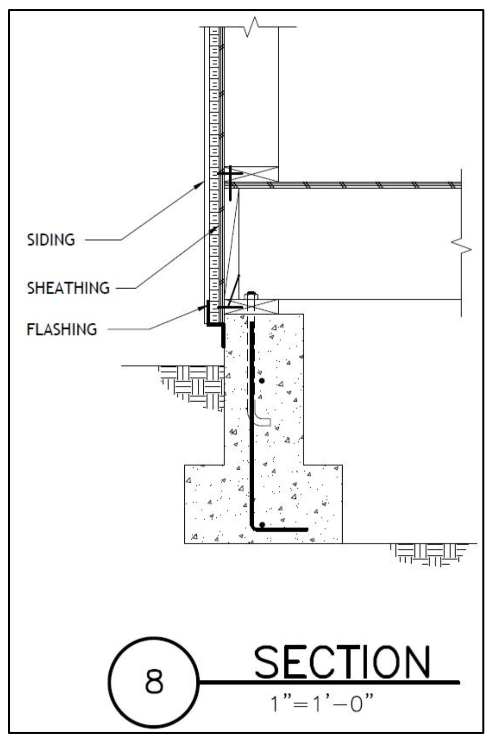


Figure 47. CI Wall: Section Diagram 2

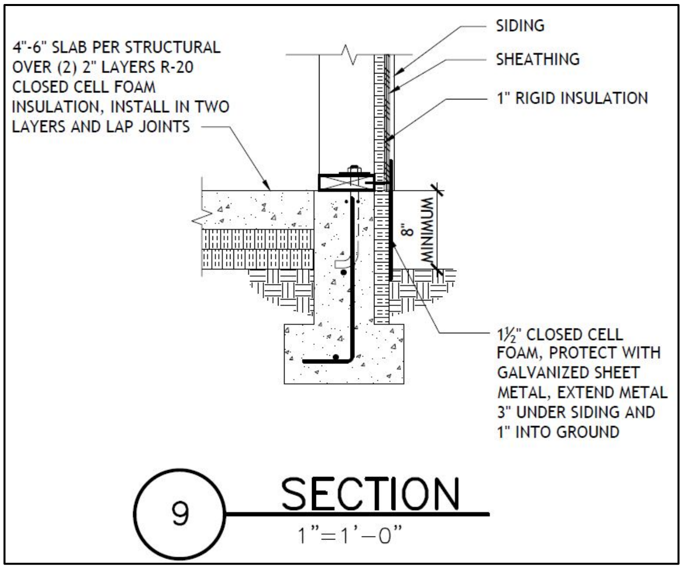


Figure 48. CI Wall: Section Diagram 3

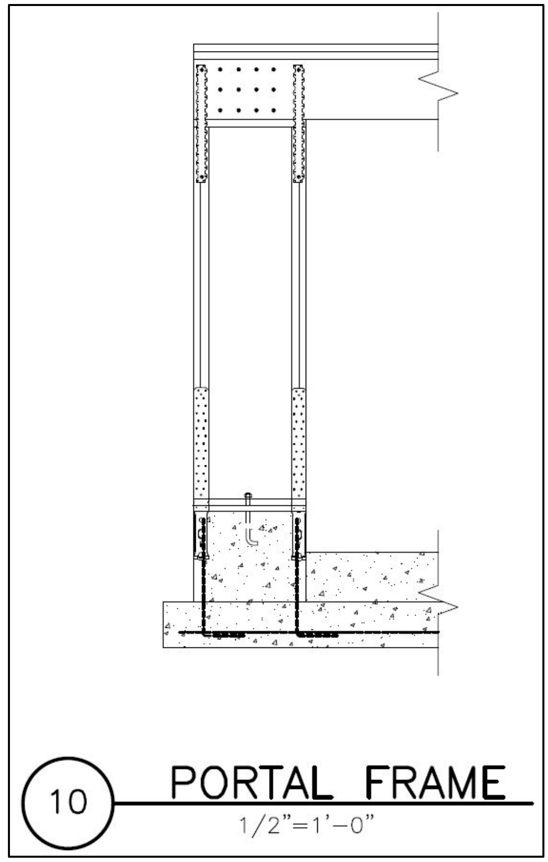


Figure 49. CI Wall: Portal Frame

Appendix A3 – Detailed Drawings of 2x4 Double Stud Wall with Blown-In Fibrous Insulation

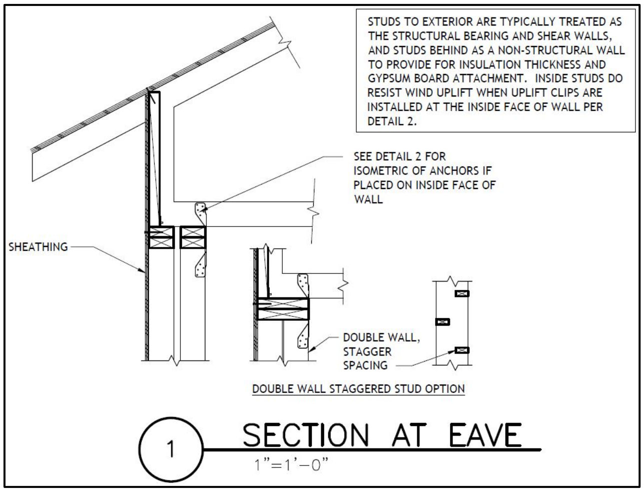


Figure 50. DSW: Section at Eave

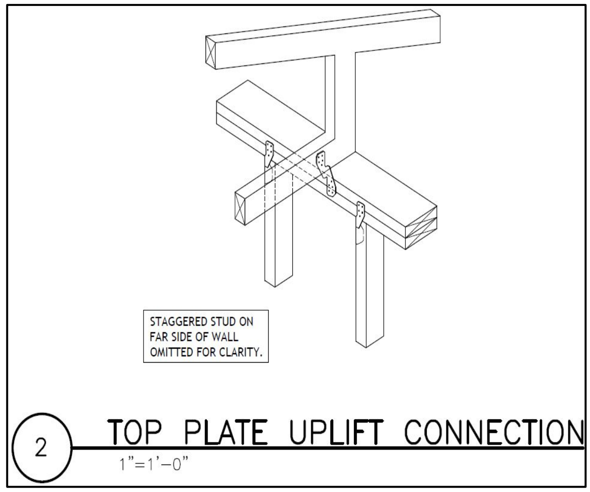


Figure 51. DSW: Top Plate Uplift Connection

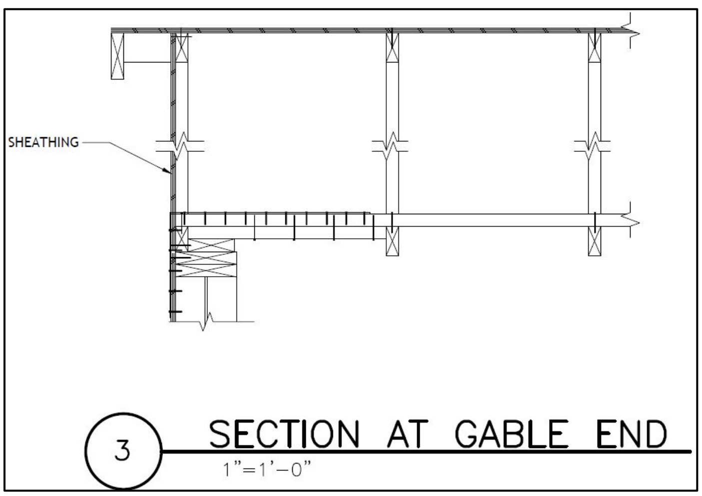


Figure 52. DSW: Section at Gable End

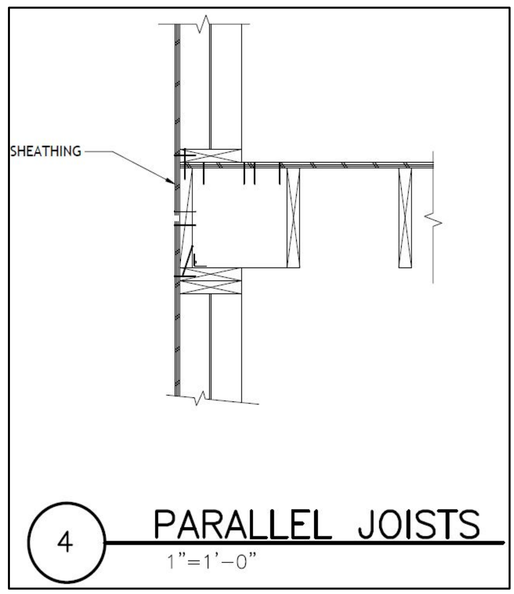


Figure 53. DSW: Parallel Joists

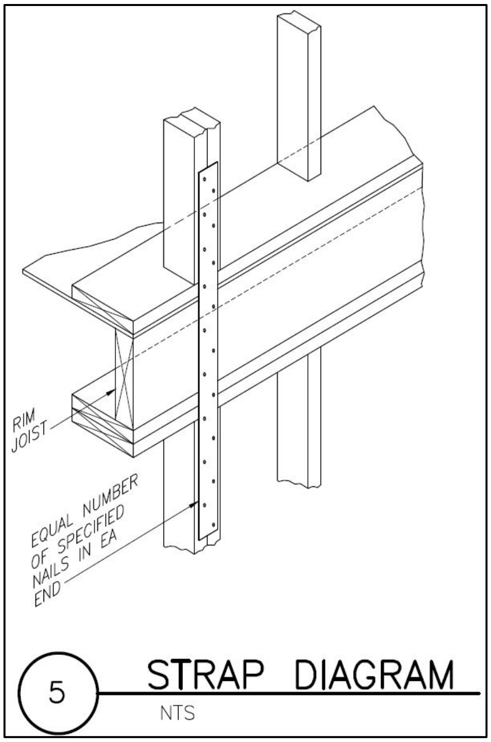


Figure 54. DSW: Strap Diagram

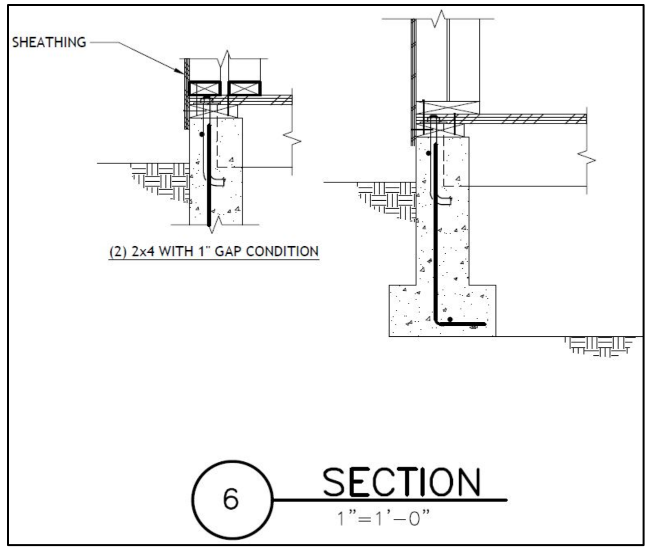


Figure 55. DSW: Section Diagram 1

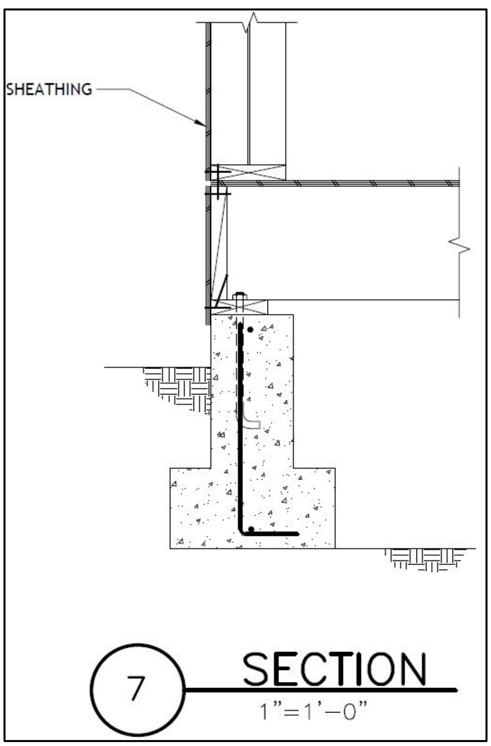


Figure 56. DSW: Section Diagram 2

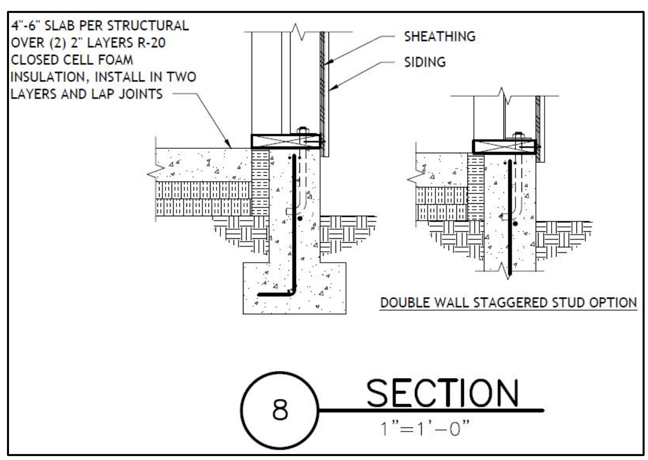


Figure 57. DSW: Section Diagram 3

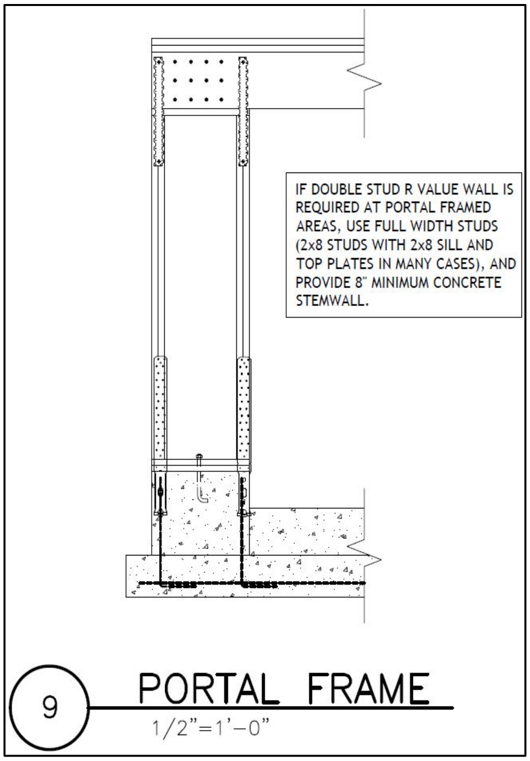


Figure 58. DSW: Portal Frame

Appendix B: Passive House-level Wall Variation Drawings

2x6 with Continuous Insulation Wall

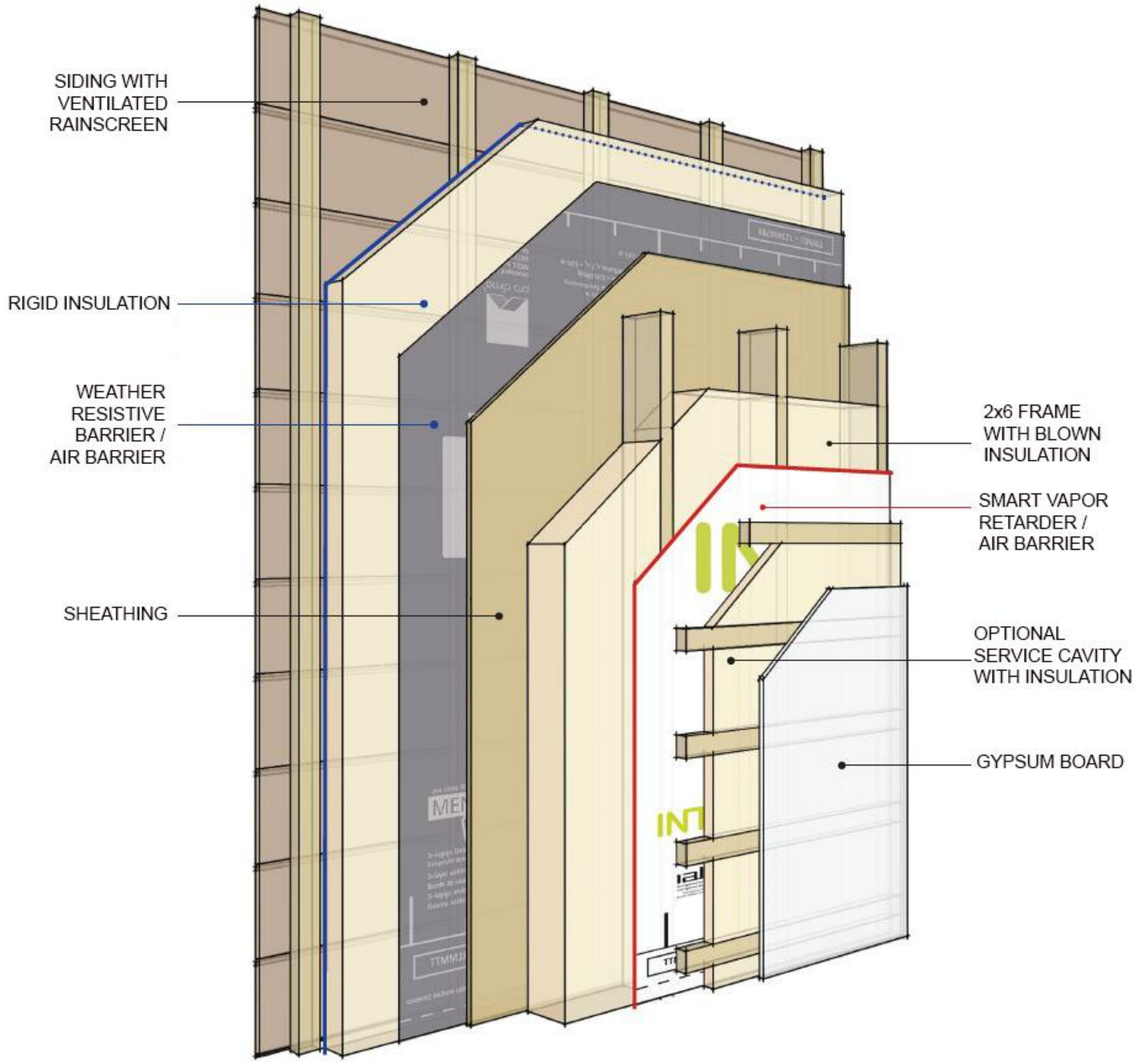


Image courtesy of 475 Home Performance Building Supply

475 Double Wall

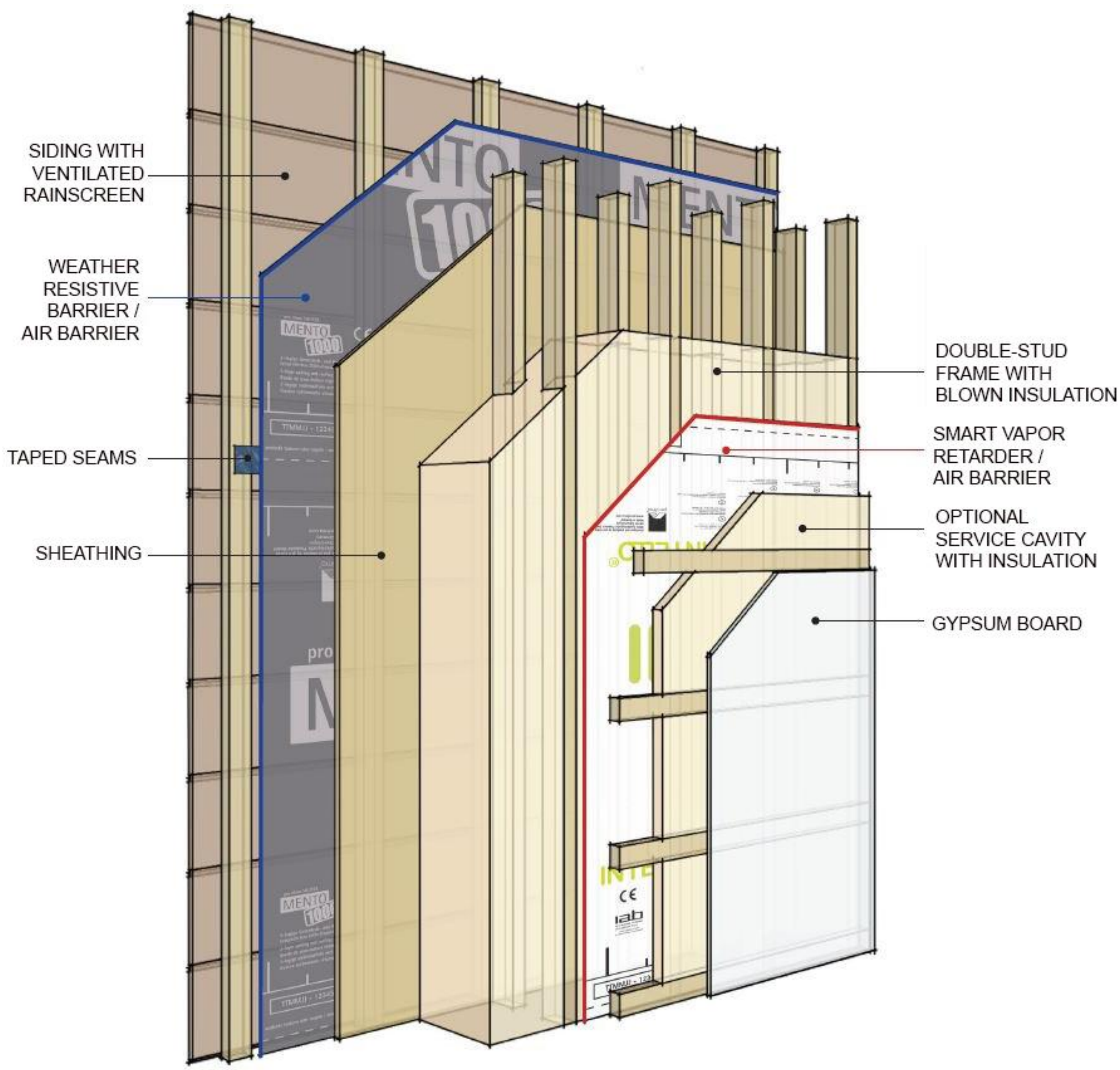


Image courtesy of 475 Home Performance Building Supply

Appendix C – High Performance Wall WUFI Analysis

A thermal moisture analysis of the three different high-performance wall systems provided by Skylar Swinford of Energy Systems Consultants.

NEEA High Performance Wall WUFI Analysis

Prepared for:

Earth Advantage, Inc

Date: December 11, 2019

Prepared by: Skylar Swinford

SUMMARY

Energy Systems Consultants was retained to evaluate the long-term moisture durability and hygrothermal performance of 3 high performance wall assembly types (Exterior CI, Thermally Broken Sheathing, Double Stud) in the climates of Portland, OR, Boise, ID and Spokane, WA using ASHRAE RP-1325 extreme year weather files.

The results from the hygrothermal analysis were compared alongside the results of a 'base case' 2x6 wall assembly under the same boundary conditions. The results suggest that the proposed high performance wall assemblies are suitable for use in Climate Zone 5B and 4C and will perform comparably to historical wall assemblies that utilize standard 2x6 construction. The high performance assemblies are in compliance with prescriptive IRC requirements for vapor control, rains screens, and exterior insulation thickness for each climate zone.

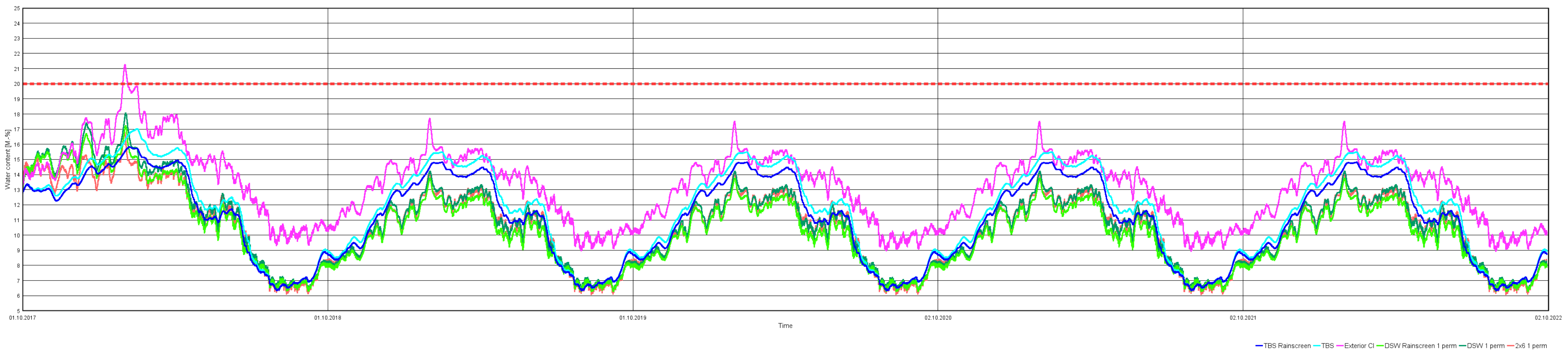
The proposed wall designs were analyzed and modeled using WUFI PRO 6.3 for a period of 5 years and each assembly was verified to be in compliance with the following durability thresholds:

1. A simulated moisture content of no more than 20% by weight after the first year of simulation and no evidence of long-term moisture accumulation in 3 mm (≈1/8 in) OSB layers simulated on the inner and outer face of the exterior structural OSB sheathing.
2. Predicted mold index <3 based on the latest VTT (Viitanen) model available for WUFI 6.3
3. Declining or time-stabilized moisture content of the entire assembly with no evidence of long-term moisture accumulation.

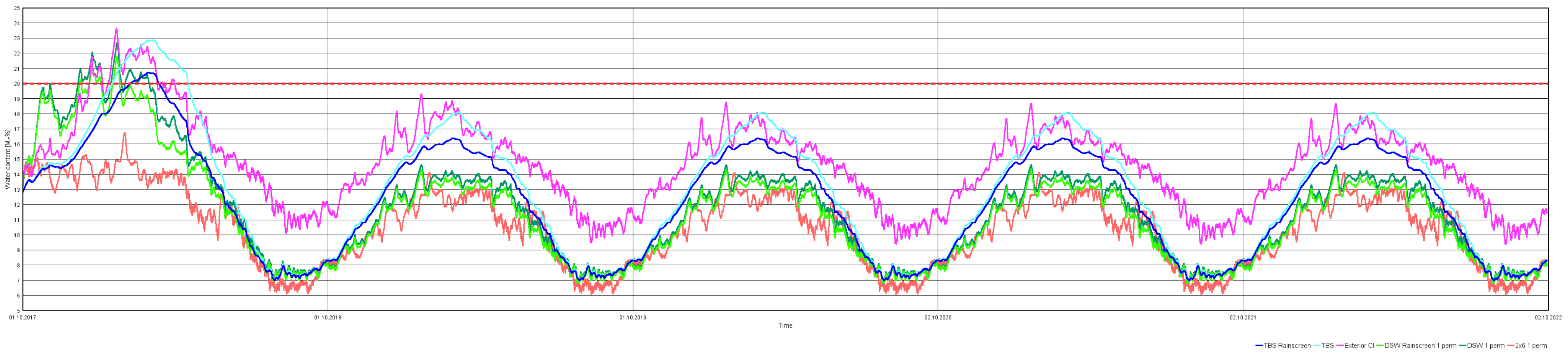
Considerations Regarding Hygrothermal Simulations

WUFI 6.3 has been validated in the field and through multiple research and testing projects with varied assemblies and climate conditions across North America and Europe. WUFI 6.3 has the capability to accurately simulate and compare the one-dimensional hygrothermal behavior of building enclosure assemblies; however, there are several assumptions regarding climate data, material properties, interior climate boundaries, etc., that are required to complete the hygrothermal analysis. It is important to understand that these results represent a one-dimensional approximation of the proposed assembly and cannot completely account for onsite variations such as poor workmanship, unplanned air and water leaks, differing material properties, etc.

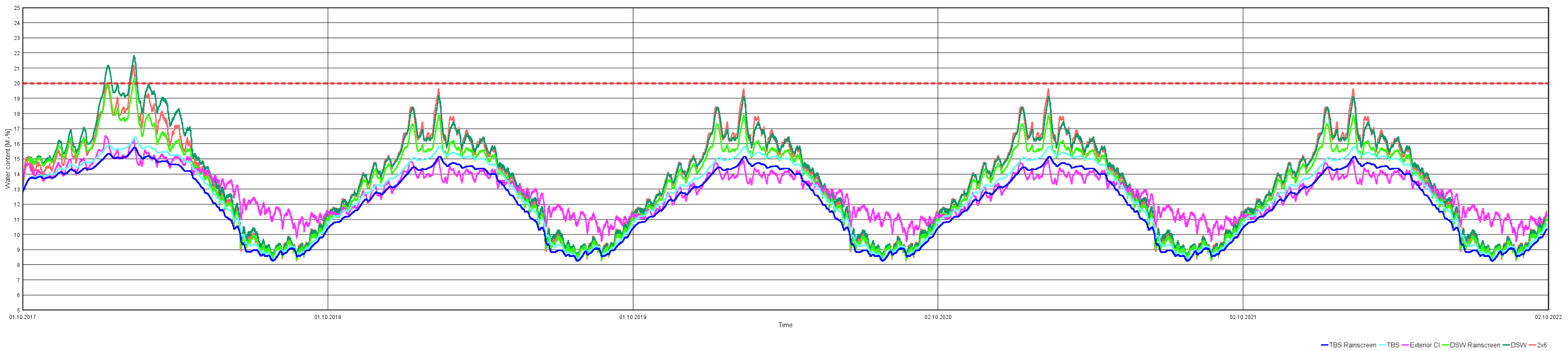
Boise CZ 5B



Spokane CZ 5B

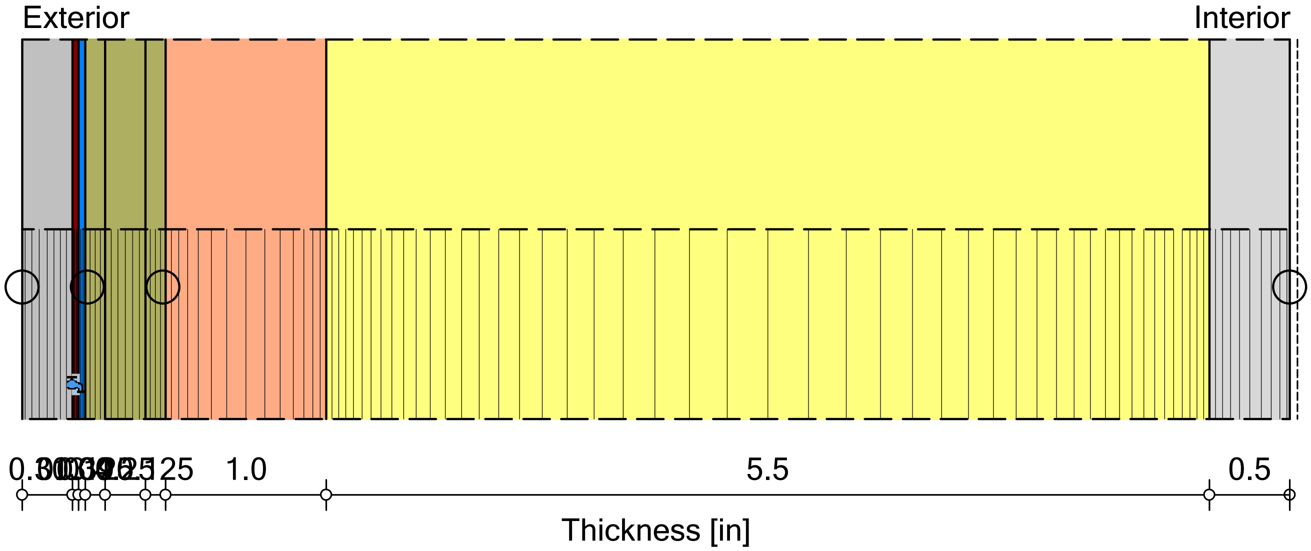


Portland CZ 4C



Component Assembly

Case: TBS FC: Boise CZ 5B



◯ - Monitor positions

- Heat/Moisture source/sink positions

Materials:

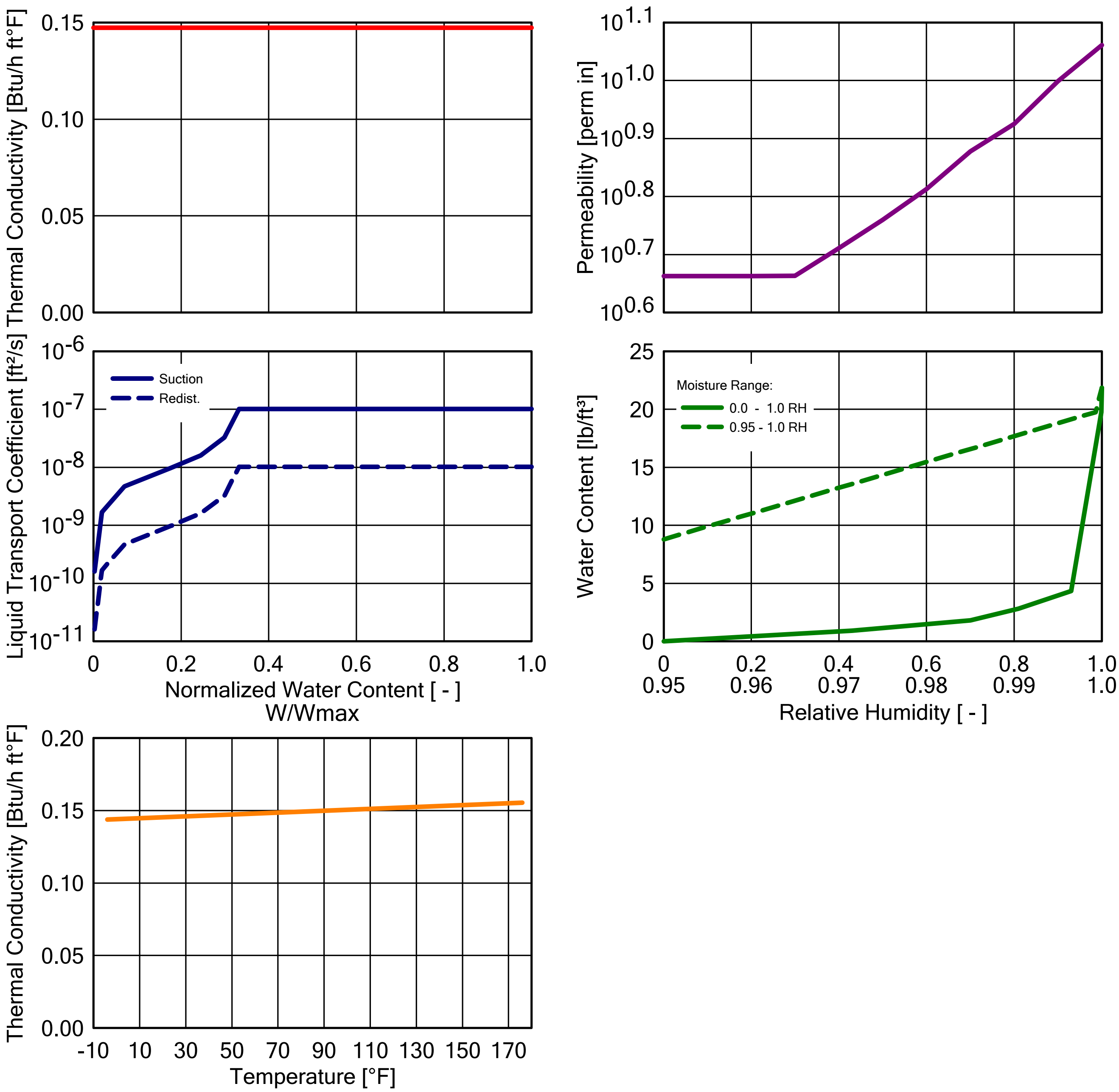
	- Cement Board	0.313 in
	- *1% DR Condensation Film	0.039 in
	- *OSB-Integrated WRB (14 perm)	0.04 in
	- *ZIP Sheathing (outer)	0.125 in
	- *ZIP Sheathing (core)	0.25 in
	- *ZIP Sheathing (inner)	0.125 in
	- Polyisocyanurate Insulation	1.0 in
	- Fiber Glass	5.5 in
	- Interior Gypsum Board	0.5 in

sd-Value Int. [perm]: 4.69

Total Thickness: 7.892 in
R-Value: 29.91 h ft² °F/Btu
U-Value: 0.032 Btu/h ft²°F

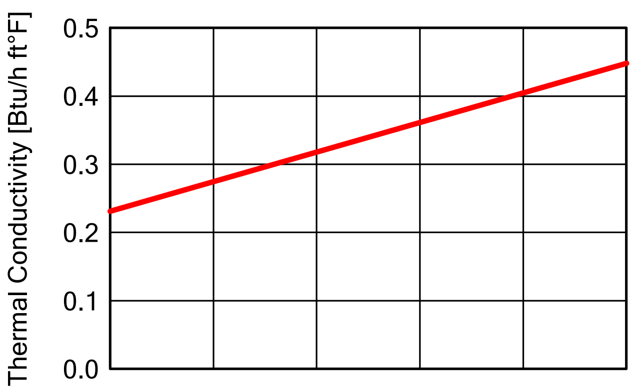
Material: Cement Board

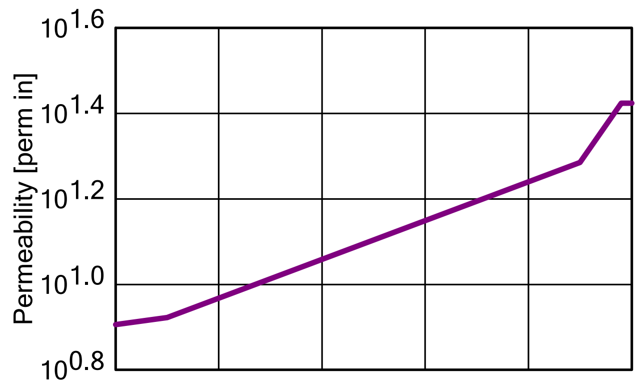
Property	Unit	Value
Bulk density	[lb/ft³]	70.5436
Porosity	[ft³/ft³]	0.48
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2006
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.1473
Permeability	[perm in]	4.6
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642

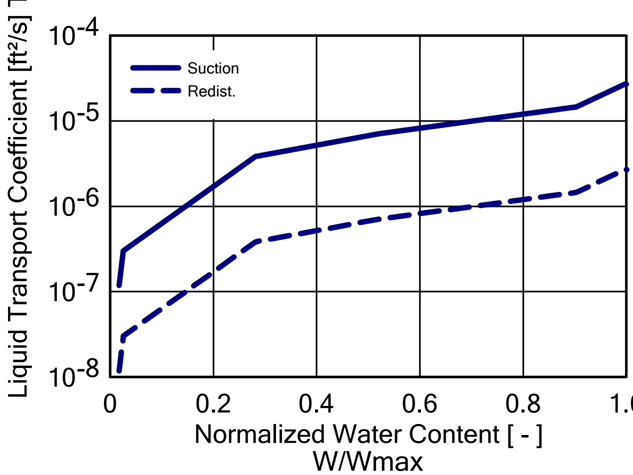


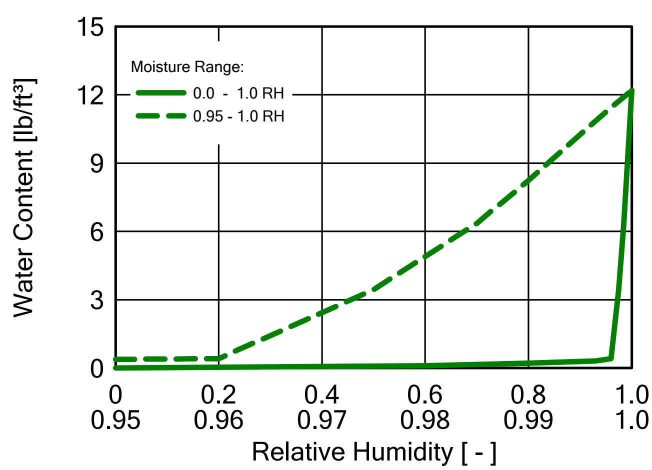
Material: *1% DR Condensation Film

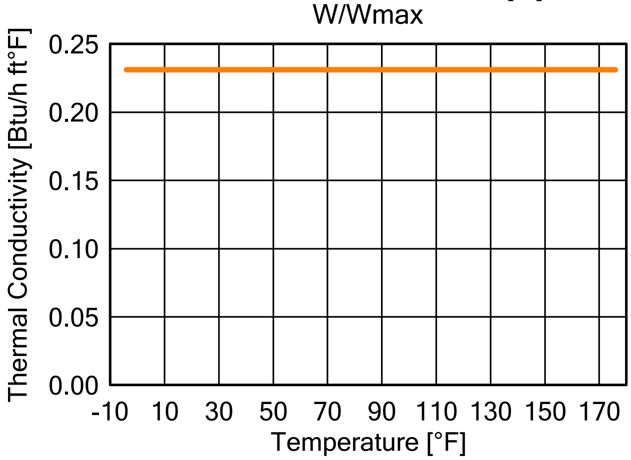
Property	Unit	Value
Bulk density	[lb/ft³]	104.2547
Porosity	[ft³/ft³]	0.196
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2006
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.2311
Permeability	[perm in]	8.05
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8.0
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0





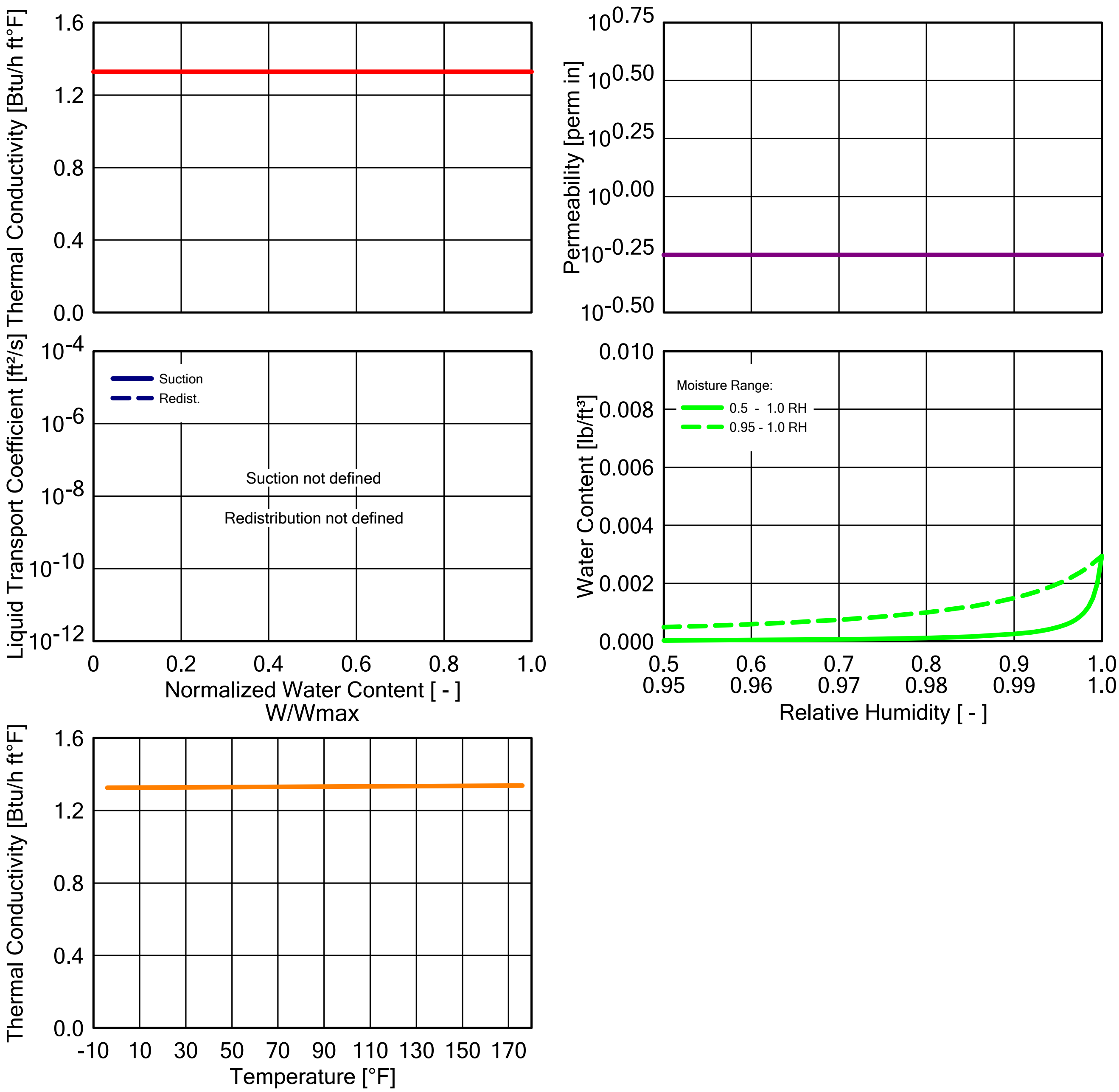






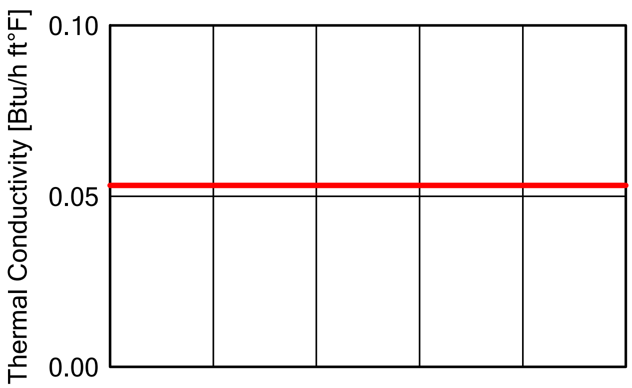
Material: *OSB-Integrated WRB (14 perm)

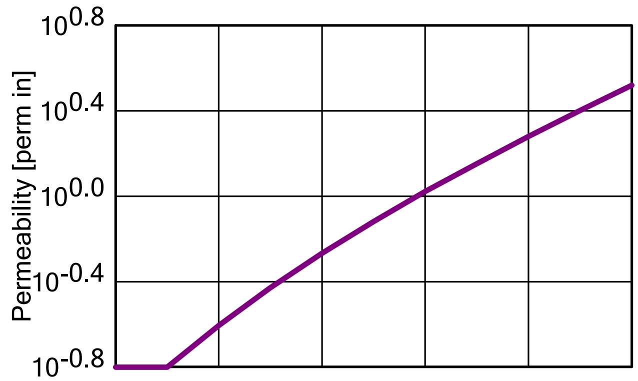
Property	Unit	Value
Bulk density	[lb/ft³]	8.11563
Porosity	[ft³/ft³]	0.001
Specific Heat Capacity, Dry	[Btu/lb°F]	0.549346
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	1.32892
Permeability	[perm in]	0.56
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41988E-5

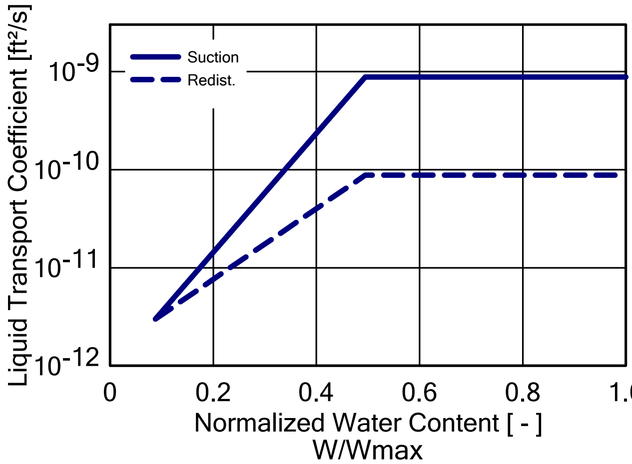


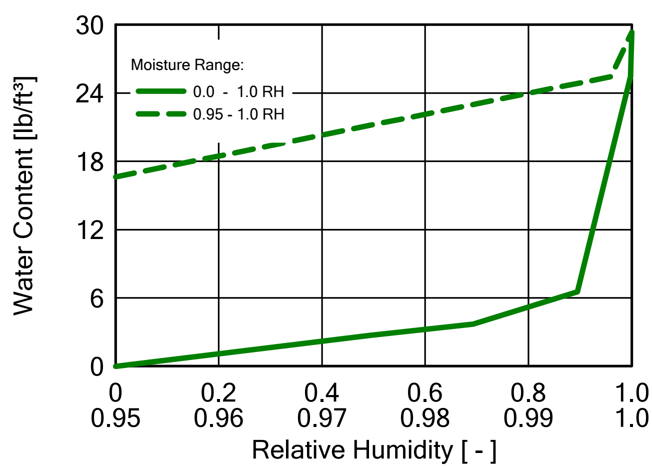
Material: *ZIP Sheathing (inner)

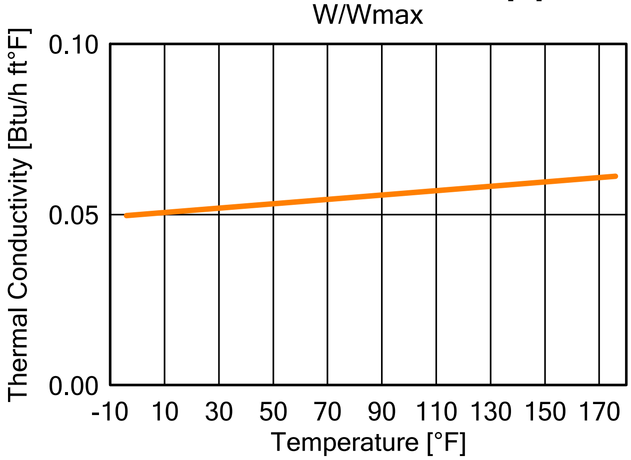
Property	Unit	Value
Bulk density	[lb/ft³]	40.5782
Porosity	[ft³/ft³]	0.95
Specific Heat Capacity, Dry	[Btu/lb°F]	0.449
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.0532
Permeability	[perm in]	0.1585
Reference Water Content	[lb/ft³]	5.2003
Free Water Saturation	[lb/ft³]	29.3411
Water Absorption Coefficient	[lb/in²s^0.5]	0.0000031
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642





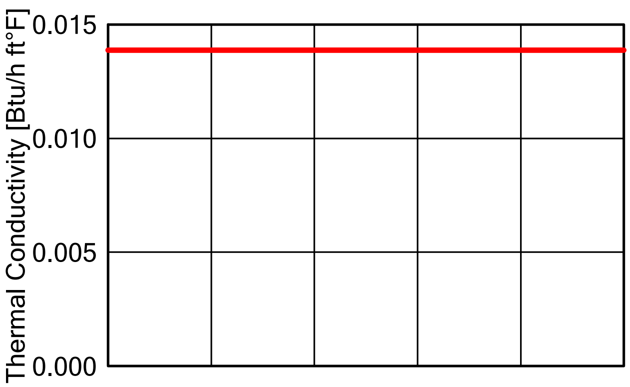


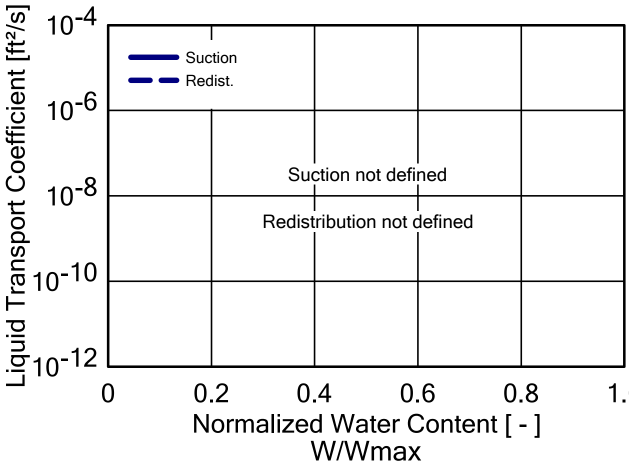


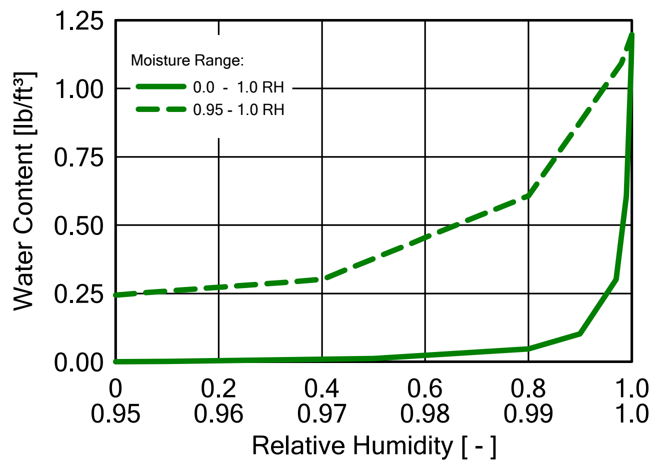


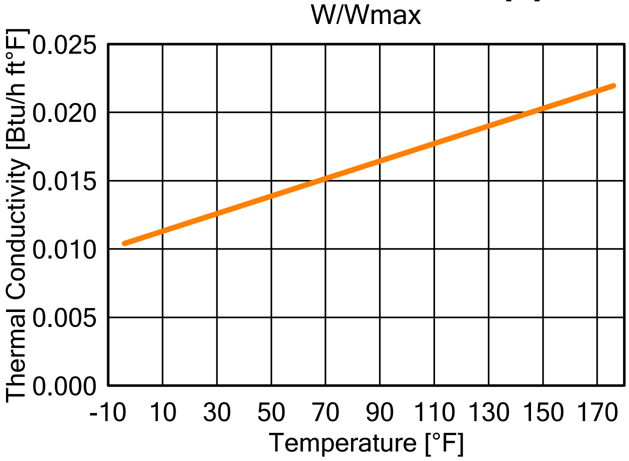
Material: Polyisocyanurate Insulation

Property	Unit	Value
Bulk density	[lb/ft³]	1.65
Porosity	[ft³/ft³]	0.99
Specific Heat Capacity, Dry	[Btu/lb°F]	0.3511
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.01387
Permeability	[perm in]	2.5
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41990E-5



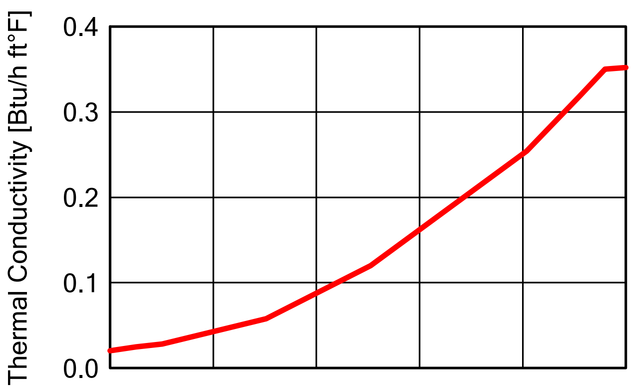


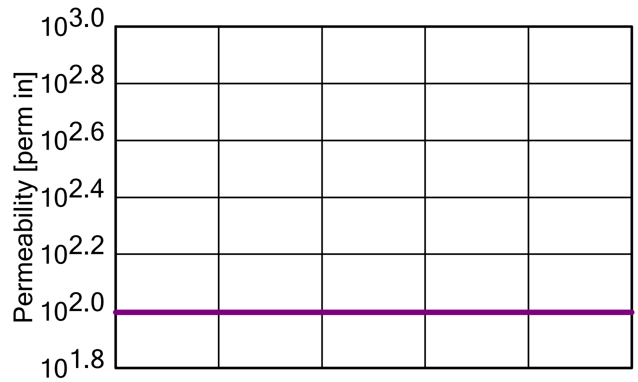


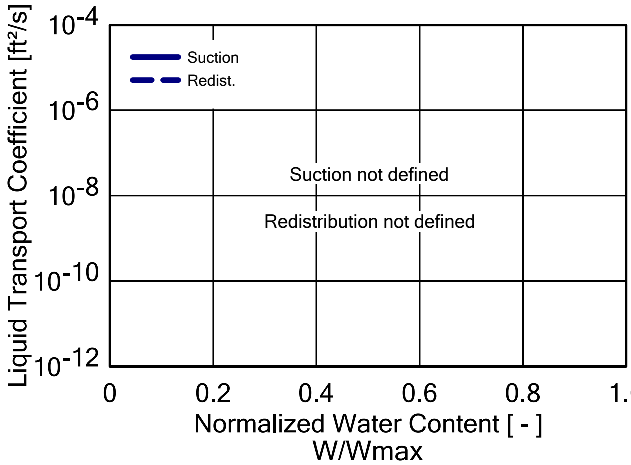


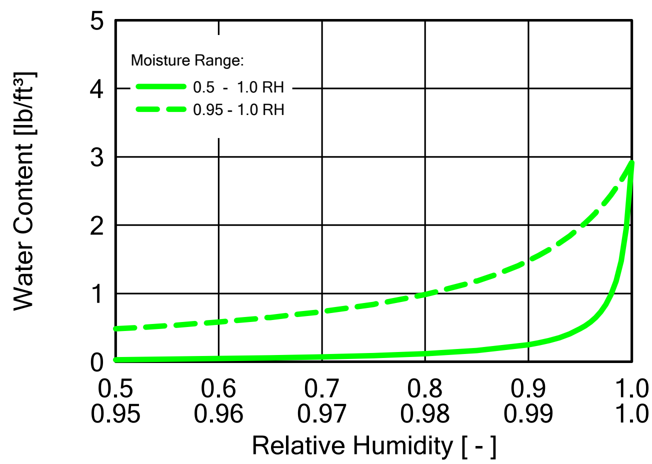
Material: Fiber Glass

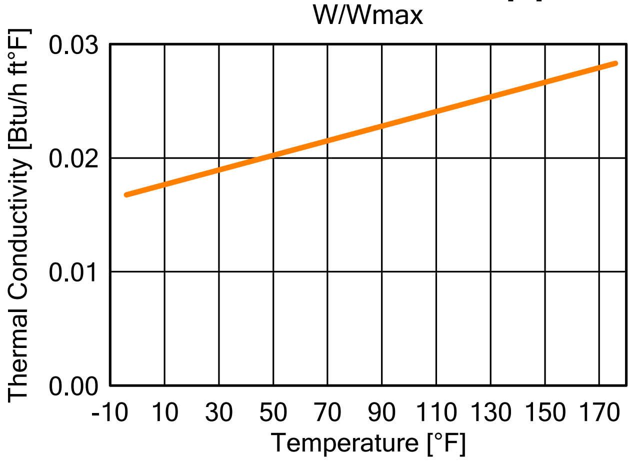
Property	Unit	Value
Bulk density	[lb/ft³]	1.9
Porosity	[ft³/ft³]	0.99
Specific Heat Capacity, Dry	[Btu/lb°F]	0.201
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.02022
Permeability	[perm in]	99
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41990E-5





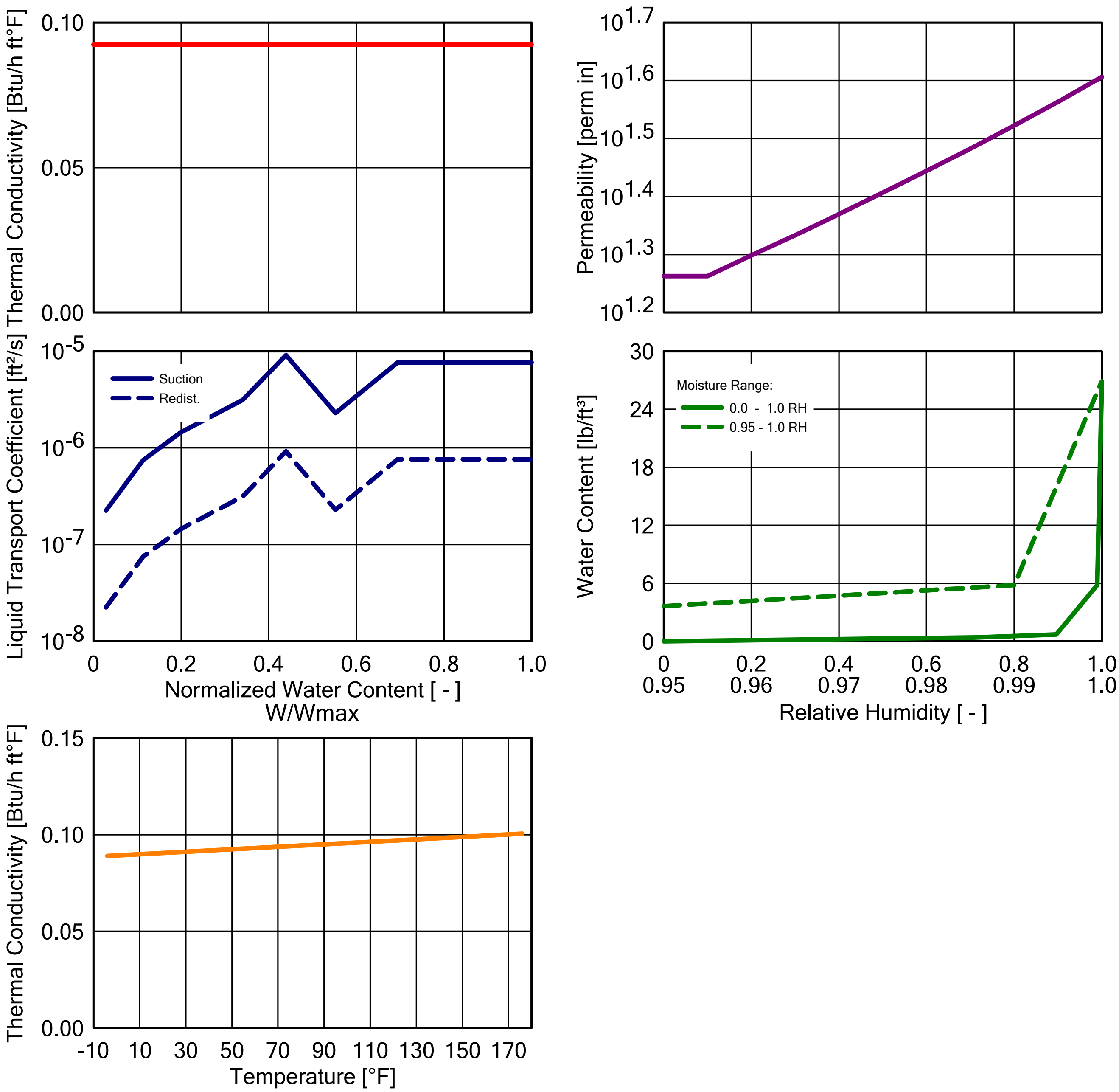






Material: Interior Gypsum Board

Property	Unit	Value
Bulk density	[lb/ft³]	39.0175
Porosity	[ft³/ft³]	0.706
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2078
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.0924
Permeability	[perm in]	18.3215
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642



Boundary Conditions

Exterior (Left Side)

Location: Boise, ID; ASHRAE Year 3
Temperature Shift: 0.0 °F
Orientation / Inclination: North / 90 °

Interior (Right Side)

Indoor Climate: EN 15026
Medium Moisture Load (EN/WTA)

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	Bright	[-]	0.2
Long-Wave Radiation Emissivity	Bright	[-]	----
Adhering Fraction of Rain	Depending on inclination o	[-]	0.7
Explicit Radiation Balance			no

Interior (Right Side)

Name	Description	Unit	Value
Heat Resistance	External Wall	[h ft² °F/Btu]	0.7098
Permeance	Latex paint 2	[perm]	4.69

Sources, Sinks

*1% DR Condensation Film

Name	Type		
1% ASHRAE160	*Moisture Source; Fraction of Rain Load*		
	Whole Layer		
	Cut-Off at Free Water Saturation	[lb/ft³]	
	User-Defined	[%]	1

Results from Last Calculation

Status of Calculation

Calculation: Time and Date	12/11/2016 12:44:05 PM
Computing Time	1 min,0 sec.
Begin / End of calculation	10/1/2017 / 10/1/2022
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[lb/ft²]	14.21 -15.65
Integral of fluxes, right side (kr,dr)	[lb/ft²]	1.4E-7 -0.79
Balance 1	[lb/ft²]	-0.16
Balance 2	[lb/ft²]	-0.16

Water Content [lb/ft²]

	Start	End	Min.	Max.
Total Water Content	0.37	0.2	0.14	0.82

Water Content [lb/ft³]

Layer/Material	Start	End	Min.	Max.
Cement Board	2.73	0.88	0.36	20.98
*1% DR Condensation Film	0.21	0.07	0.03	12.03
*OSB-Integrated WRB (14 perm)	0.00	0.00	0.00	0.00
*ZIP Sheathing (outer)	5.20	3.02	1.73	6.47
*ZIP Sheathing (core)	5.20	3.47	2.29	6.22
*ZIP Sheathing (inner)	5.20	3.63	2.57	6.91
Polyisocyanurate Insulation	0.05	0.03	0.01	0.14
Fiber Glass	0.12	0.05	0.04	0.12
Interior Gypsum Board	0.54	0.30	0.12	0.54

Time Integral of fluxes

Heat Flux, left side	[Btu/ft²]	-1.4E+0005
Heat Flux, right side	[Btu/ft²]	-27306.86
Moisture Fluxes, left side	[lb/ft²]	-1.44
Moisture Fluxes, right side	[lb/ft²]	-0.79

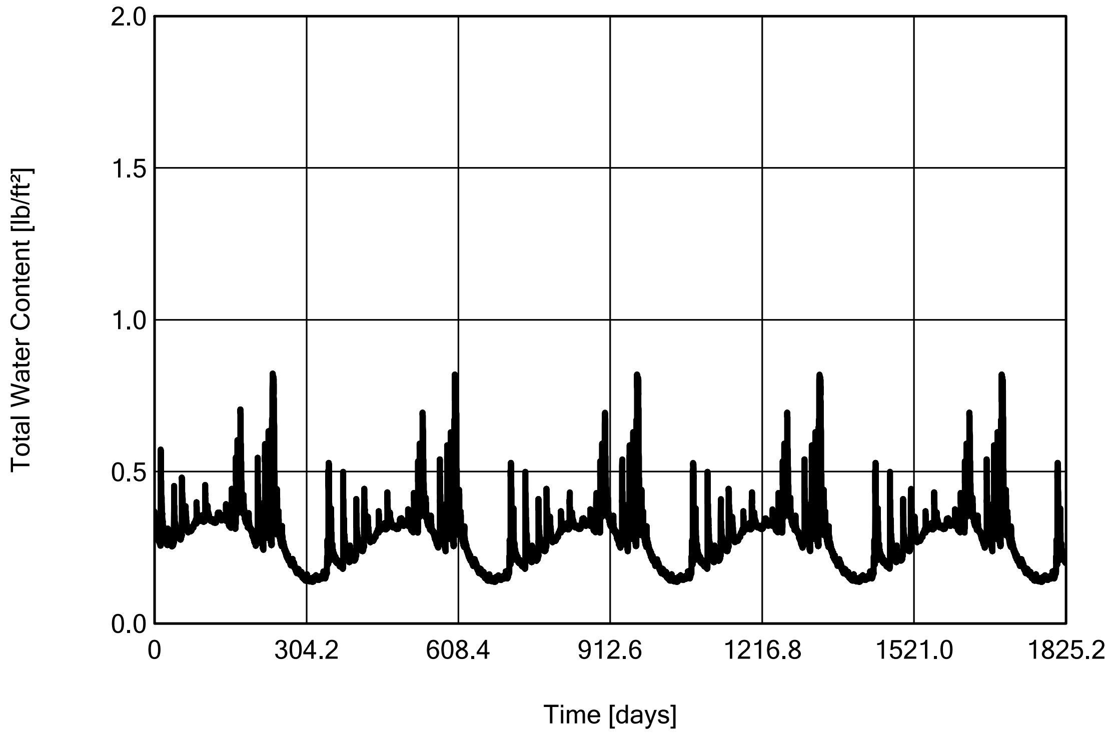
Hygrothermal Sources

Heat Sources	[Btu/ft²]	0.0

Hygrothermal Sources (Continue)

Moisture Sources	[lb/ft²]	0.491
Unreleased Moisture Sources (due to cut-off)	[lb/ft²]	0.0
1% ASHRAE160 (Moisture Source)	[lb/ft²]	0.491

Total Water Content in Construction



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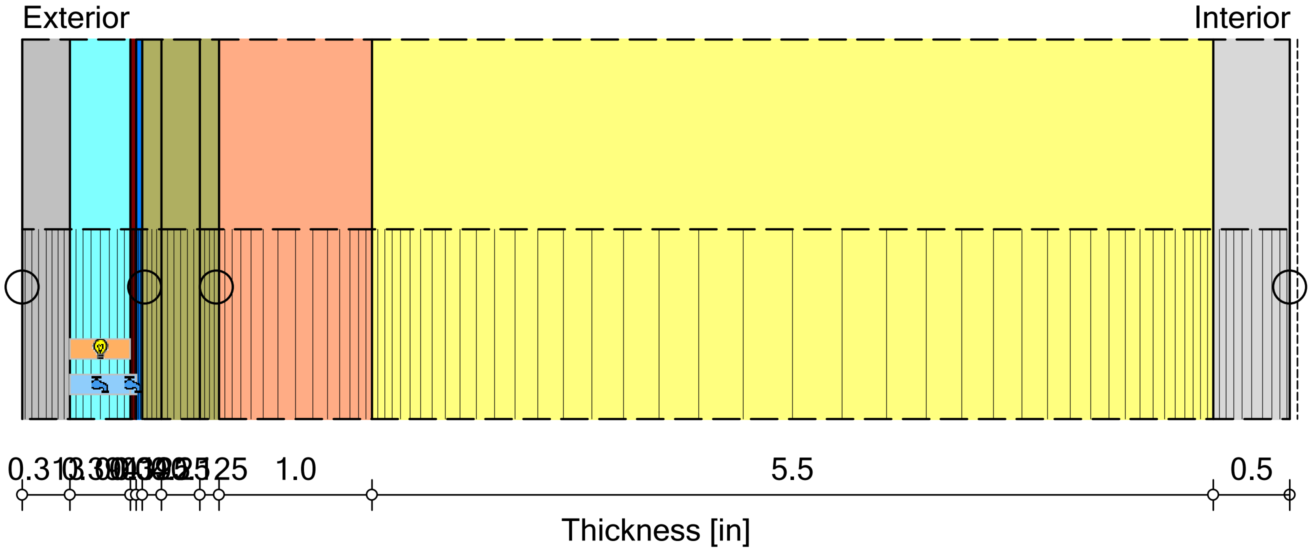
Component Assembly

Case: TBS FC Rainscreen: Boise CZ 5B



- Monitor positions

- Heat/Moisture source/sink positions

Materials:

- Cement Board	0.313 in
- Air Layer 10 mm; without additional moisture capacity	0.394 in
- *1% DR Condensation Film	0.039 in
- *OSB-Integrated WRB (14 perm)	0.04 in
- *ZIP Sheathing (outer)	0.125 in
- *ZIP Sheathing (core)	0.25 in
- *ZIP Sheathing (inner)	0.125 in
- Polyisocyanurate Insulation	1.0 in
- Fiber Glass	5.5 in
- Interior Gypsum Board	0.5 in

sd-Value Int. [perm]: 4.69

Total Thickness: 8.285 in
R-Value: 30.71 h ft² °F/Btu
U-Value: 0.031 Btu/h ft²°F

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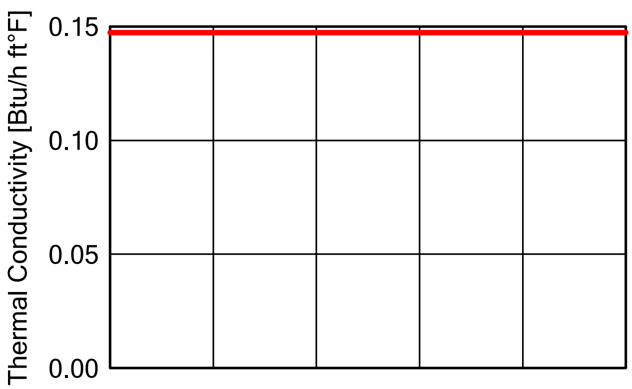
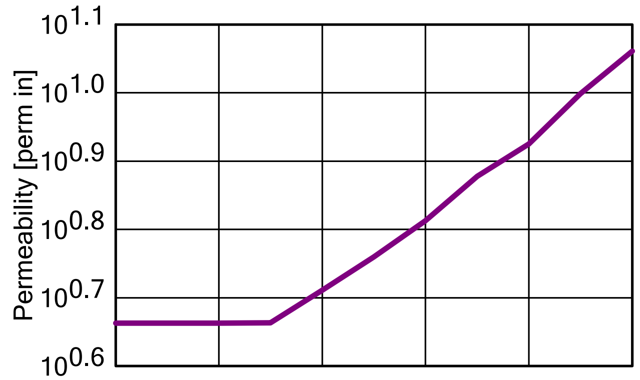
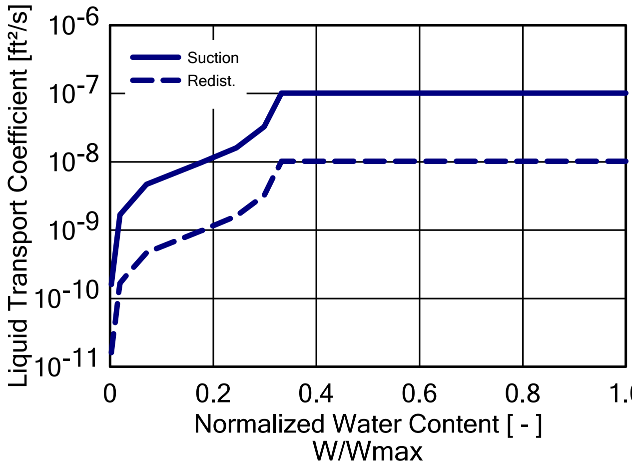
WUFI Pro 6.3

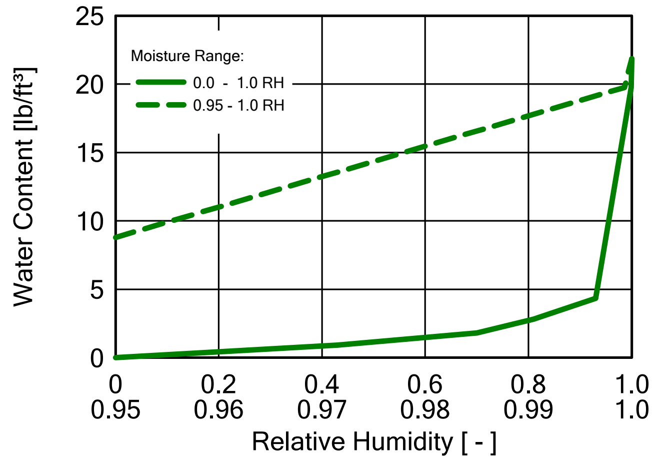
Material: Cement Board

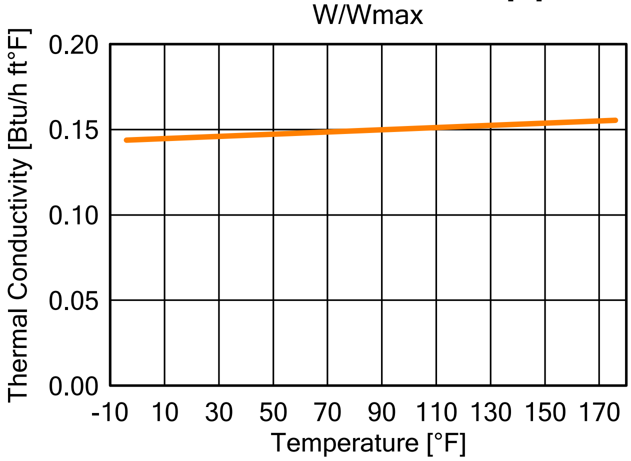
Property	Unit	Value
Bulk density	[lb/ft³]	70.5436
Porosity	[ft³/ft³]	0.48
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2006
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.1473
Permeability	[perm in]	4.6
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642





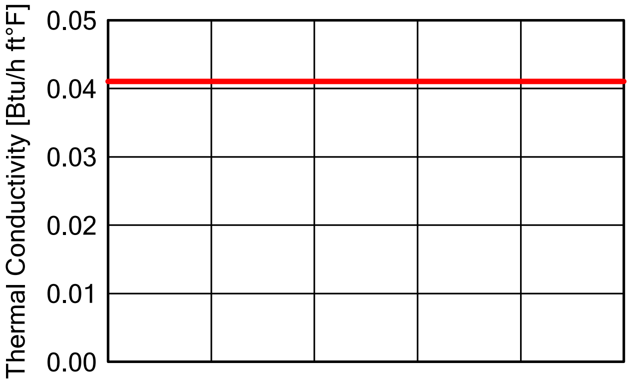


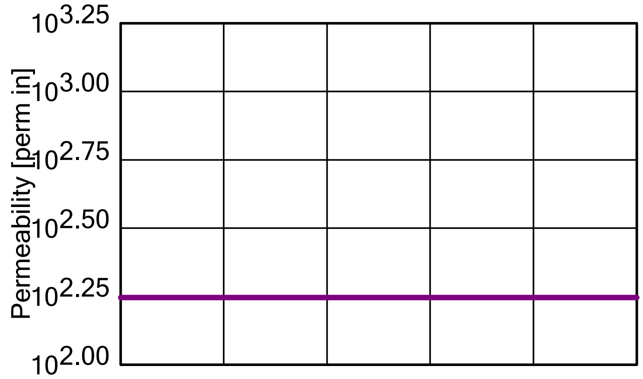


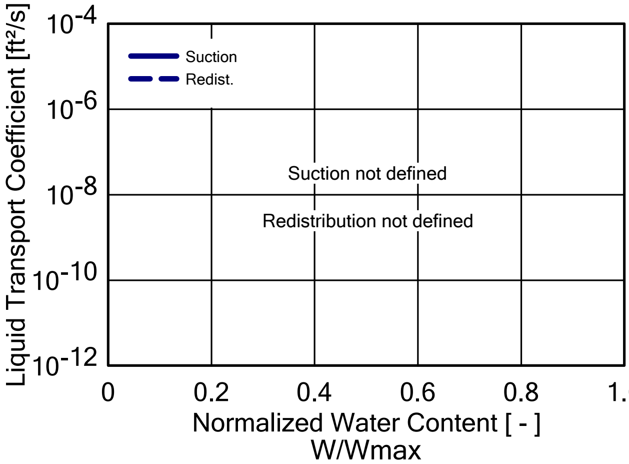


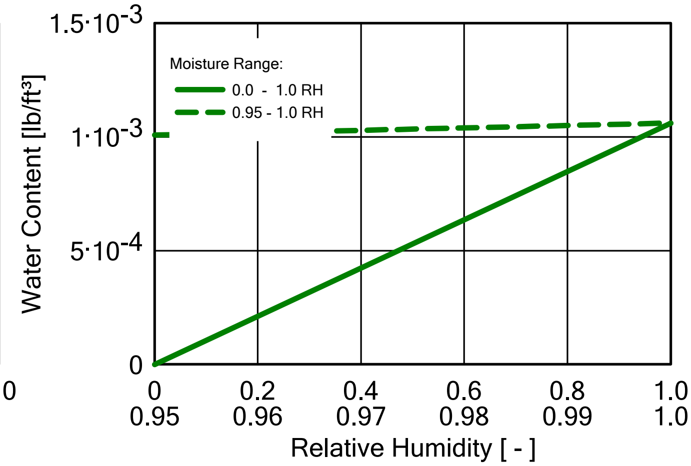
Material: Air Layer 10 mm; without additional moisture capacity

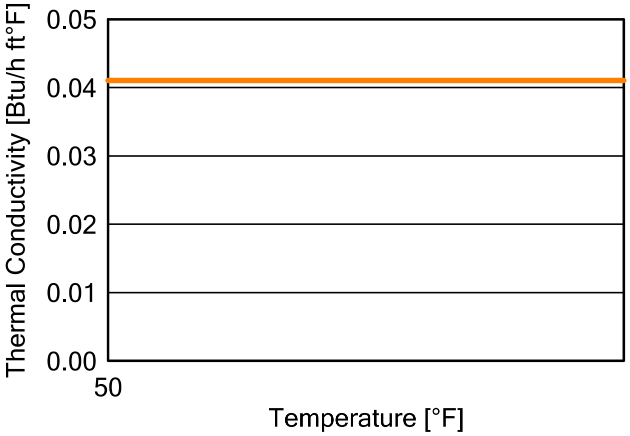
Property	Unit	Value
Bulk density	[lb/ft³]	0.0811563
Porosity	[ft³/ft³]	0.999
Specific Heat Capacity, Dry	[Btu/lb°F]	0.238846
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.041023
Permeability	[perm in]	176.438







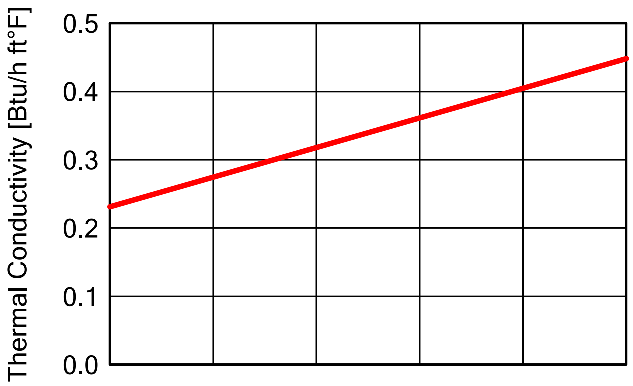


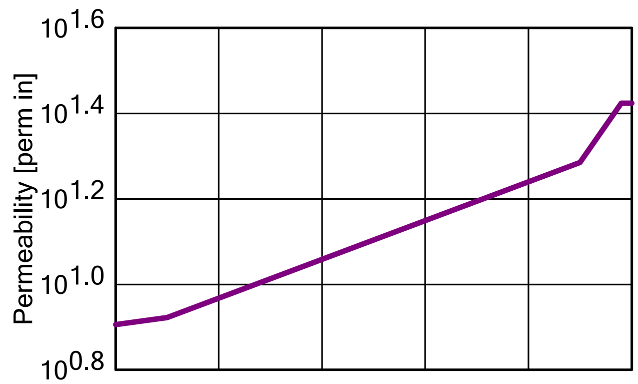


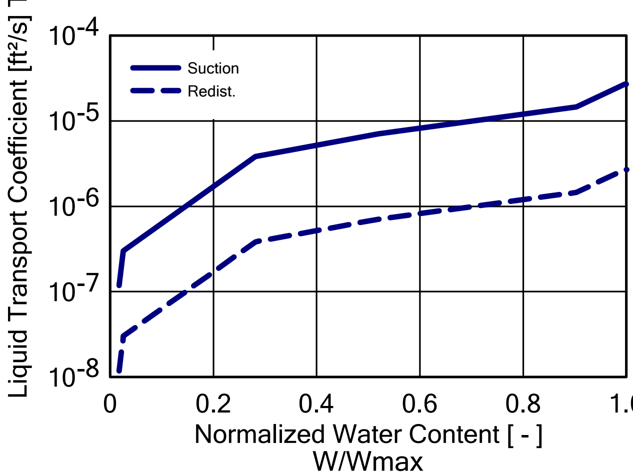
WUFI Pro 6.3

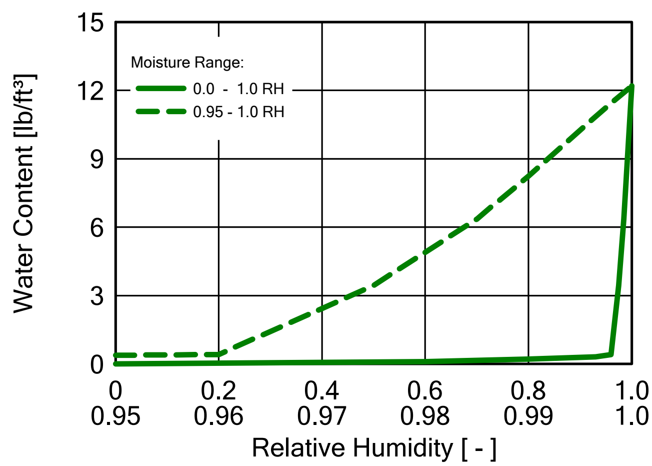
Material: *1% DR Condensation Film

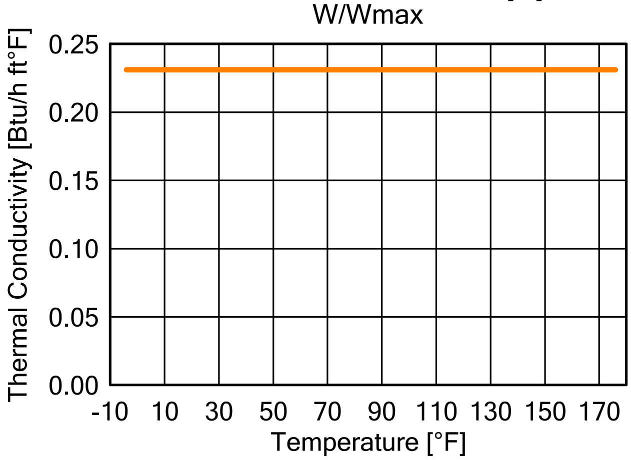
Property	Unit	Value
Bulk density	[lb/ft³]	104.2547
Porosity	[ft³/ft³]	0.196
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2006
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.2311
Permeability	[perm in]	8.05
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8.0
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0











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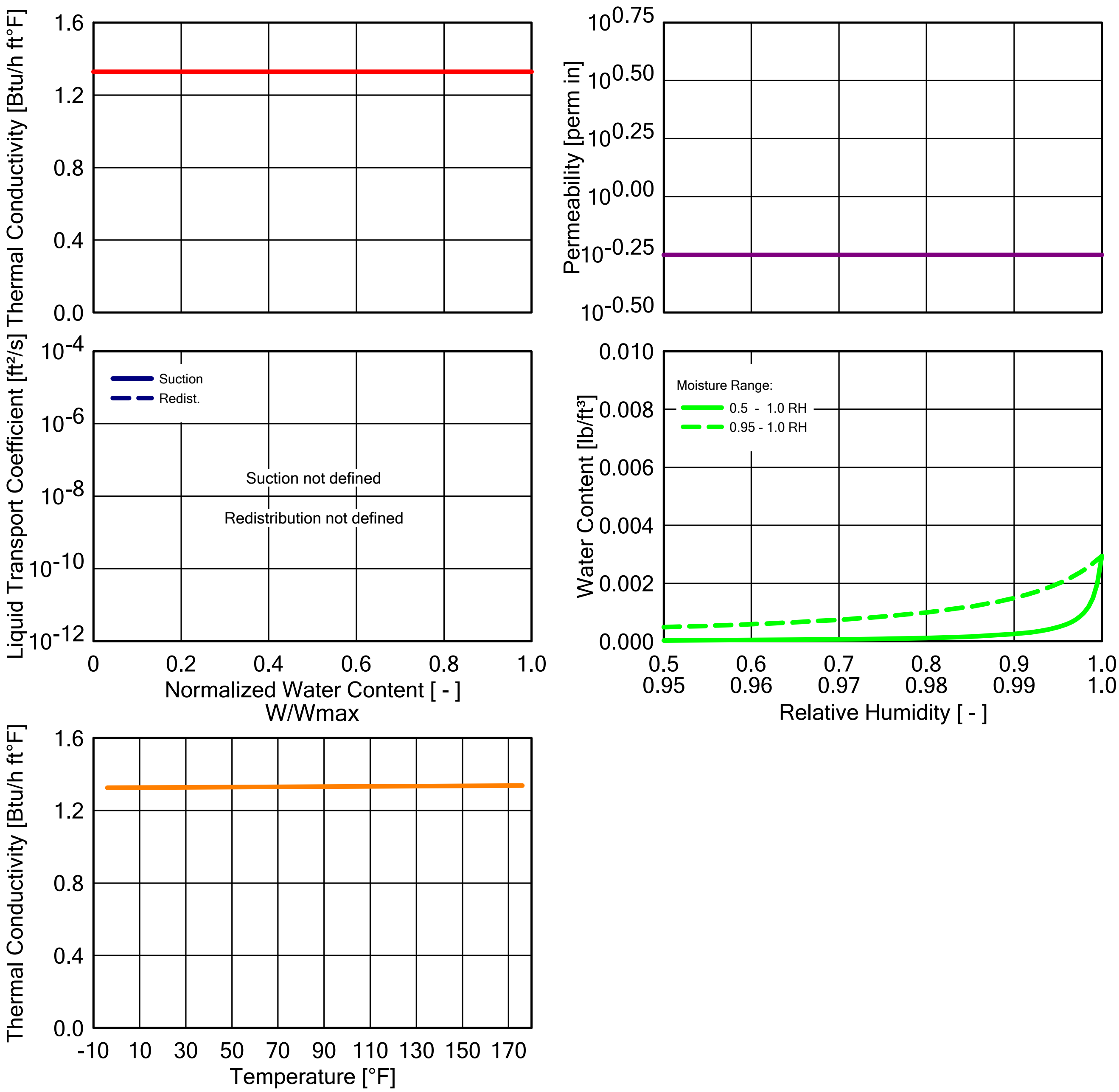
Material: *OSB-Integrated WRB (14 perm)

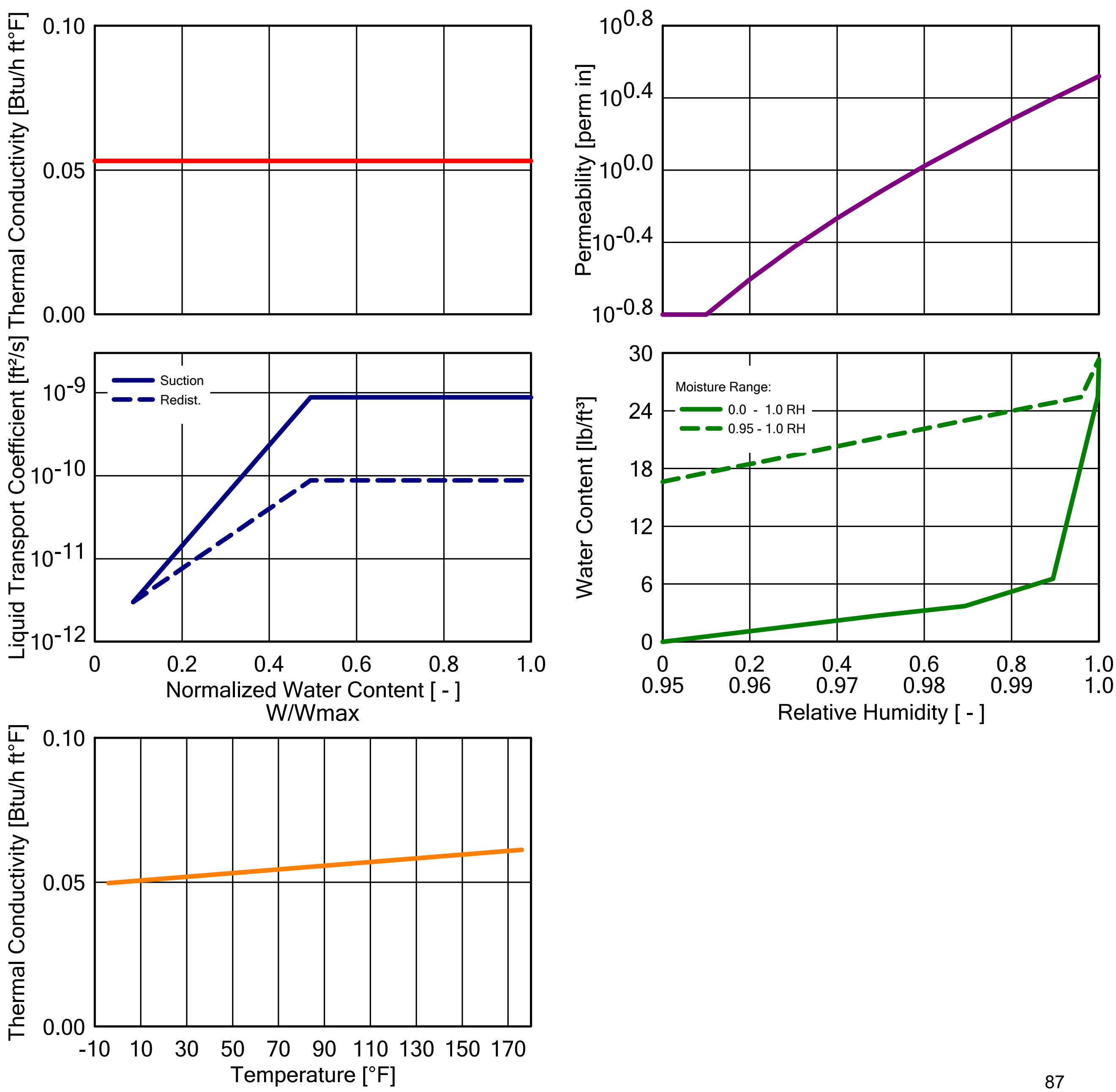
Property	Unit	Value
Bulk density	[lb/ft³]	8.11563
Porosity	[ft³/ft³]	0.001
Specific Heat Capacity, Dry	[Btu/lb°F]	0.549346
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	1.32892
Permeability	[perm in]	0.56
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41988E-5



WUFI Pro 6.3

Material: *ZIP Sheathing (inner)

Property	Unit	Value
Bulk density	[lb/ft³]	40.5782
Porosity	[ft³/ft³]	0.95
Specific Heat Capacity, Dry	[Btu/lb°F]	0.449
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.0532
Permeability	[perm in]	0.1585
Reference Water Content	[lb/ft³]	5.2003
Free Water Saturation	[lb/ft³]	29.3411
Water Absorption Coefficient	[lb/in²s^0.5]	0.0000031
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642



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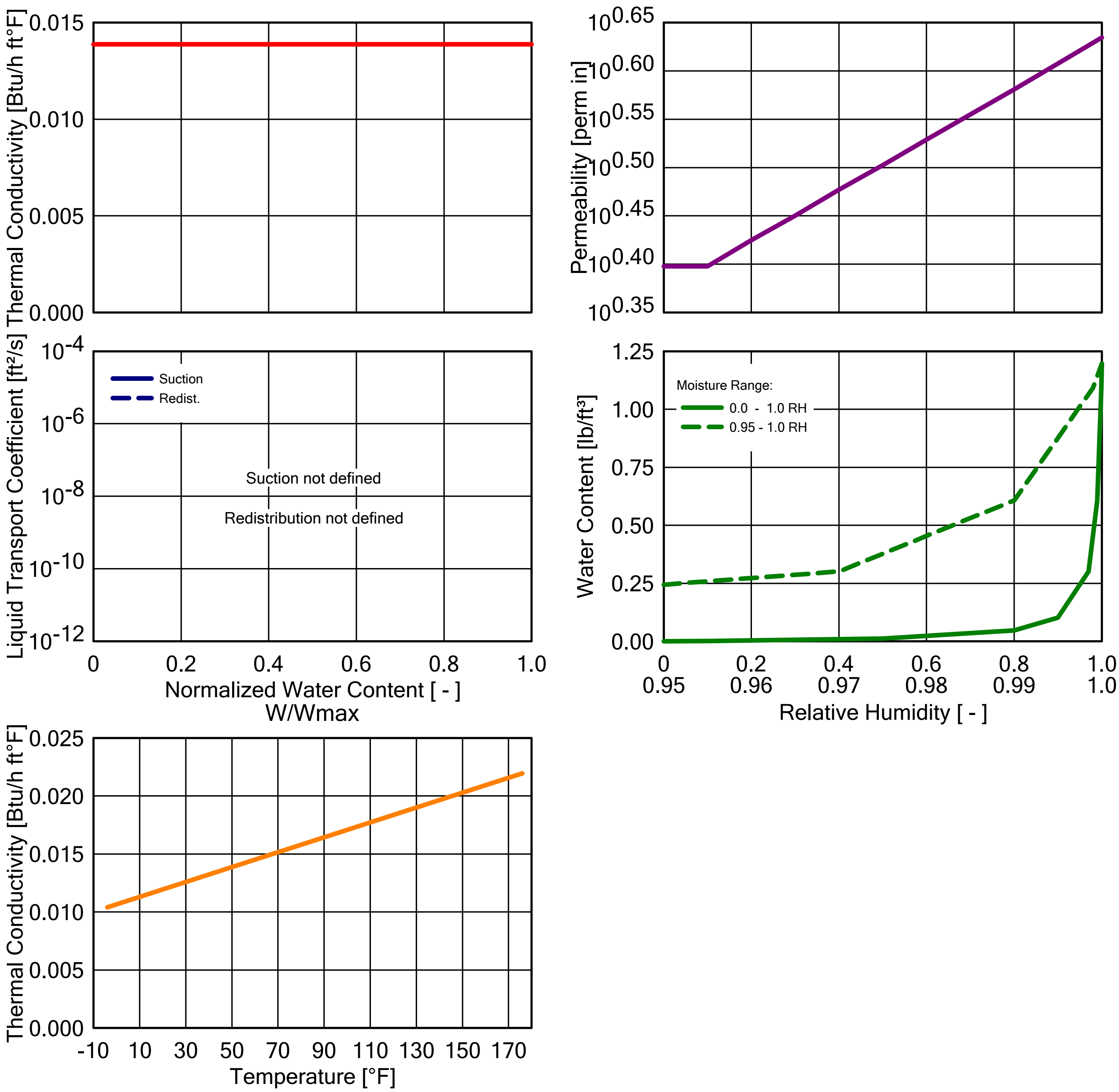
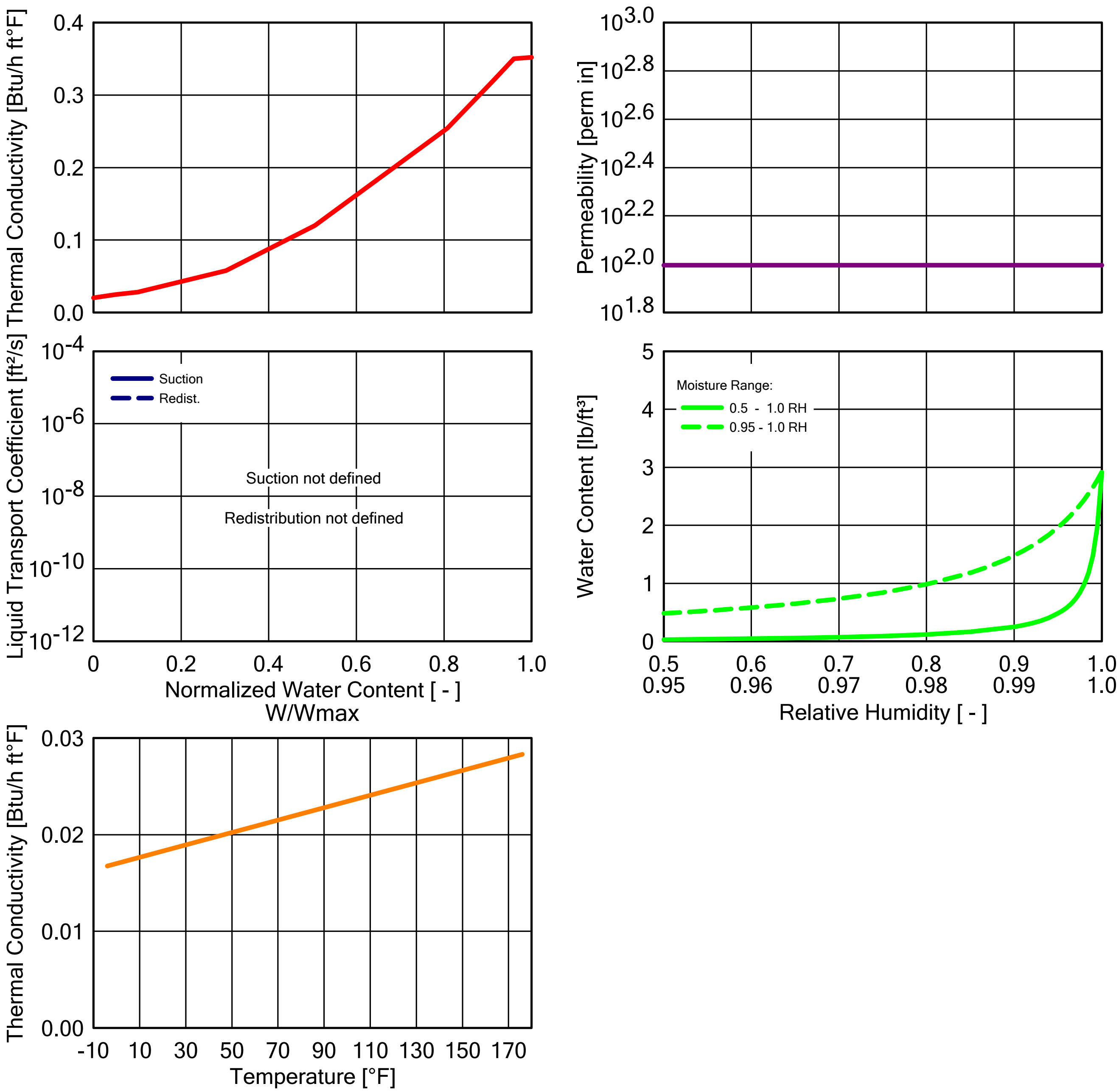
Material: Polyisocyanurate Insulation

Property	Unit	Value
Bulk density	[lb/ft³]	1.65
Porosity	[ft³/ft³]	0.99
Specific Heat Capacity, Dry	[Btu/lb°F]	0.3511
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.01387
Permeability	[perm in]	2.5
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41990E-5



Material: Fiber Glass

Property	Unit	Value
Bulk density	[lb/ft³]	1.9
Porosity	[ft³/ft³]	0.99
Specific Heat Capacity, Dry	[Btu/lb°F]	0.201
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.02022
Permeability	[perm in]	99
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41990E-5



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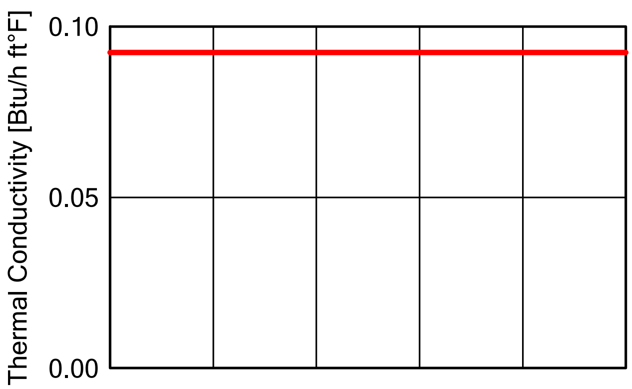
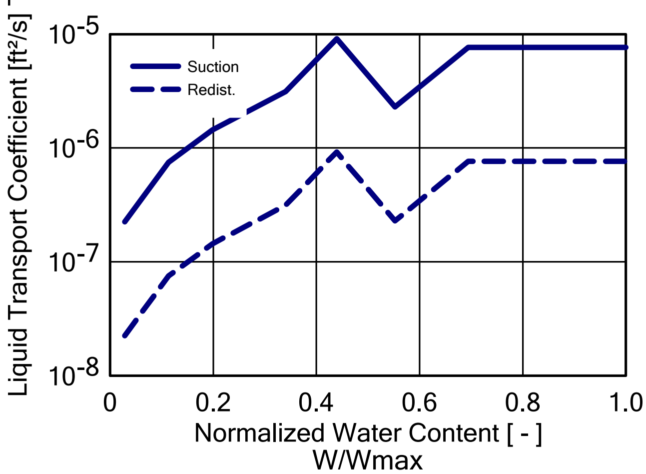
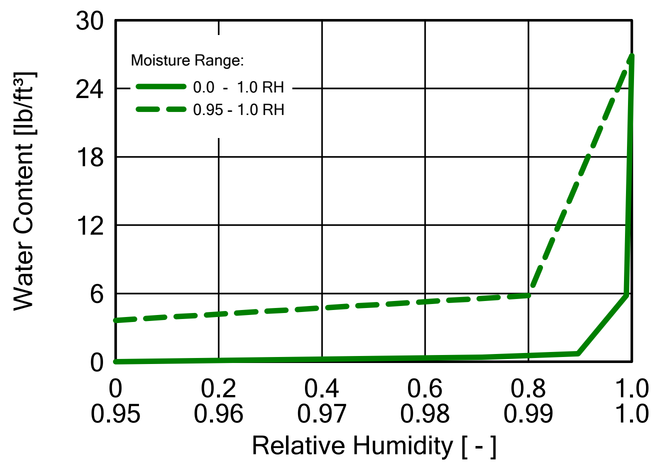
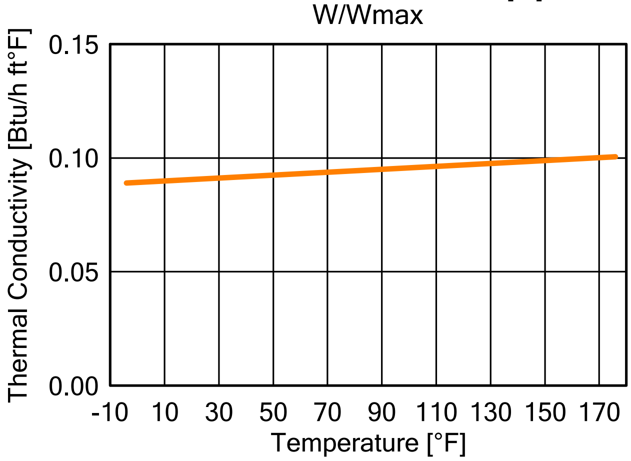
Material: Interior Gypsum Board

Property	Unit	Value
Bulk density	[lb/ft³]	39.0175
Porosity	[ft³/ft³]	0.706
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2078
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.0924
Permeability	[perm in]	18.3215
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642









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Boundary Conditions

Exterior (Left Side)

Location:	Boise, ID; ASHRAE Year 3
Temperature Shift:	0.0 °F
Orientation / Inclination:	North / 90 °

Interior (Right Side)

Indoor Climate:	EN 15026 Medium Moisture Load (EN/WTA)

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	Bright	[-]	0.2
Long-Wave Radiation Emissivity	Bright	[-]	----
Adhering Fraction of Rain	Depending on inclination o	[-]	0.7
Explicit Radiation Balance			no

Interior (Right Side)

Name	Description	Unit	Value
Heat Resistance	External Wall	[h ft² °F/Btu]	0.7098
Permeance	Latex paint 2	[perm]	4.69

Sources, Sinks

Air Layer 10 mm; without additional moisture capacity

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

*1% DR Condensation Film

Name	Type		
1% ASHRAE160	*Moisture Source; Fraction of Rain Load*		
	Whole Layer		
	Cut-Off at Free Water Saturation	[lb/ft³]	
	User-Defined	[%]	1

Results from Last Calculation

Status of Calculation

Calculation: Time and Date	12/11/2016 12:42:32 PM
Computing Time	1 min,31 sec.
Begin / End of calculation	10/1/2017 / 10/1/2022
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[lb/ft²]	14.4 -14.12
Integral of fluxes, right side (kr,dr)	[lb/ft²]	1E-7 -0.83
Balance 1	[lb/ft²]	-0.17
Balance 2	[lb/ft²]	-0.18

Water Content [lb/ft²]

	Start	End	Min.	Max.
Total Water Content	0.37	0.2	0.14	0.78

Water Content [lb/ft³]

Layer/Material	Start	End	Min.	Max.
Cement Board	2.73	0.85	0.33	21.24
Air Layer 10 mm; without additional m	0.00	0.00	0.00	0.00
*1% DR Condensation Film	0.21	0.07	0.03	2.84
*OSB-Integrated WRB (14 perm)	0.00	0.00	0.00	0.00
*ZIP Sheathing (outer)	5.20	2.89	1.71	6.06
*ZIP Sheathing (core)	5.20	3.36	2.29	5.85
*ZIP Sheathing (inner)	5.20	3.55	2.57	6.42
Polyisocyanurate Insulation	0.05	0.03	0.01	0.13
Fiber Glass	0.12	0.05	0.04	0.12
Interior Gypsum Board	0.54	0.30	0.12	0.54

Time Integral of fluxes

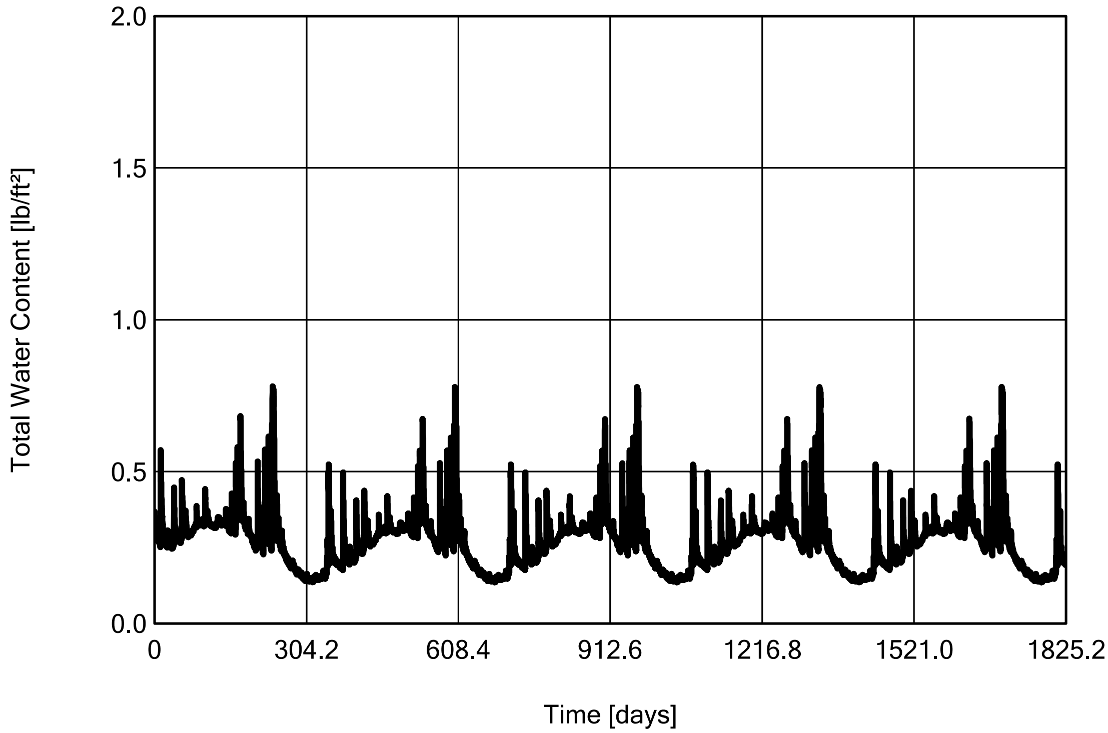
Heat Flux, left side	[Btu/ft²]	-1.4E+0005
Heat Flux, right side	[Btu/ft²]	-26653.06
Moisture Fluxes, left side	[lb/ft²]	0.31
Moisture Fluxes, right side	[lb/ft²]	-0.83

Hygrothermal Sources

Hygrothermal Sources (Continue)

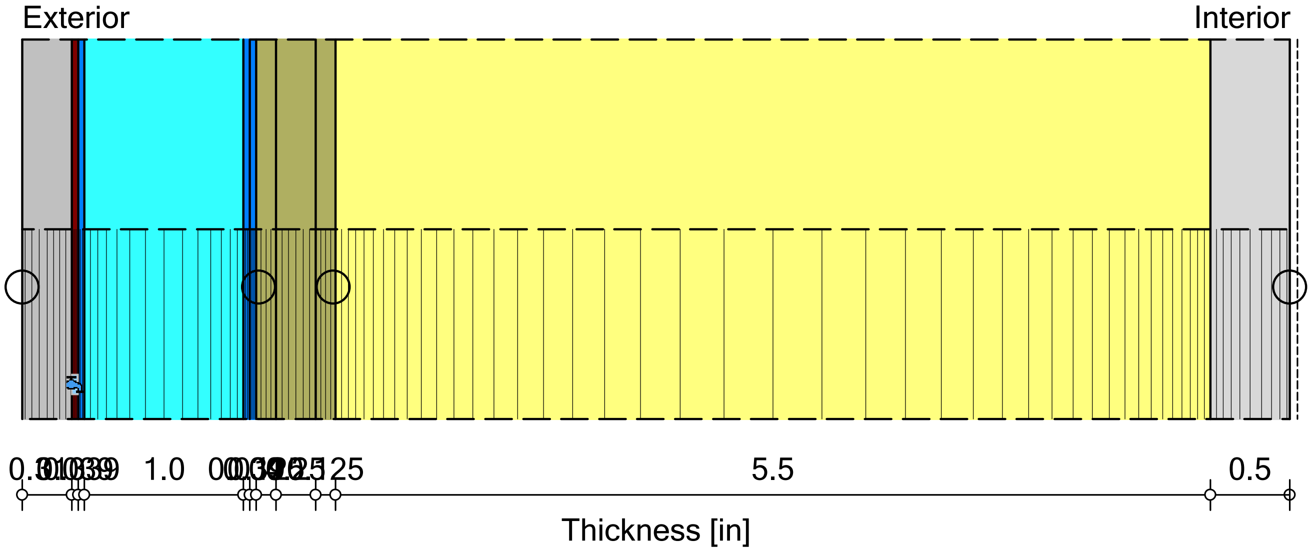
Heat Sources	[Btu/ft²]	-804.64
20ACH (Air Change Source)	[Btu/ft²]	-804.64
Moisture Sources	[lb/ft²]	-1.293
Unreleased Moisture Sources (due to cut-off)	[lb/ft²]	-0.003
20ACH (Air Change Source)	[lb/ft²]	-1.784
1% ASHRAE160 (Moisture Source)	[lb/ft²]	0.491

Total Water Content in Construction



Component Assembly

Case: Exterior CI FC: Boise CZ 5B



- Monitor positions

- Heat/Moisture source/sink positions

Materials:

- Cement Board	0.313 in
- *1% DR Condensation Film	0.039 in
- vapour retarder (sd=50m)	0.039 in
- *Extruded Polystyrene Insulation - XPS	1.0 in
- vapour retarder (sd=50m)	0.039 in
- *OSB-Integrated WRB (14 perm)	0.04 in
- *ZIP Sheathing (outer)	0.125 in
- *ZIP Sheathing (core)	0.25 in
- *ZIP Sheathing (inner)	0.125 in
- Fiber Glass	5.5 in
- Interior Gypsum Board	0.5 in

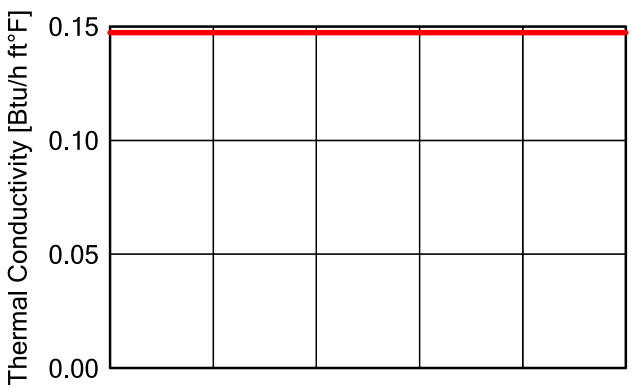
sd-Value Int. [perm]: 4.69

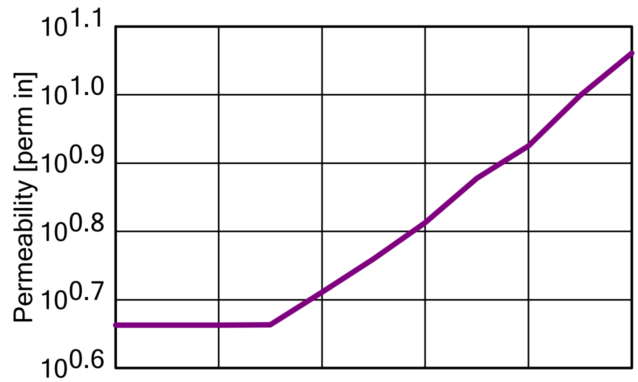
Total Thickness: 7.97 in
R-Value: 28.91 h ft² °F/Btu
U-Value: 0.033 Btu/h ft²°F

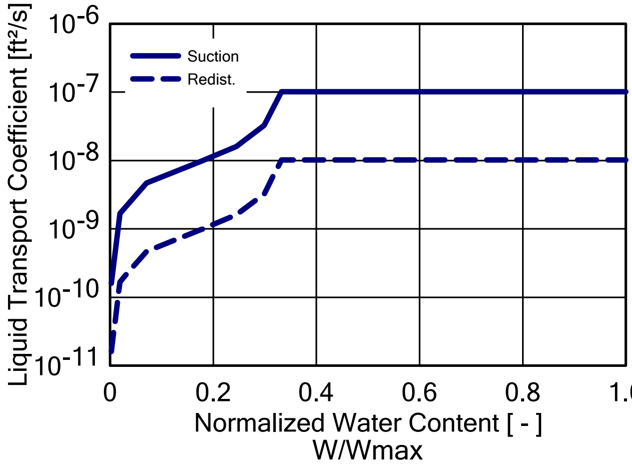
WUFI Pro 6.3

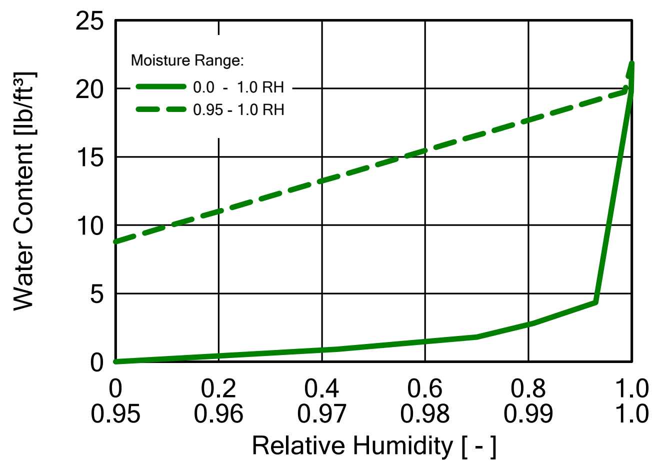
Material: Cement Board

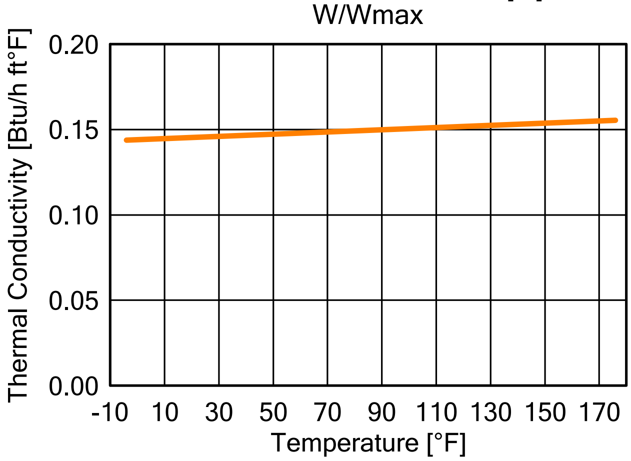
Property	Unit	Value
Bulk density	[lb/ft³]	70.5436
Porosity	[ft³/ft³]	0.48
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2006
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.1473
Permeability	[perm in]	4.6
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642





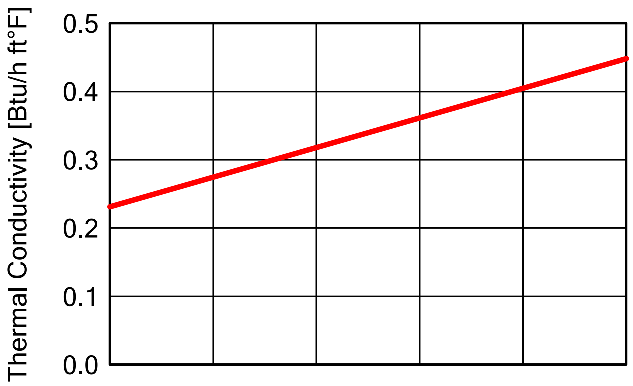


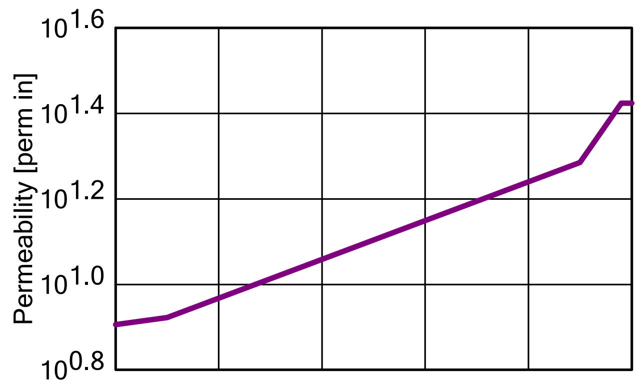


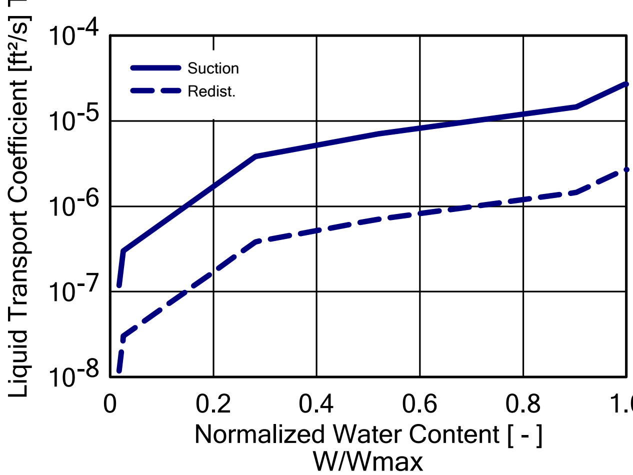


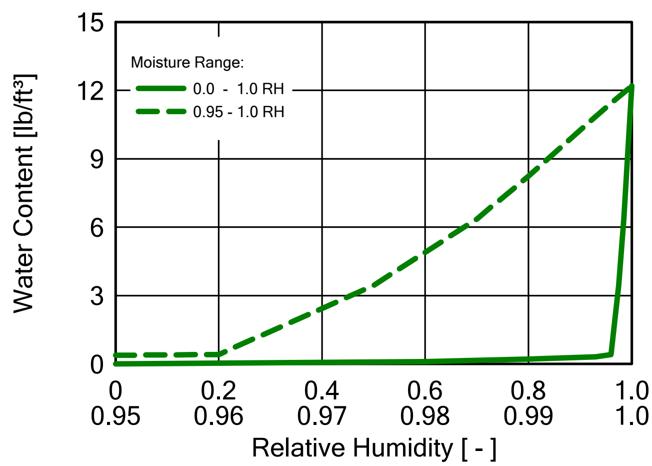
Material: *1% DR Condensation Film

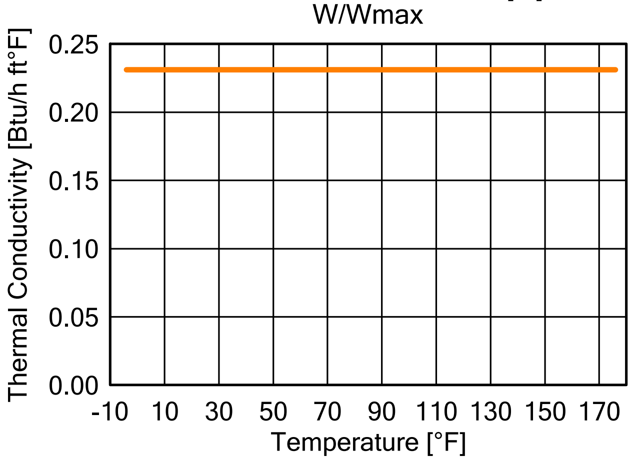
Property	Unit	Value
Bulk density	[lb/ft³]	104.2547
Porosity	[ft³/ft³]	0.196
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2006
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.2311
Permeability	[perm in]	8.05
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8.0
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0







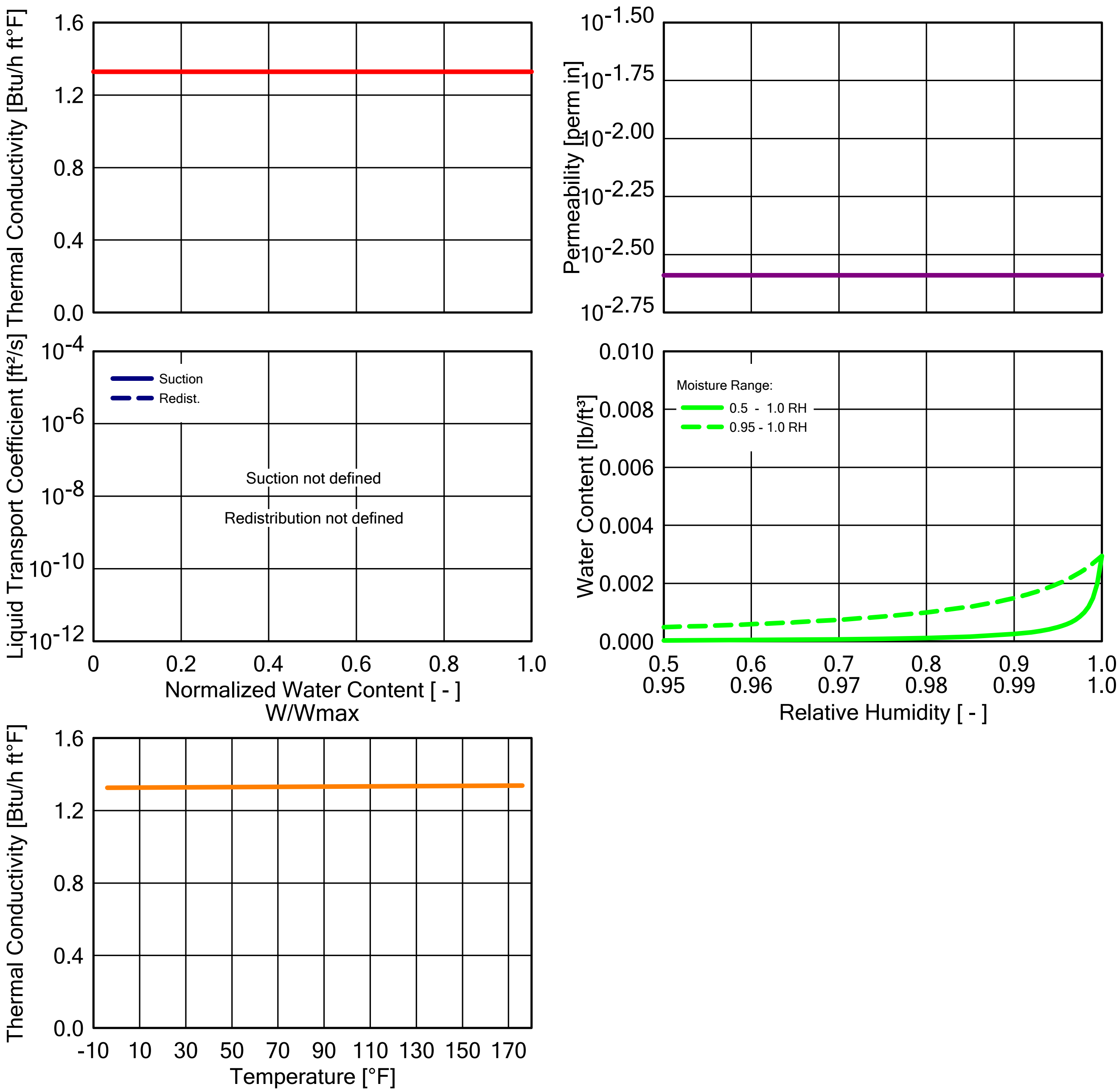




WUFI Pro 6.3

Material: vapour retarder (sd=50m)

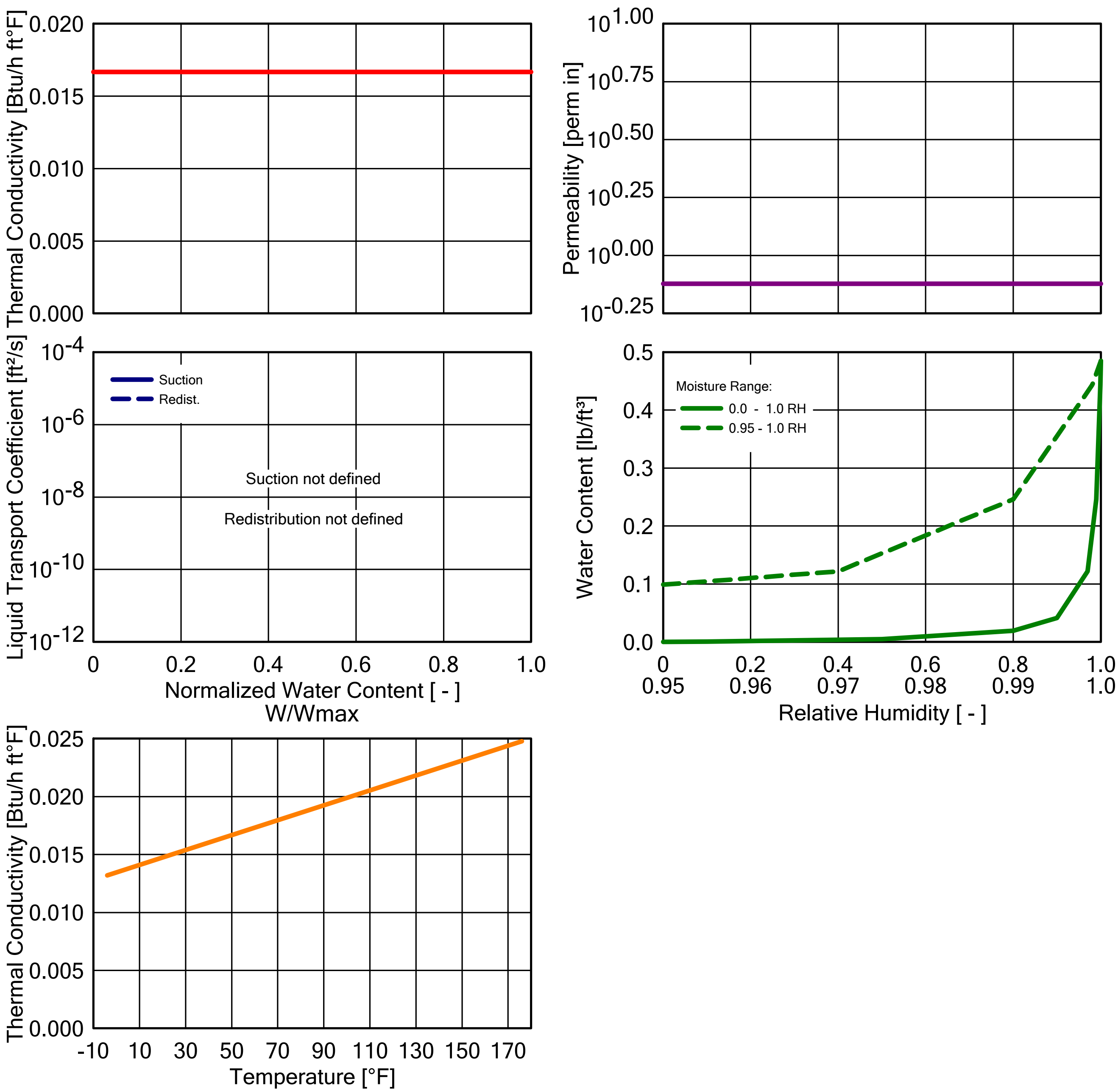
Property	Unit	Value
Bulk density	[lb/ft³]	8.11563
Porosity	[ft³/ft³]	0.001
Specific Heat Capacity, Dry	[Btu/lb°F]	0.549346
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	1.32892
Permeability	[perm in]	0.002576
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41988E-5



WUFI Pro 6.3

Material: *Extruded Polystyrene Insulation - XPS

Property	Unit	Value
Bulk density	[lb/ft³]	1.78544
Porosity	[ft³/ft³]	0.99
Specific Heat Capacity, Dry	[Btu/lb°F]	0.351103
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	1.6667E-2
Permeability	[perm in]	0.755159
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41988E-5
Thermal Conductivity, Design Value	[Btu/h ft°F]	0.0166667



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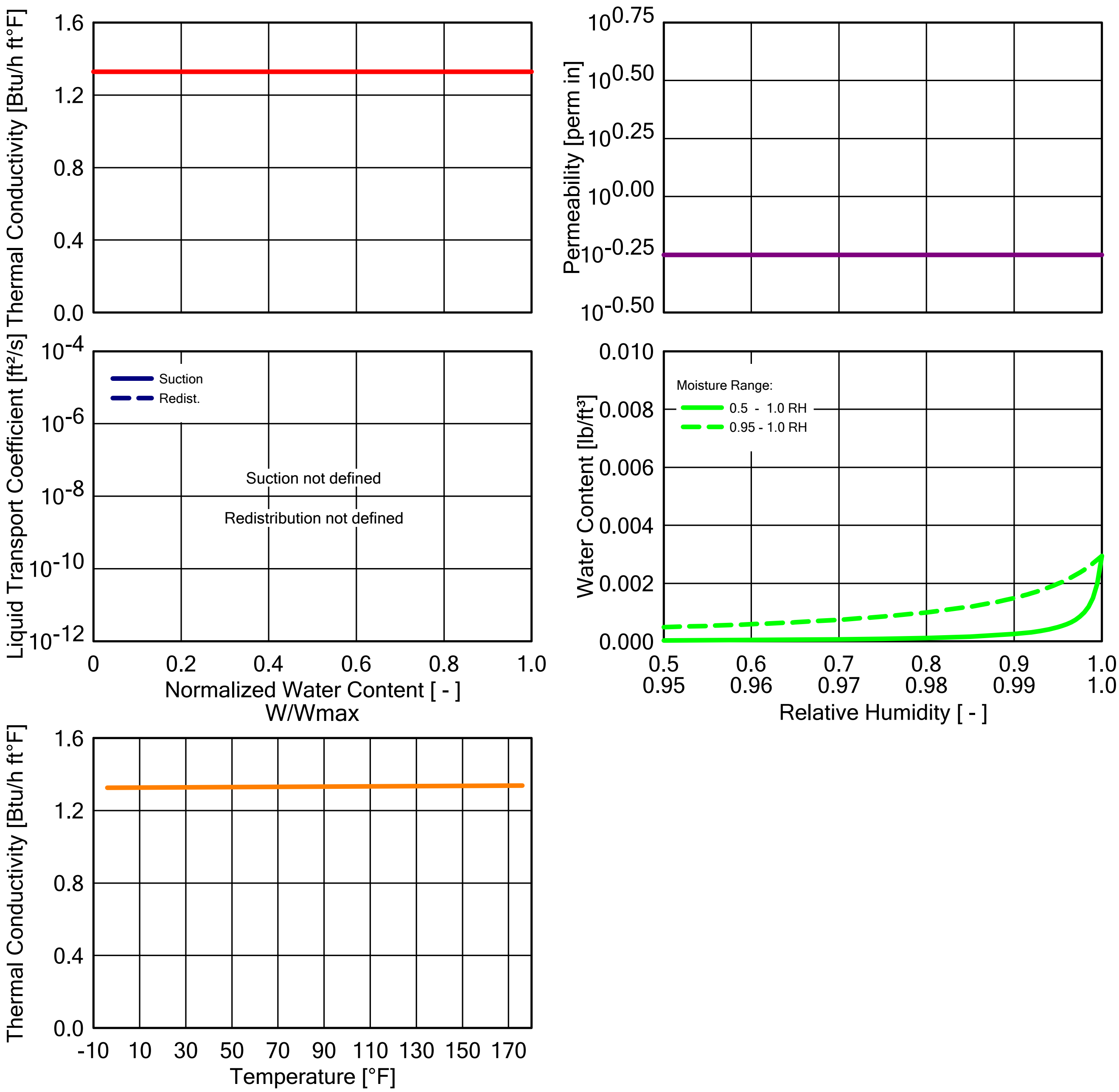
Material: *OSB-Integrated WRB (14 perm)

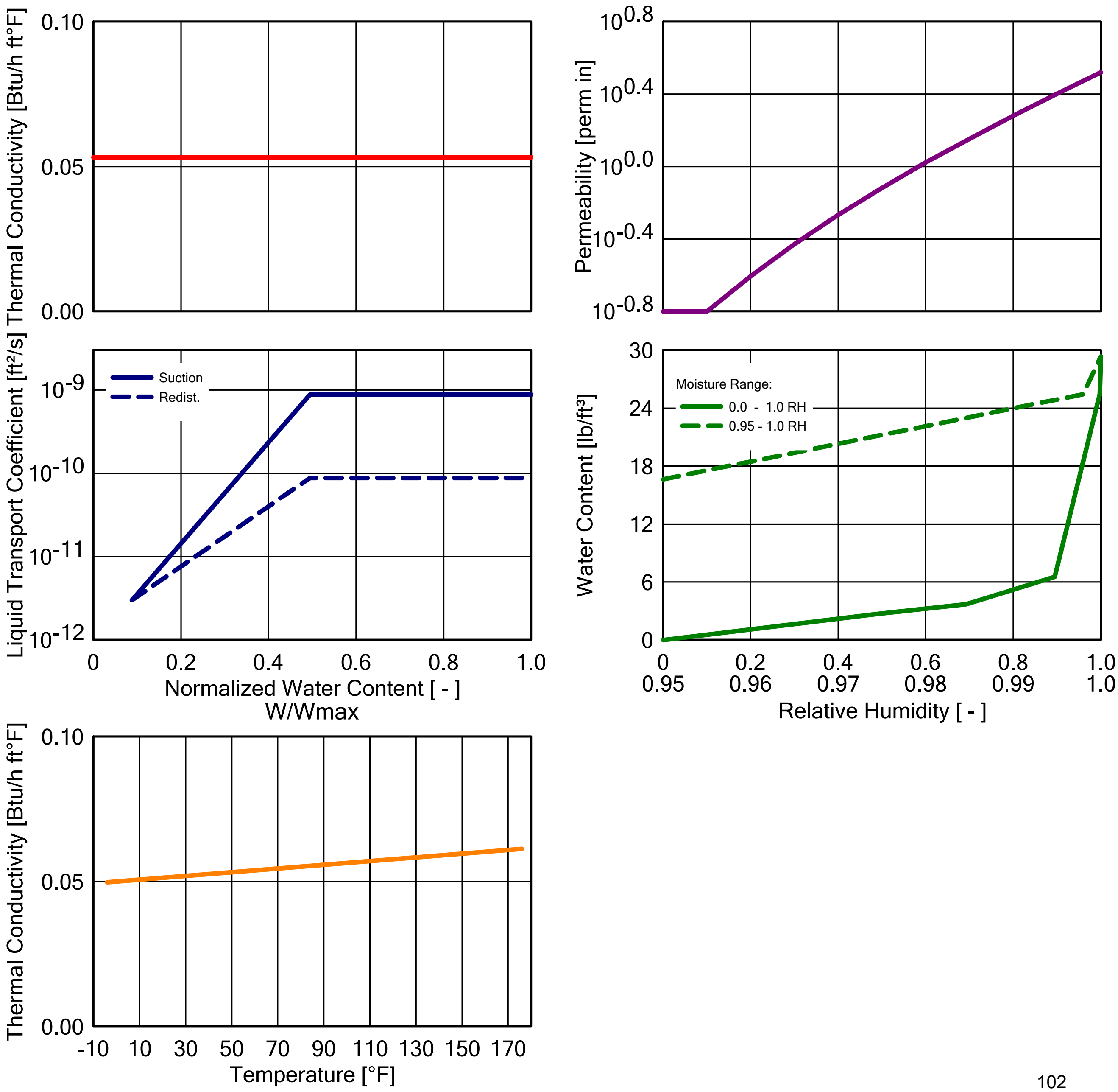
Property	Unit	Value
Bulk density	[lb/ft³]	8.11563
Porosity	[ft³/ft³]	0.001
Specific Heat Capacity, Dry	[Btu/lb°F]	0.549346
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	1.32892
Permeability	[perm in]	0.56
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41988E-5



WUFI Pro 6.3

Material: *ZIP Sheathing (inner)

Property	Unit	Value
Bulk density	[lb/ft³]	40.5782
Porosity	[ft³/ft³]	0.95
Specific Heat Capacity, Dry	[Btu/lb°F]	0.449
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.0532
Permeability	[perm in]	0.1585
Reference Water Content	[lb/ft³]	5.2003
Free Water Saturation	[lb/ft³]	29.3411
Water Absorption Coefficient	[lb/in²s^0.5]	0.0000031
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642



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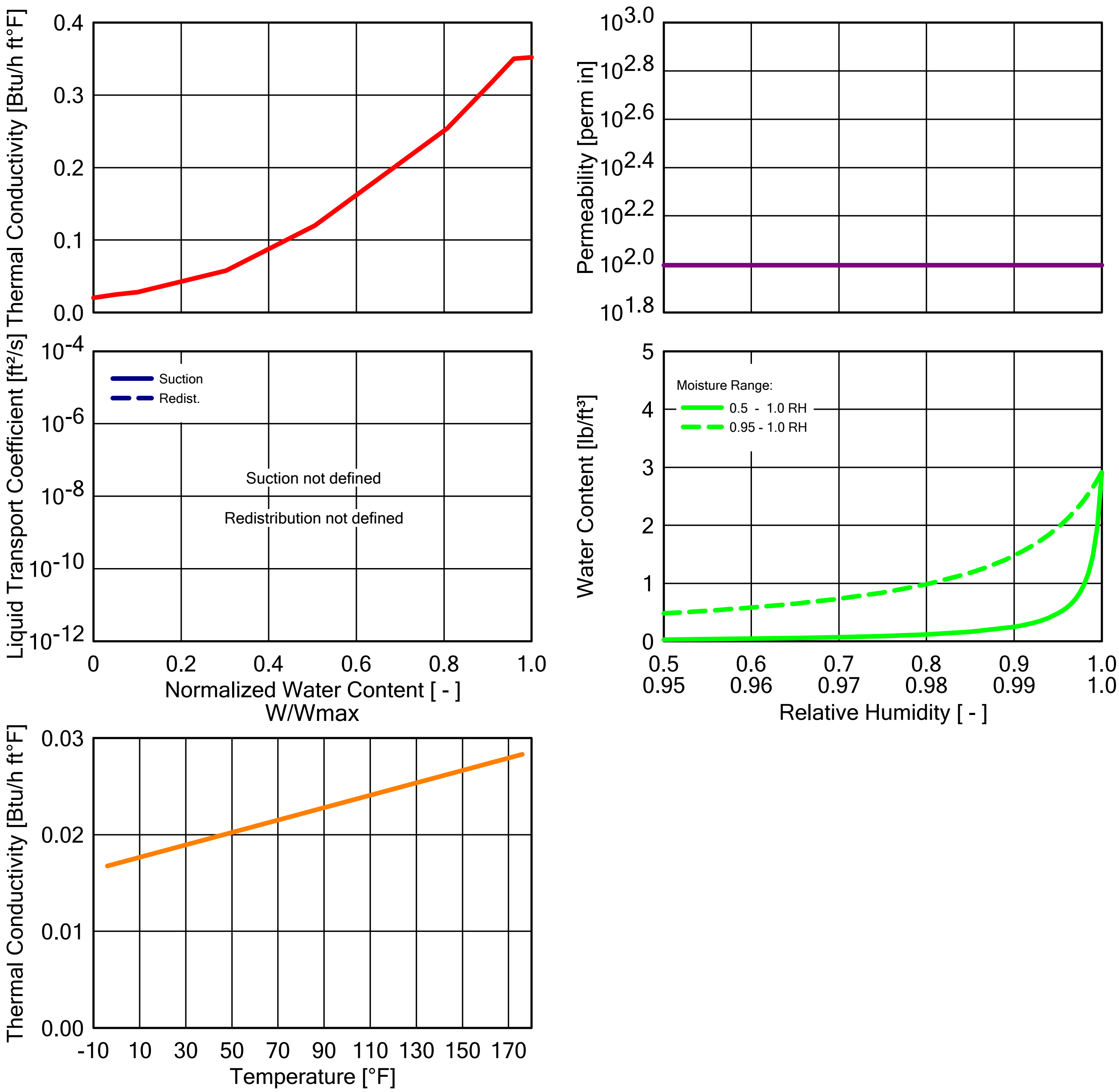
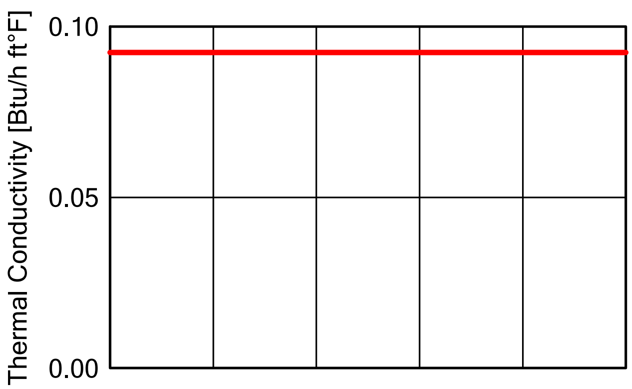
Material: Fiber Glass

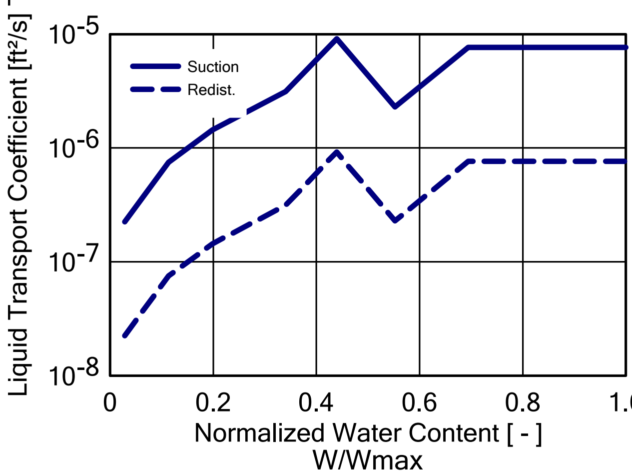
Property	Unit	Value
Bulk density	[lb/ft³]	1.9
Porosity	[ft³/ft³]	0.99
Specific Heat Capacity, Dry	[Btu/lb°F]	0.201
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.02022
Permeability	[perm in]	99
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41990E-5

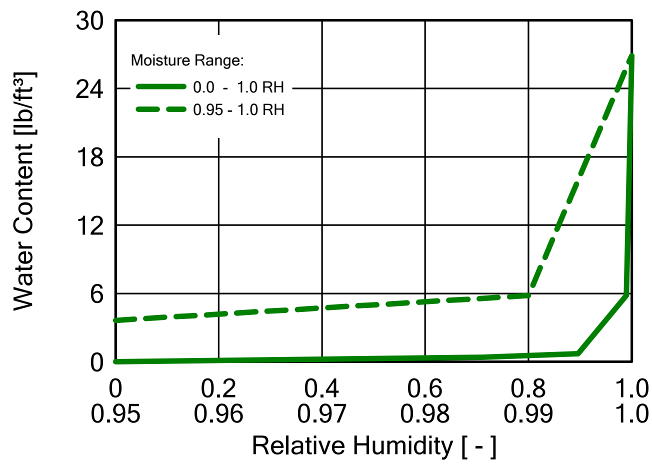


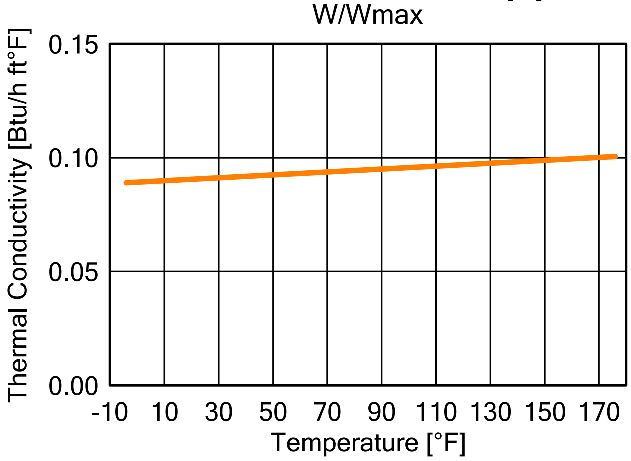
Material: Interior Gypsum Board

Property	Unit	Value
Bulk density	[lb/ft³]	39.0175
Porosity	[ft³/ft³]	0.706
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2078
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.0924
Permeability	[perm in]	18.3215
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642









Boundary Conditions

Exterior (Left Side)
Location: Boise, ID; ASHRAE Year 3
Temperature Shift: 0.0 °F
Orientation / Inclination: North / 90 °

Interior (Right Side)
Indoor Climate: EN 15026
Medium Moisture Load (EN/WTA)

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	Bright	[-]	0.2
Long-Wave Radiation Emissivity	Bright	[-]	----
Adhering Fraction of Rain	Depending on inclination o	[-]	0.7
Explicit Radiation Balance			no

Interior (Right Side)

Name	Description	Unit	Value
Heat Resistance	External Wall	[h ft² °F/Btu]	0.7098
Permeance	Latex paint 2	[perm]	4.69

Sources, Sinks

*1% DR Condensation Film

Name	Type		
1% ASHRAE160	*Moisture Source; Fraction of Rain Load*		
	Whole Layer		
	Cut-Off at Free Water Saturation	[lb/ft³]	
	User-Defined	[%]	1

Results from Last Calculation

Status of Calculation

Calculation: Time and Date	12/11/2016 12:45:08 PM
Computing Time	1 min,12 sec.
Begin / End of calculation	10/1/2017 / 10/1/2022
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[lb/ft²]	14.02 -14.59
Integral of fluxes, right side (kr,dr)	[lb/ft²]	1E-6 0.05
Balance 1	[lb/ft²]	-0.13
Balance 2	[lb/ft²]	-0.13

Water Content [lb/ft²]

	Start	End	Min.	Max.
Total Water Content	0.37	0.23	0.22	0.89

Water Content [lb/ft³]

Layer/Material	Start	End	Min.	Max.
Cement Board	2.73	0.81	0.32	21.00
*1% DR Condensation Film	0.21	0.06	0.03	12.04
vapour retarder (sd=50m)	0.00	0.00	0.00	0.00
*Extruded Polystyrene Insulation - XP	0.02	0.01	0.00	0.03
vapour retarder (sd=50m)	0.00	0.00	0.00	0.00
*OSB-Integrated WRB (14 perm)	0.00	0.00	0.00	0.00
*ZIP Sheathing (outer)	5.20	4.07	3.96	7.25
*ZIP Sheathing (core)	5.20	4.10	3.91	6.90
*ZIP Sheathing (inner)	5.20	4.09	3.63	8.63
Fiber Glass	0.12	0.05	0.04	0.12
Interior Gypsum Board	0.54	0.31	0.11	0.54

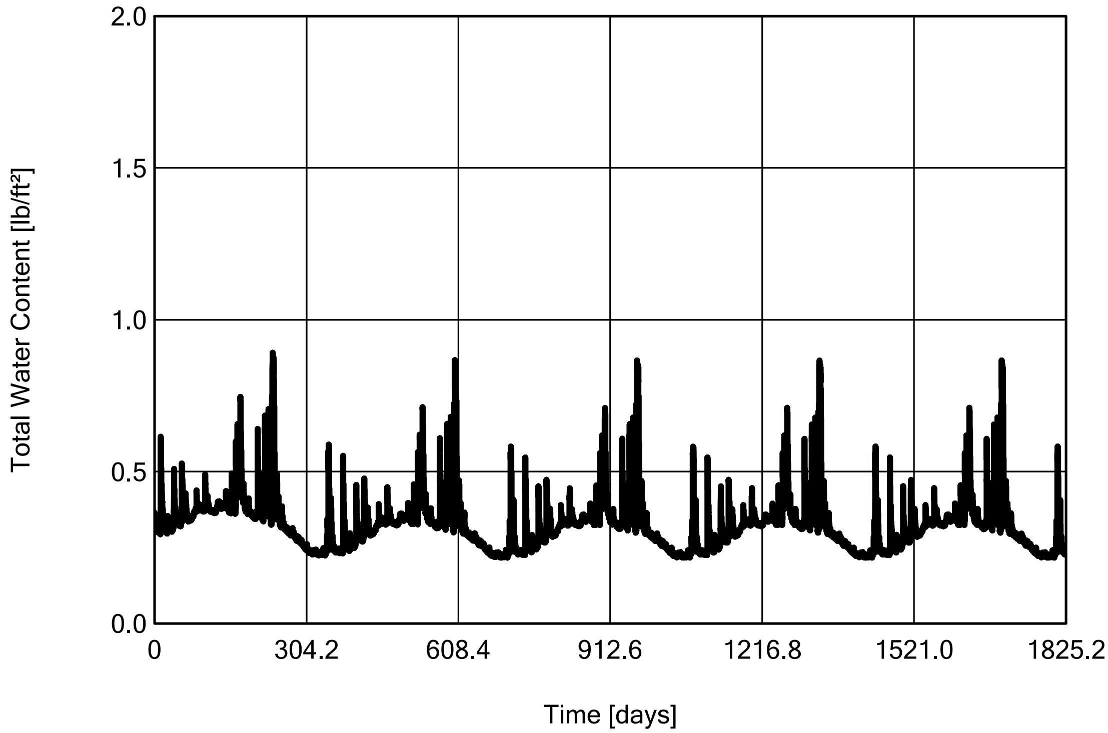
Time Integral of fluxes

Heat Flux, left side	[Btu/ft²]	-1.4E+0005
Heat Flux, right side	[Btu/ft²]	-28239.95
Moisture Fluxes, left side	[lb/ft²]	-0.57
Moisture Fluxes, right side	[lb/ft²]	0.05

Hygrothermal Sources

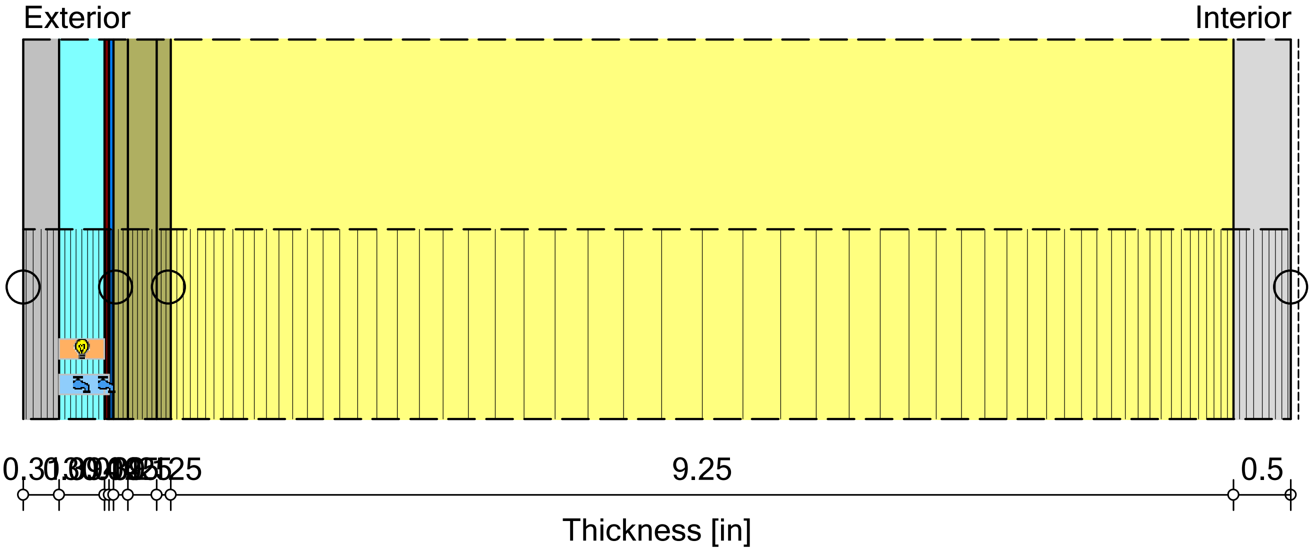
Heat Sources	[Btu/ft²]	0.0
Moisture Sources	[lb/ft²]	0.491
Unreleased Moisture Sources (due to cut-off)	[lb/ft²]	0.0
1% ASHRAE160 (Moisture Source)	[lb/ft²]	0.491

Total Water Content in Construction



Component Assembly

Case: DSW FC Rainscreen 1 perm: Boise CZ 5B



- Monitor positions

- Heat/Moisture source/sink positions

Materials:

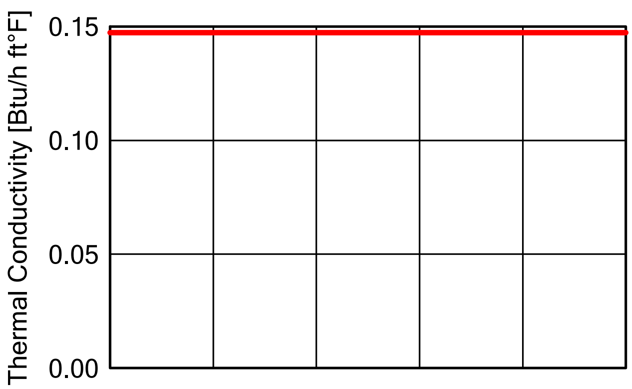
- Cement Board	0.313 in
- Air Layer 10 mm; without additional moisture capacity	0.394 in
- *1% DR Condensation Film	0.039 in
- *OSB-Integrated WRB (14 perm)	0.04 in
- *ZIP Sheathing (outer)	0.125 in
- *ZIP Sheathing (core)	0.25 in
- *ZIP Sheathing (inner)	0.125 in
- Fiber Glass	9.25 in
- Interior Gypsum Board	0.5 in

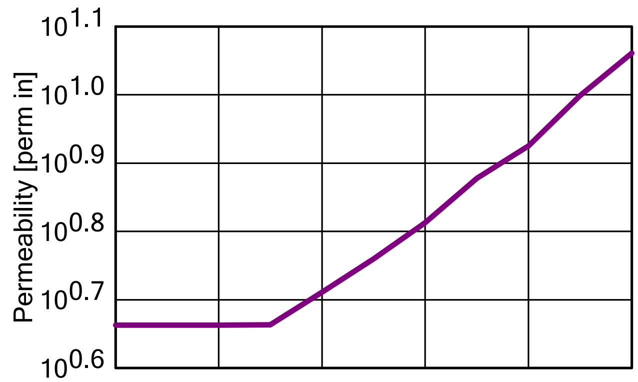
sd-Value Int. [perm]: 1

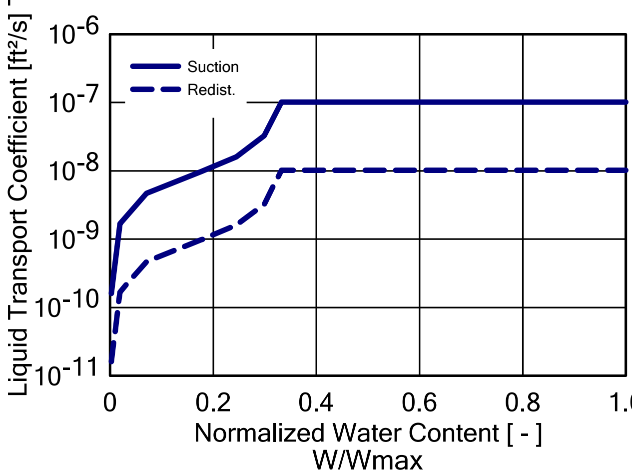
Total Thickness: 11.035 in
R-Value: 40.03 h ft² °F/Btu
U-Value: 0.024 Btu/h ft²°F

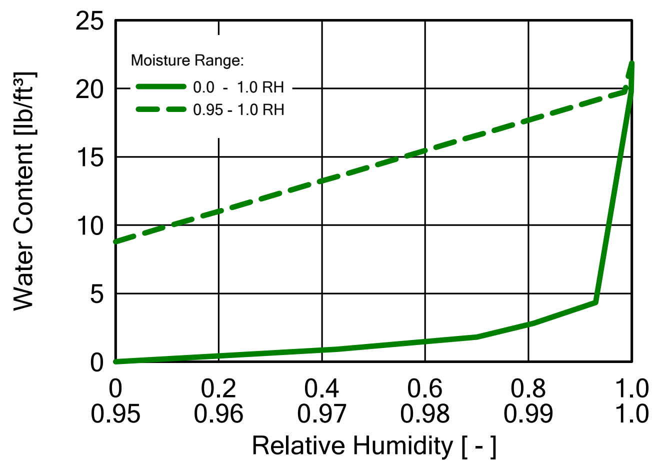
Material: Cement Board

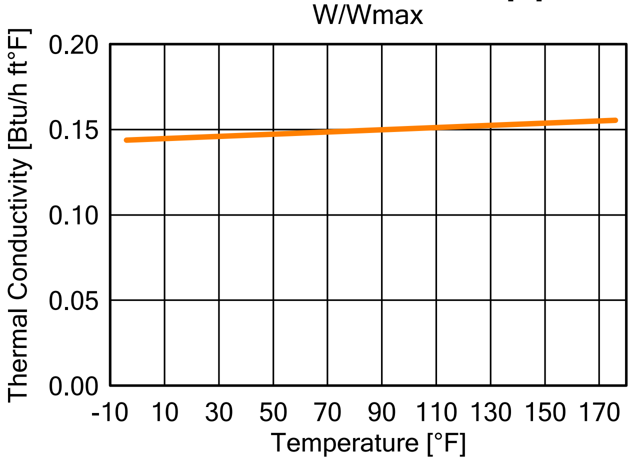
Property	Unit	Value
Bulk density	[lb/ft³]	70.5436
Porosity	[ft³/ft³]	0.48
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2006
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.1473
Permeability	[perm in]	4.6
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642





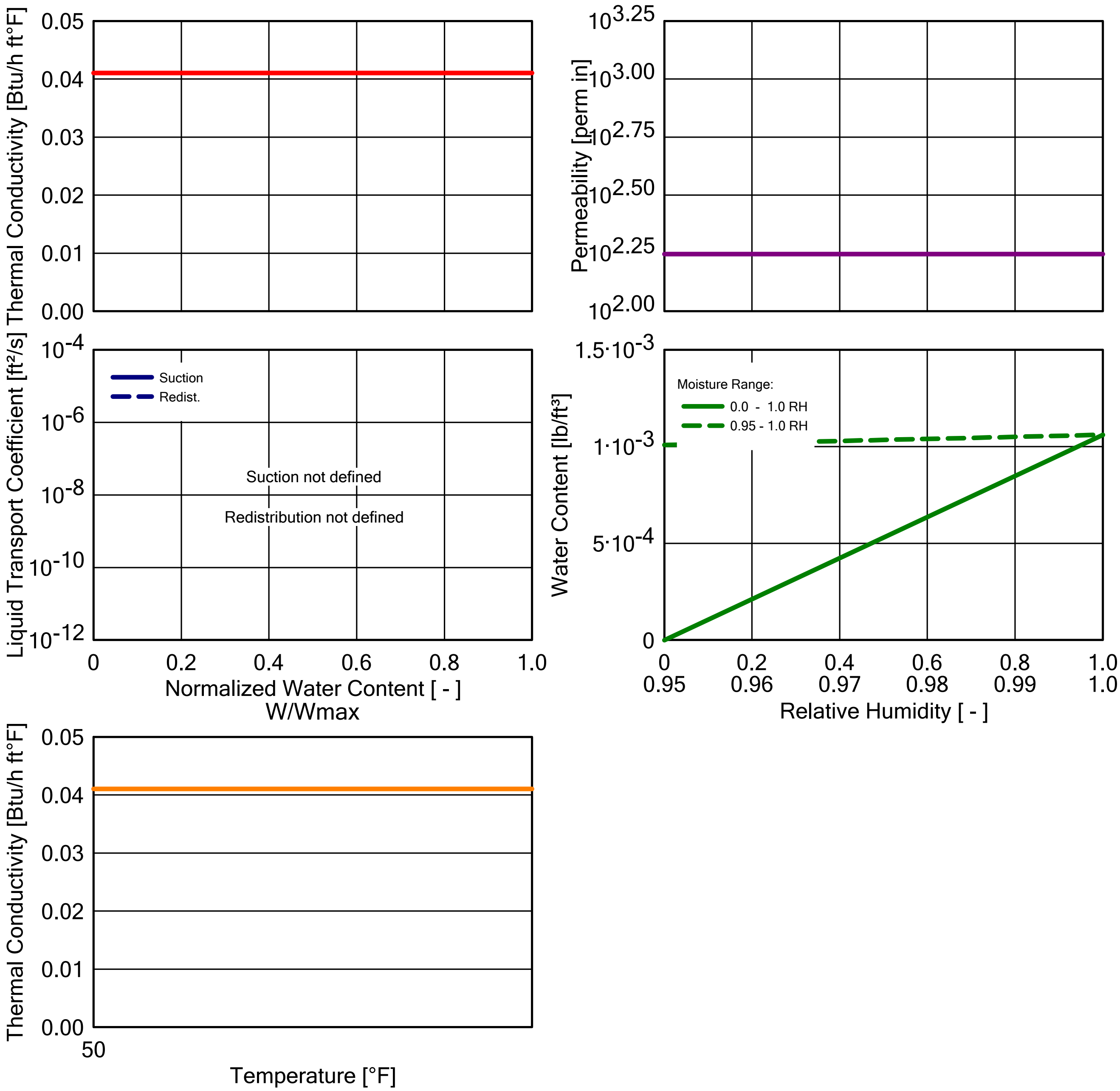






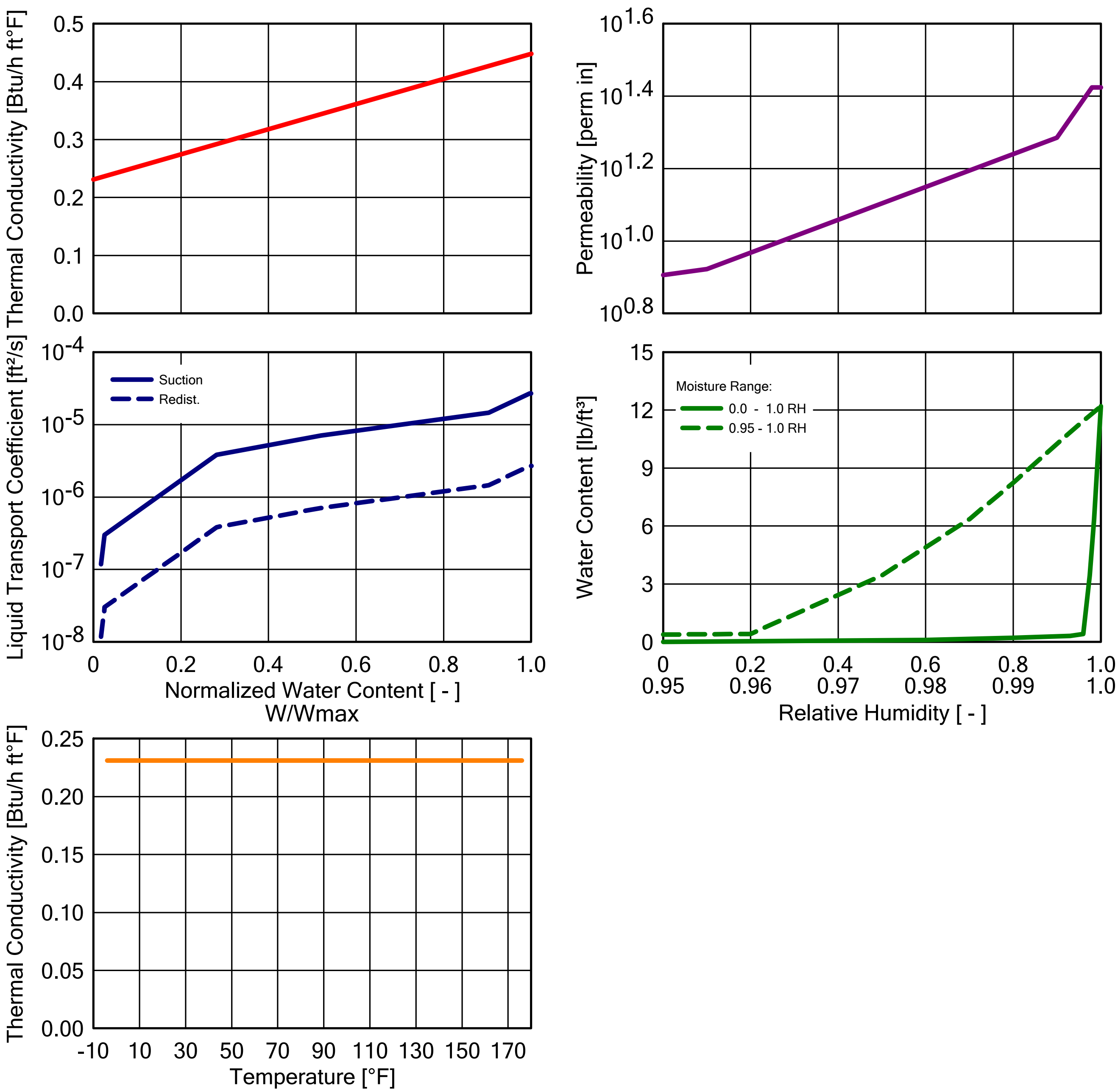
Material: Air Layer 10 mm; without additional moisture capacity

Property	Unit	Value
Bulk density	[lb/ft³]	0.0811563
Porosity	[ft³/ft³]	0.999
Specific Heat Capacity, Dry	[Btu/lb°F]	0.238846
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.041023
Permeability	[perm in]	176.438



Material: *1% DR Condensation Film

Property	Unit	Value
Bulk density	[lb/ft³]	104.2547
Porosity	[ft³/ft³]	0.196
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2006
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.2311
Permeability	[perm in]	8.05
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8.0
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0



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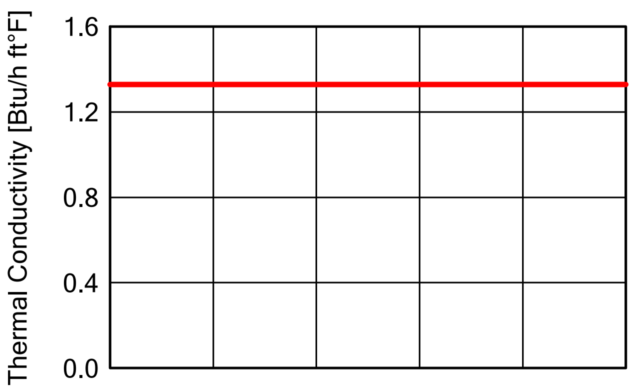
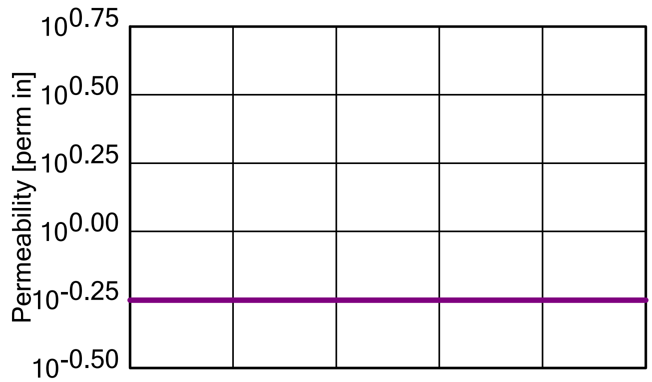
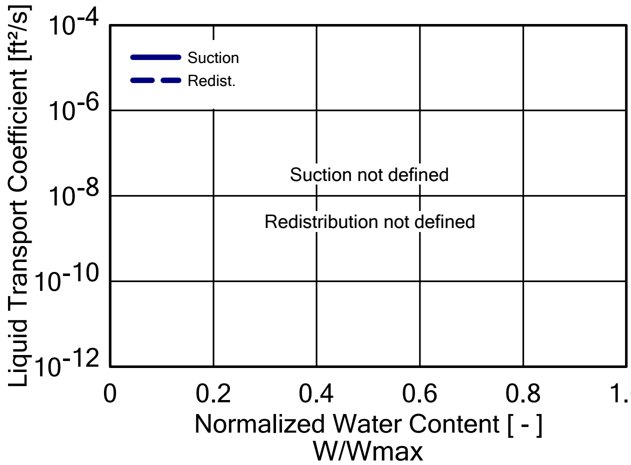
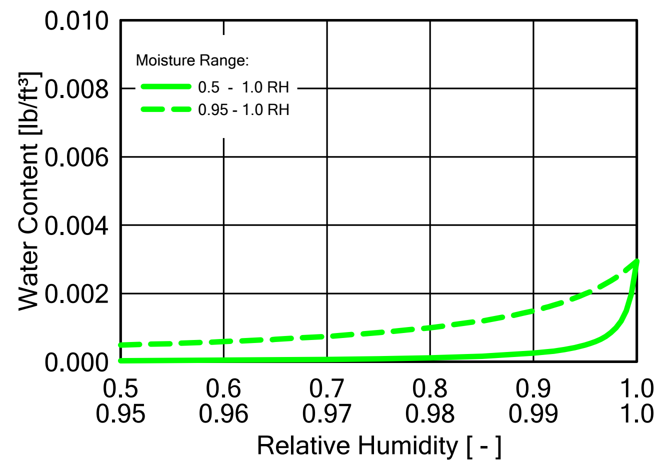
Material: *OSB-Integrated WRB (14 perm)

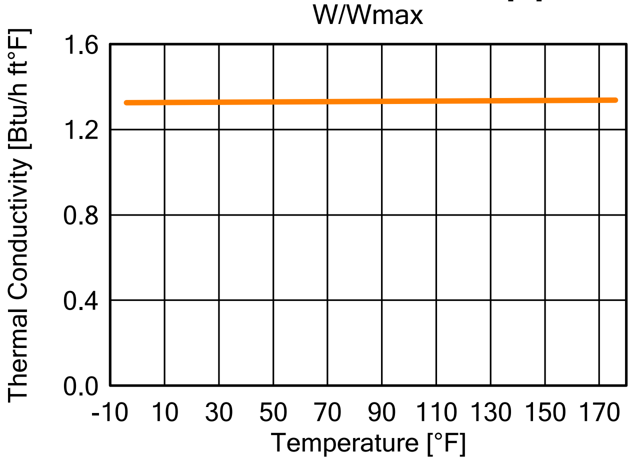
Property	Unit	Value
Bulk density	[lb/ft³]	8.11563
Porosity	[ft³/ft³]	0.001
Specific Heat Capacity, Dry	[Btu/lb°F]	0.549346
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	1.32892
Permeability	[perm in]	0.56
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41988E-5





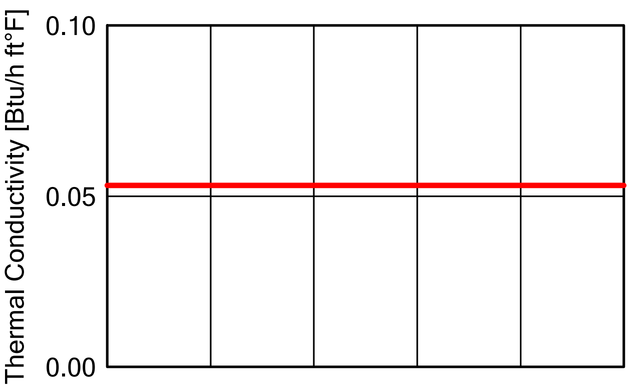


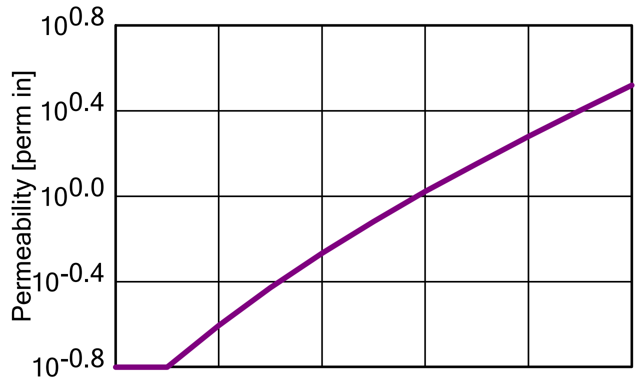


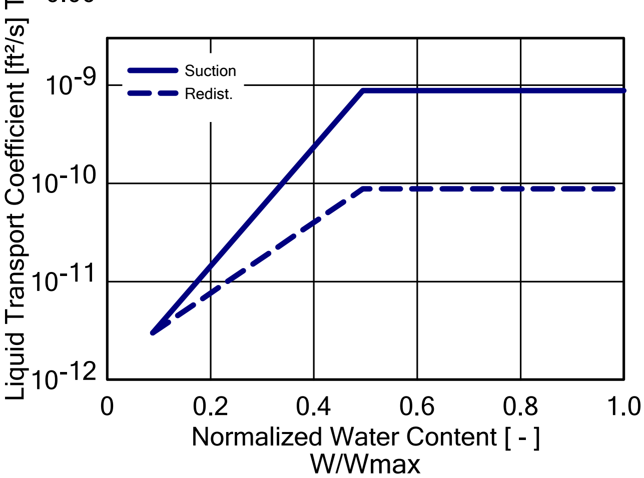


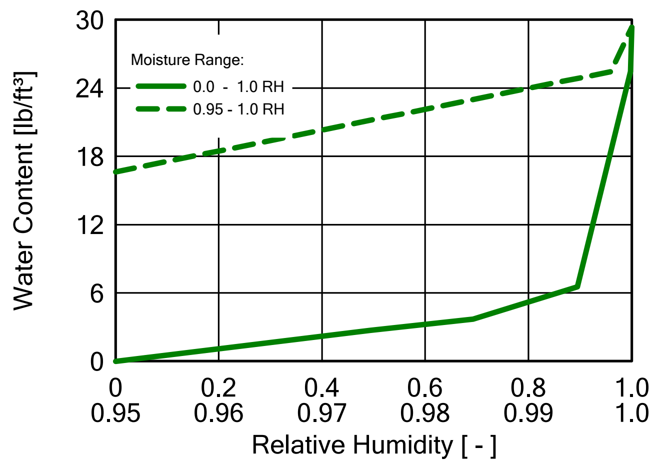
Material: *ZIP Sheathing (inner)

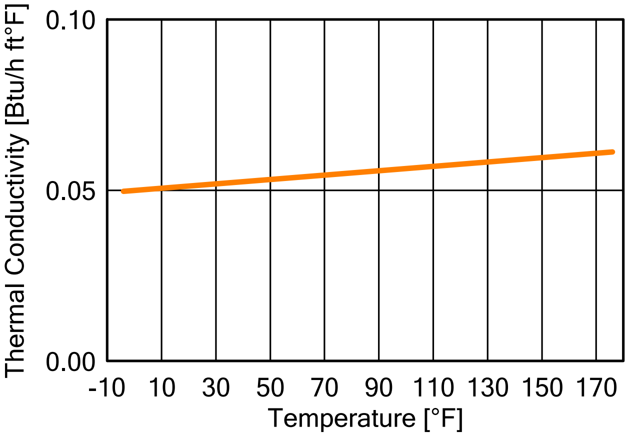
Property	Unit	Value
Bulk density	[lb/ft³]	40.5782
Porosity	[ft³/ft³]	0.95
Specific Heat Capacity, Dry	[Btu/lb°F]	0.449
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.0532
Permeability	[perm in]	0.1585
Reference Water Content	[lb/ft³]	5.2003
Free Water Saturation	[lb/ft³]	29.3411
Water Absorption Coefficient	[lb/in²s^0.5]	0.0000031
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642





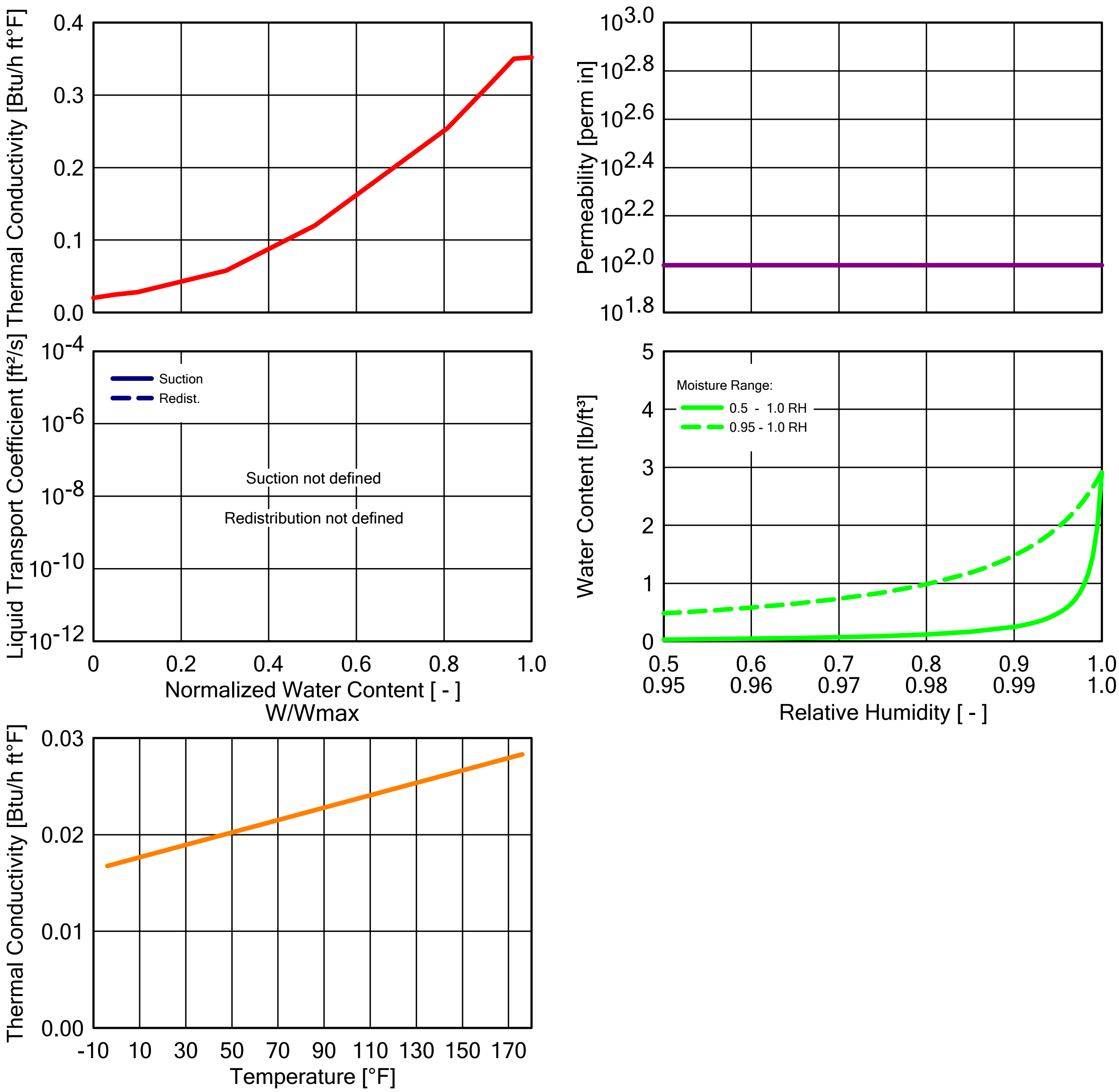






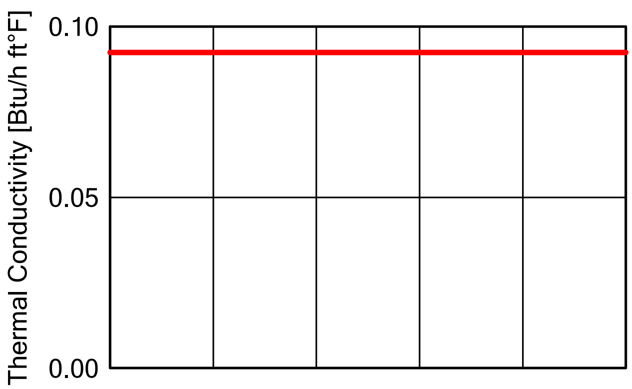
Material: Fiber Glass

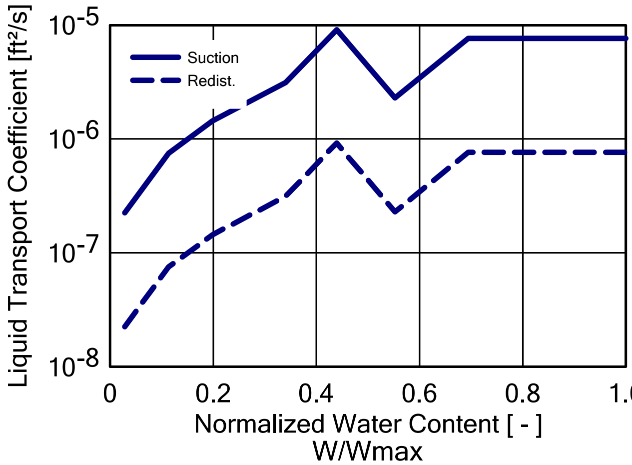
Property	Unit	Value
Bulk density	[lb/ft³]	1.9
Porosity	[ft³/ft³]	0.99
Specific Heat Capacity, Dry	[Btu/lb°F]	0.201
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.02022
Permeability	[perm in]	99
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41990E-5

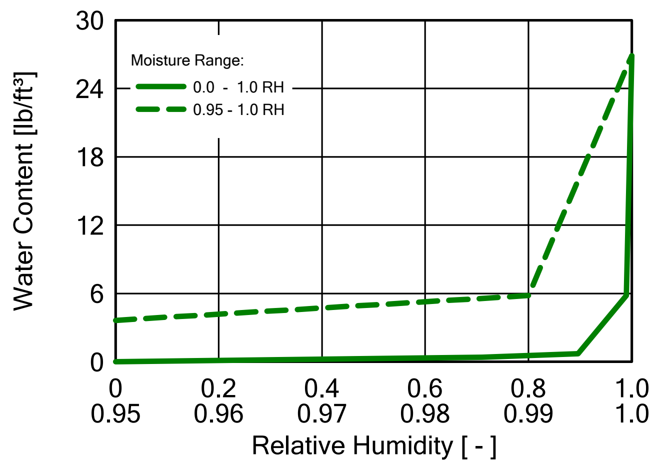


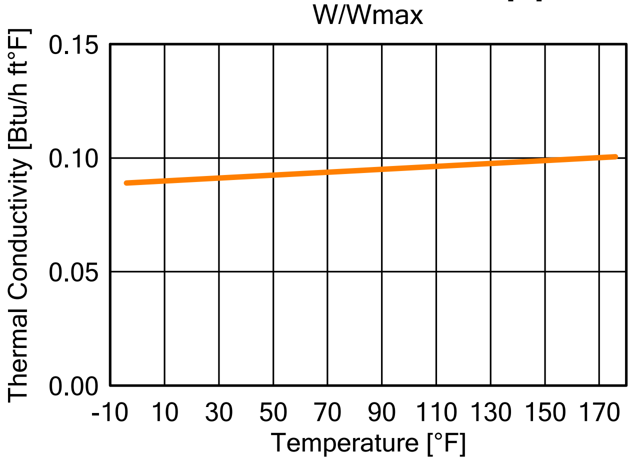
Material: Interior Gypsum Board

Property	Unit	Value
Bulk density	[lb/ft³]	39.0175
Porosity	[ft³/ft³]	0.706
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2078
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.0924
Permeability	[perm in]	18.3215
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642









Boundary Conditions

Exterior (Left Side)

Location: Boise, ID; ASHRAE Year 3
Temperature Shift: 0.0 °F
Orientation / Inclination: North / 90 °

Interior (Right Side)

Indoor Climate: EN 15026
Medium Moisture Load (EN/WTA)

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	Bright	[-]	0.2
Long-Wave Radiation Emissivity	Bright	[-]	----
Adhering Fraction of Rain	Depending on inclination o	[-]	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]	1

Sources, Sinks

Air Layer 10 mm; without additional moisture capacity

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

*1% DR Condensation Film

Name	Type		
1% ASHRAE160	*Moisture Source; Fraction of Rain Load*		
	Whole Layer		
	Cut-Off at Free Water Saturation	[lb/ft³]	
	User-Defined	[%]	1

Results from Last Calculation

Status of Calculation

Calculation: Time and Date	12/11/2016 12:46:23 PM
Computing Time	1 min,25 sec.
Begin / End of calculation	10/1/2017 / 10/1/2022
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[lb/ft²]	13.4 -12.91
Integral of fluxes, right side (kr,dr)	[lb/ft²]	6E-8 -0.53
Balance 1	[lb/ft²]	-0.21
Balance 2	[lb/ft²]	-0.22

Water Content [lb/ft²]

	Start	End	Min.	Max.
Total Water Content	0.4	0.19	0.14	0.79

Water Content [lb/ft³]

Layer/Material	Start	End	Min.	Max.
Cement Board	2.73	0.85	0.33	21.23
Air Layer 10 mm; without additional m	0.00	0.00	0.00	0.00
*1% DR Condensation Film	0.21	0.07	0.03	3.49
*OSB-Integrated WRB (14 perm)	0.00	0.00	0.00	0.00
*ZIP Sheathing (outer)	5.20	2.80	1.73	5.99
*ZIP Sheathing (core)	5.20	3.16	2.28	5.81
*ZIP Sheathing (inner)	5.20	3.22	2.55	6.99
Fiber Glass	0.12	0.03	0.03	0.12
Interior Gypsum Board	0.54	0.25	0.07	0.54

Time Integral of fluxes

Heat Flux, left side	[Btu/ft²]	-1.4E+0005
Heat Flux, right side	[Btu/ft²]	-20656.51
Moisture Fluxes, left side	[lb/ft²]	0.51
Moisture Fluxes, right side	[lb/ft²]	-0.53

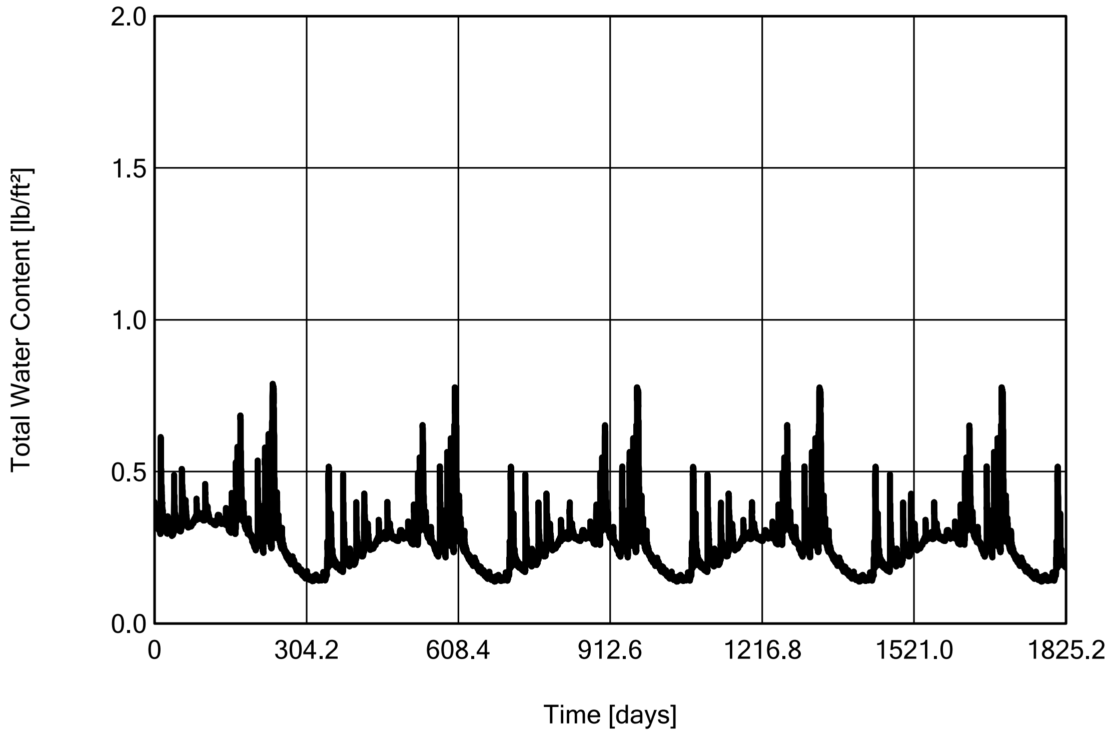
Hygrothermal Sources

Heat Sources	[Btu/ft²]	-736.69

Hygrothermal Sources (Continue)

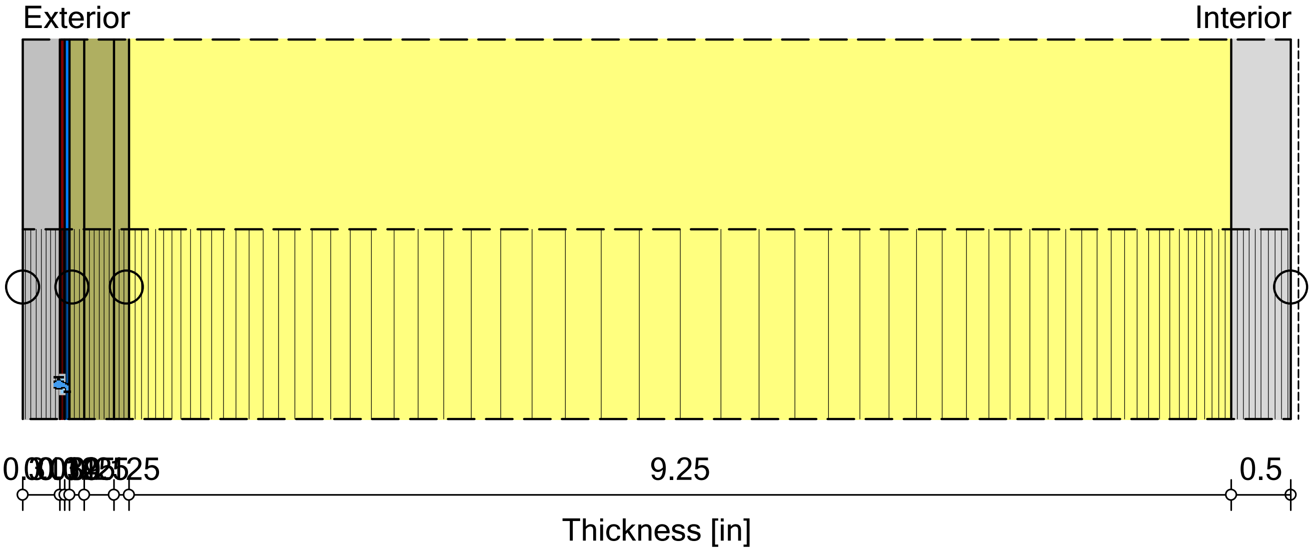
20ACH (Air Change Source)	[Btu/ft²]	-736.69
Moisture Sources	[lb/ft²]	-1.242
Unreleased Moisture Sources (due to cut-off)	[lb/ft²]	-0.003
20ACH (Air Change Source)	[lb/ft²]	-1.733
1% ASHRAE160 (Moisture Source)	[lb/ft²]	0.491

Total Water Content in Construction



Component Assembly

Case: DSW FC 1 perm: Boise CZ 5B



- Monitor positions

- Heat/Moisture source/sink positions

Materials:

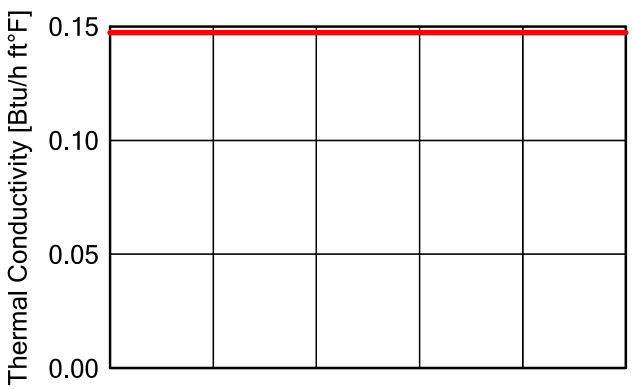
	- Cement Board	0.313 in
	- *1% DR Condensation Film	0.039 in
	- *OSB-Integrated WRB (14 perm)	0.04 in
	- *ZIP Sheathing (outer)	0.125 in
	- *ZIP Sheathing (core)	0.25 in
	- *ZIP Sheathing (inner)	0.125 in
	- Fiber Glass	9.25 in
	- Interior Gypsum Board	0.5 in

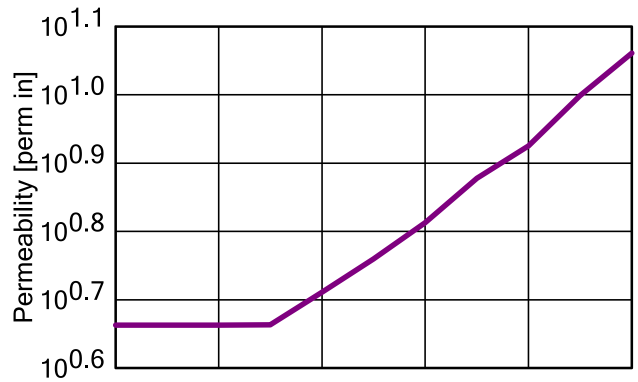
sd-Value Int. [perm]: 1

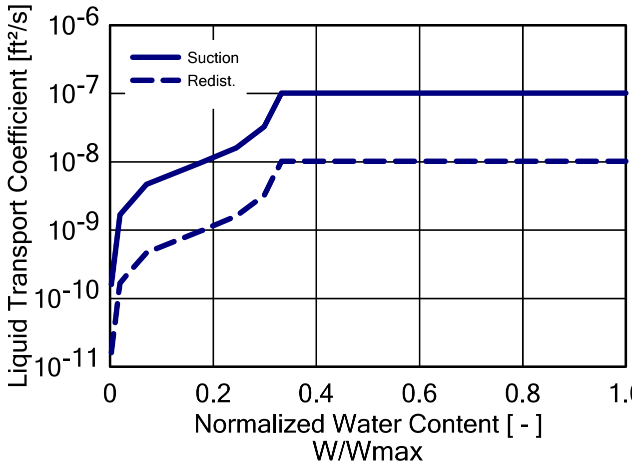
Total Thickness: 10.642 in
R-Value: 39.23 h ft² °F/Btu
U-Value: 0.025 Btu/h ft²°F

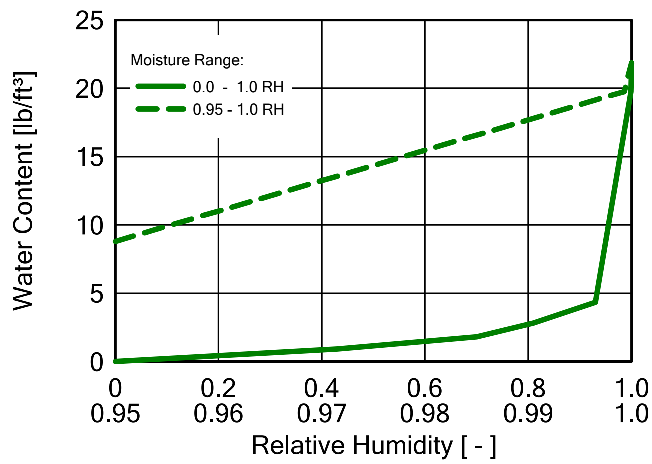
Material: Cement Board

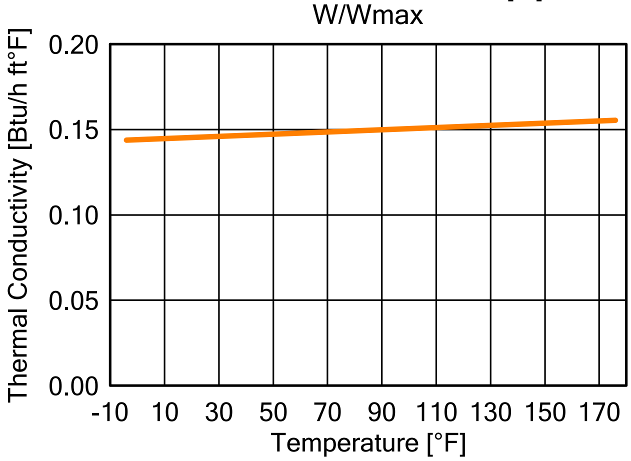
Property	Unit	Value
Bulk density	[lb/ft³]	70.5436
Porosity	[ft³/ft³]	0.48
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2006
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.1473
Permeability	[perm in]	4.6
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642





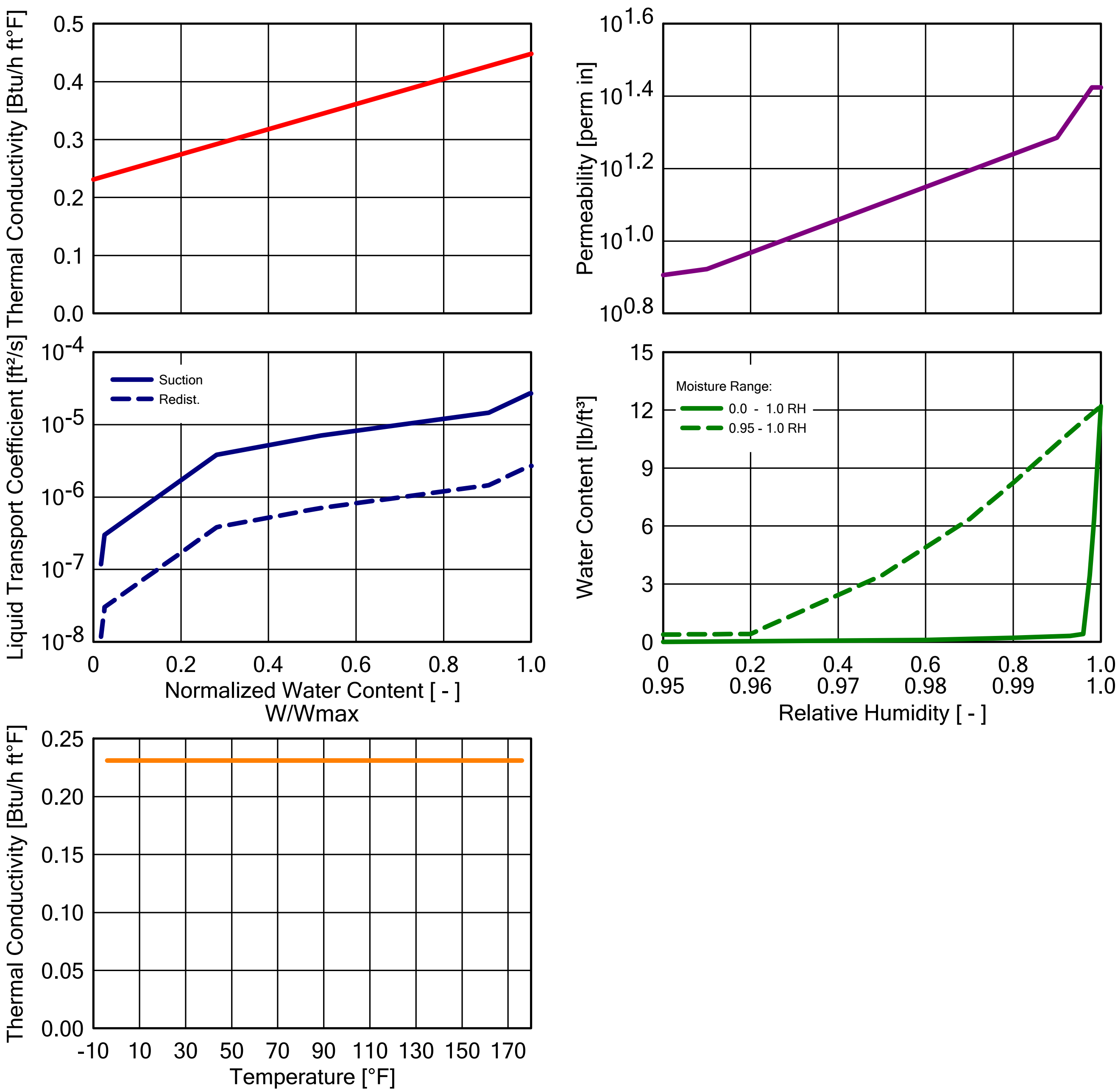






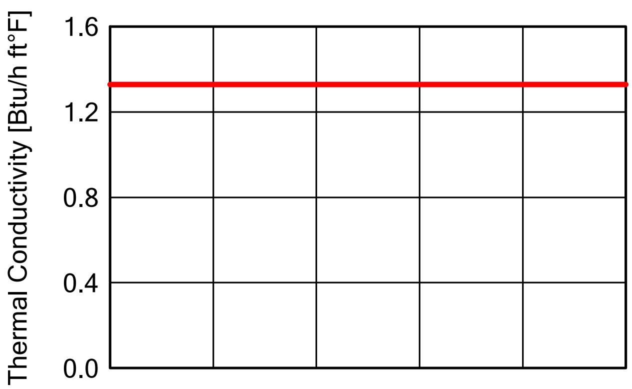
Material: *1% DR Condensation Film

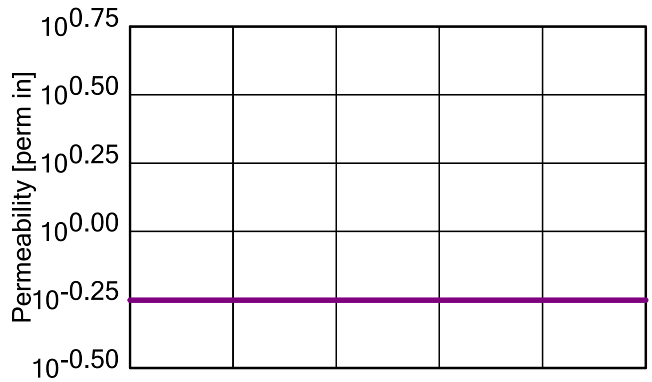
Property	Unit	Value
Bulk density	[lb/ft³]	104.2547
Porosity	[ft³/ft³]	0.196
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2006
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.2311
Permeability	[perm in]	8.05
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8.0
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0

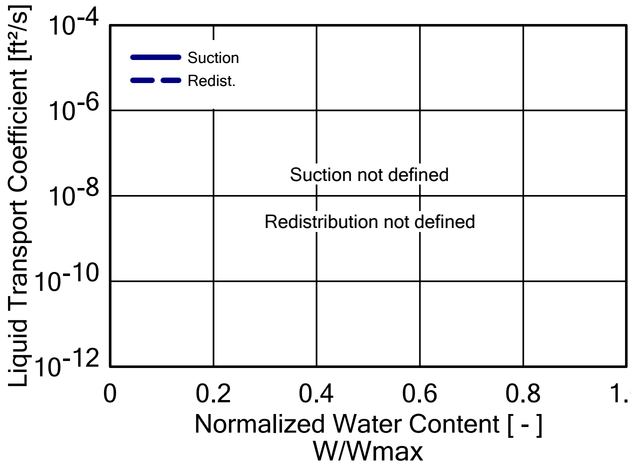


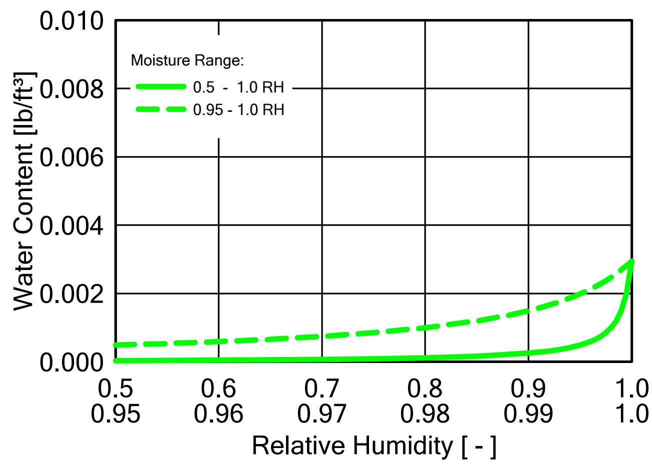
Material: *OSB-Integrated WRB (14 perm)

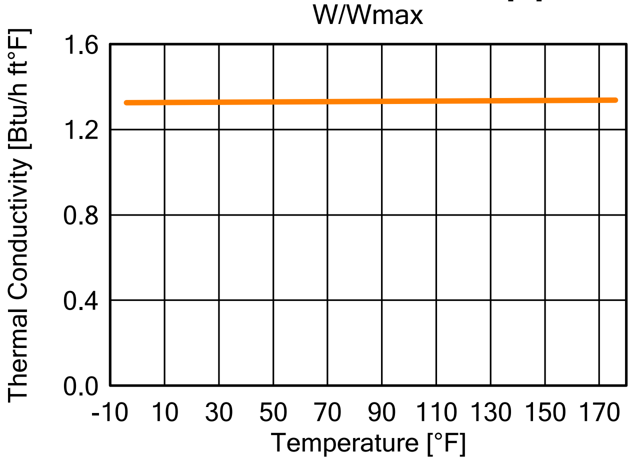
Property	Unit	Value
Bulk density	[lb/ft³]	8.11563
Porosity	[ft³/ft³]	0.001
Specific Heat Capacity, Dry	[Btu/lb°F]	0.549346
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	1.32892
Permeability	[perm in]	0.56
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41988E-5





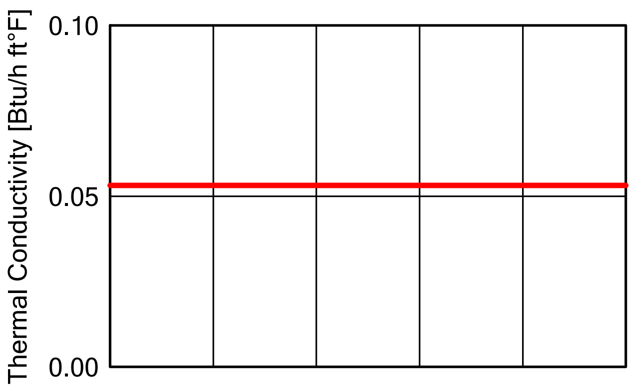


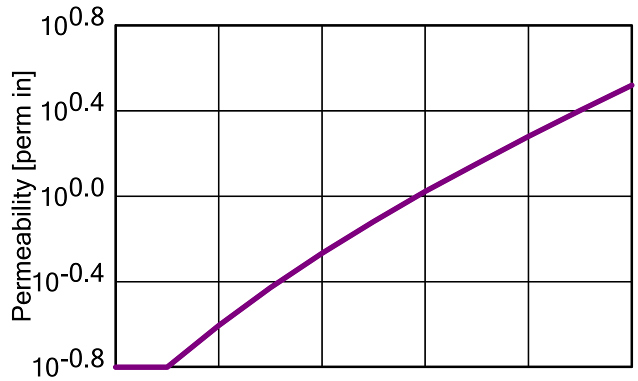


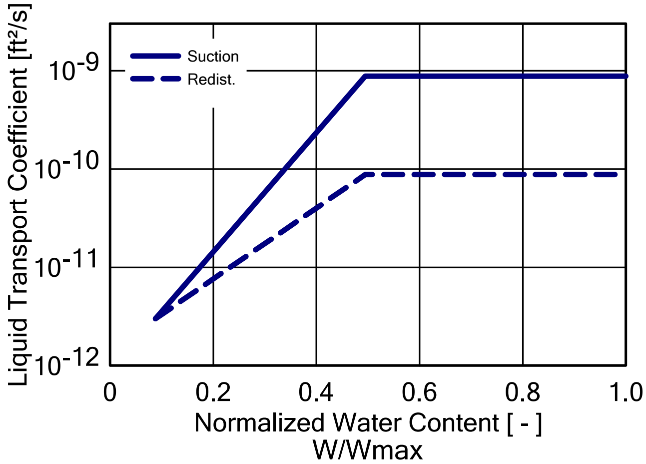


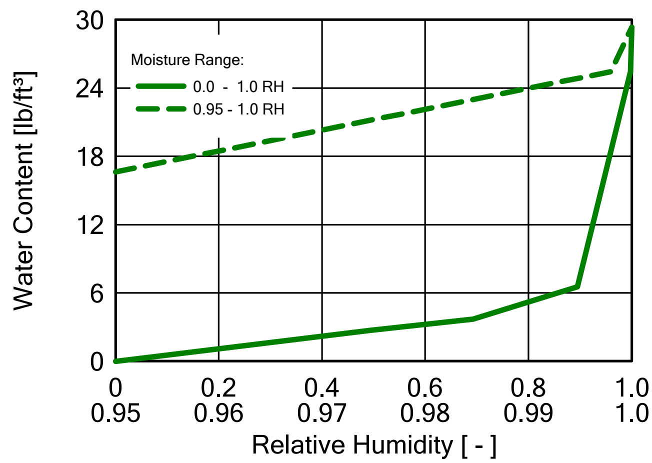
Material: *ZIP Sheathing (inner)

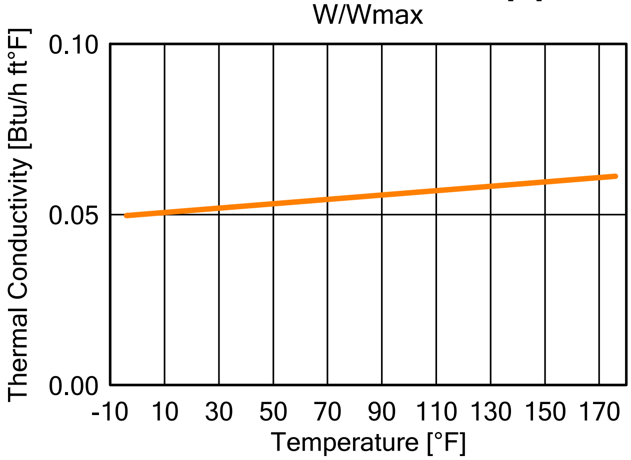
Property	Unit	Value
Bulk density	[lb/ft³]	40.5782
Porosity	[ft³/ft³]	0.95
Specific Heat Capacity, Dry	[Btu/lb°F]	0.449
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.0532
Permeability	[perm in]	0.1585
Reference Water Content	[lb/ft³]	5.2003
Free Water Saturation	[lb/ft³]	29.3411
Water Absorption Coefficient	[lb/in²s^0.5]	0.0000031
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642





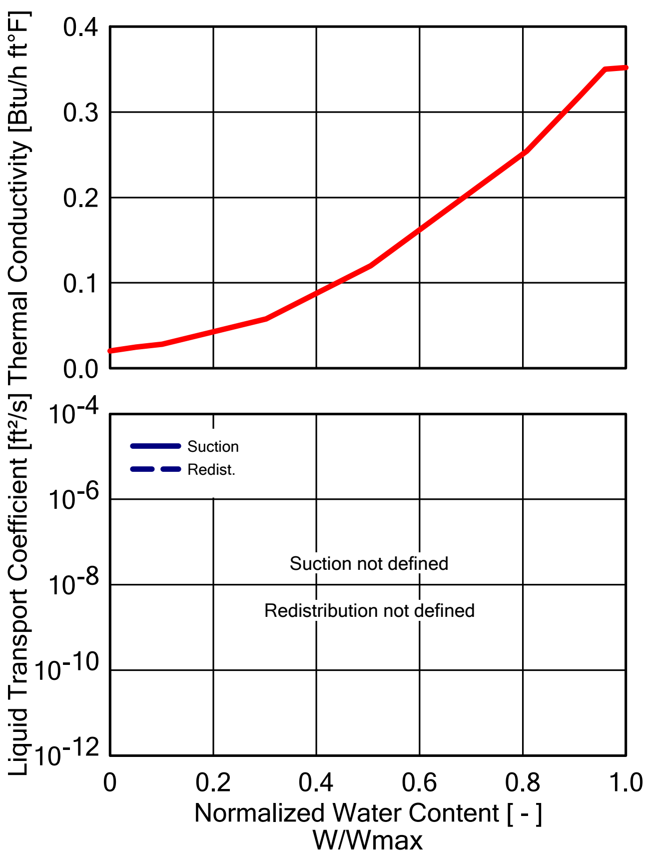


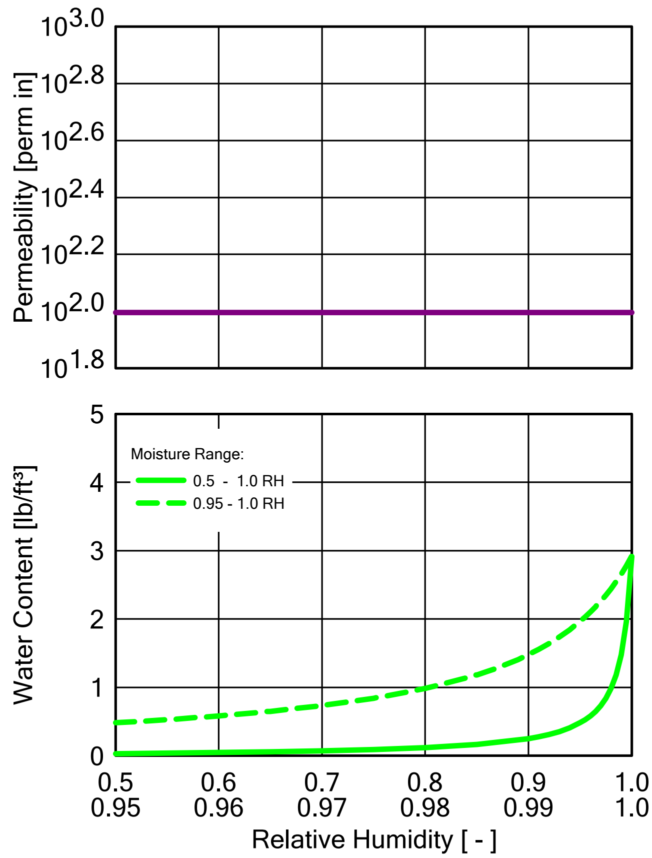


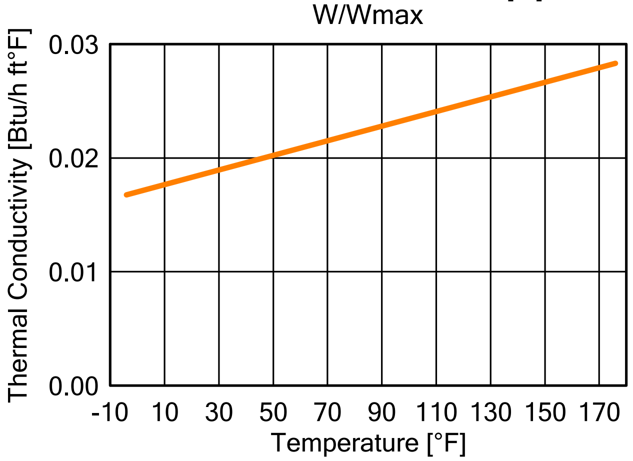


Material: Fiber Glass

Property	Unit	Value
Bulk density	[lb/ft³]	1.9
Porosity	[ft³/ft³]	0.99
Specific Heat Capacity, Dry	[Btu/lb°F]	0.201
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.02022
Permeability	[perm in]	99
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41990E-5

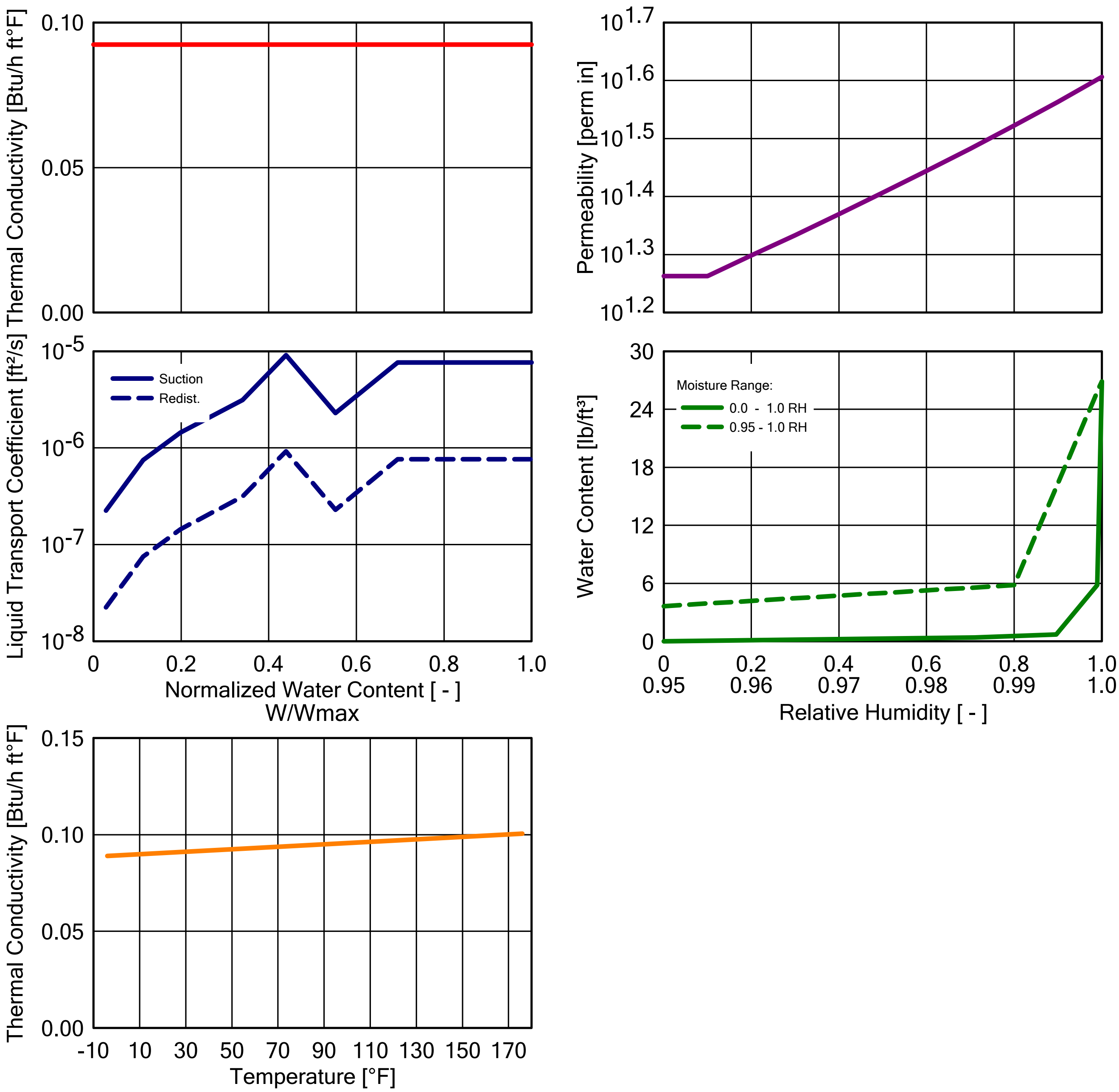






Material: Interior Gypsum Board

Property	Unit	Value
Bulk density	[lb/ft³]	39.0175
Porosity	[ft³/ft³]	0.706
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2078
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.0924
Permeability	[perm in]	18.3215
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642



Boundary Conditions

Exterior (Left Side)

Location: Boise, ID; ASHRAE Year 3
Temperature Shift: 0.0 °F
Orientation / Inclination: North / 90 °

Interior (Right Side)

Indoor Climate: EN 15026
Medium Moisture Load (EN/WTA)

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	Bright	[-]	0.2
Long-Wave Radiation Emissivity	Bright	[-]	----
Adhering Fraction of Rain	Depending on inclination o	[-]	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]	1

Sources, Sinks

*1% DR Condensation Film

Name	Type		
1% ASHRAE160	*Moisture Source; Fraction of Rain Load*		
	Whole Layer		
	Cut-Off at Free Water Saturation	[lb/ft³]	
	User-Defined	[%]	1

Results from Last Calculation

Status of Calculation

Calculation: Time and Date	12/11/2016 12:47:51 PM
Computing Time	1 min,13 sec.
Begin / End of calculation	10/1/2017 / 10/1/2022
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[lb/ft²]	13.75 -14.94
Integral of fluxes, right side (kr,dr)	[lb/ft²]	7.4E-8 -0.5
Balance 1	[lb/ft²]	-0.2
Balance 2	[lb/ft²]	-0.21

Water Content [lb/ft²]

	Start	End	Min.	Max.
Total Water Content	0.4	0.19	0.14	0.83

Water Content [lb/ft³]

Layer/Material	Start	End	Min.	Max.
Cement Board	2.73	0.87	0.36	20.97
*1% DR Condensation Film	0.21	0.07	0.03	12.03
*OSB-Integrated WRB (14 perm)	0.00	0.00	0.00	0.00
*ZIP Sheathing (outer)	5.20	2.91	1.77	6.29
*ZIP Sheathing (core)	5.20	3.25	2.31	6.03
*ZIP Sheathing (inner)	5.20	3.28	2.55	7.33
Fiber Glass	0.12	0.03	0.03	0.12
Interior Gypsum Board	0.54	0.25	0.07	0.54

Time Integral of fluxes

Heat Flux, left side	[Btu/ft²]	-1.4E+0005
Heat Flux, right side	[Btu/ft²]	-21050.96
Moisture Fluxes, left side	[lb/ft²]	-1.2
Moisture Fluxes, right side	[lb/ft²]	-0.5

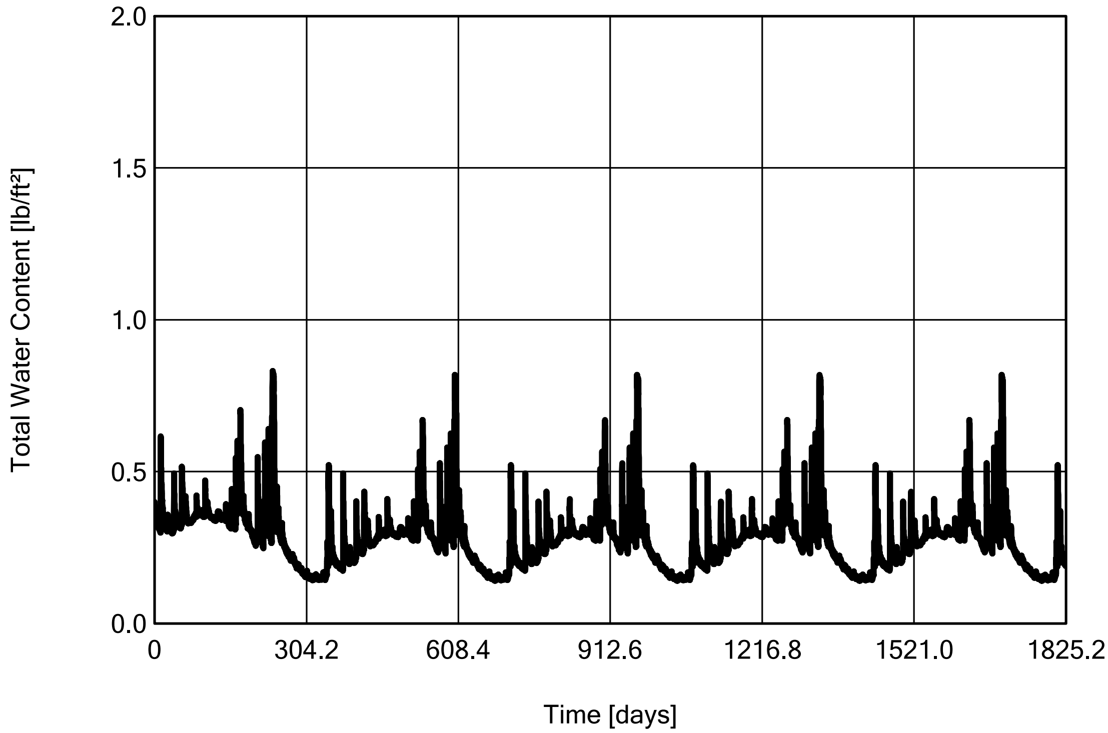
Hygrothermal Sources

Heat Sources	[Btu/ft²]	0.0
Moisture Sources	[lb/ft²]	0.491

Hygrothermal Sources (Continue)

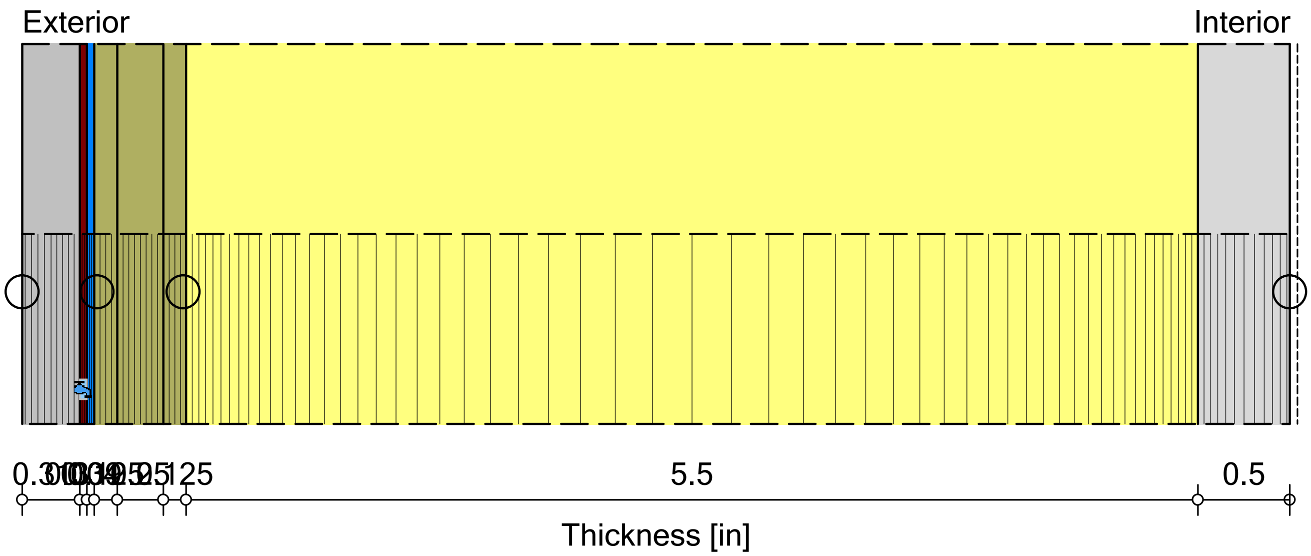
Unreleased Moisture Sources (due to cut-off)	[lb/ft²]	0.0
1% ASHRAE160 (Moisture Source)	[lb/ft²]	0.491

Total Water Content in Construction



Component Assembly

Case: 2x6 FC 1 perm: Boise CZ 5B



○ - Monitor positions

- Heat/Moisture source/sink positions

Materials:

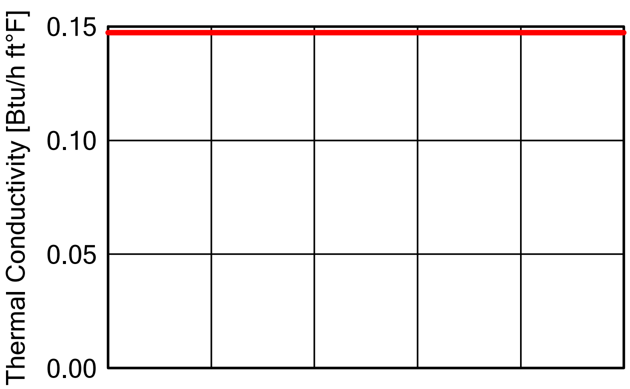
	- Cement Board	0.313 in
	- *1% DR Condensation Film	0.039 in
	- *OSB-Integrated WRB (14 perm)	0.04 in
	- *ZIP Sheathing (outer)	0.125 in
	- *ZIP Sheathing (core)	0.25 in
	- *ZIP Sheathing (inner)	0.125 in
	- Fiber Glass	5.5 in
	- Interior Gypsum Board	0.5 in

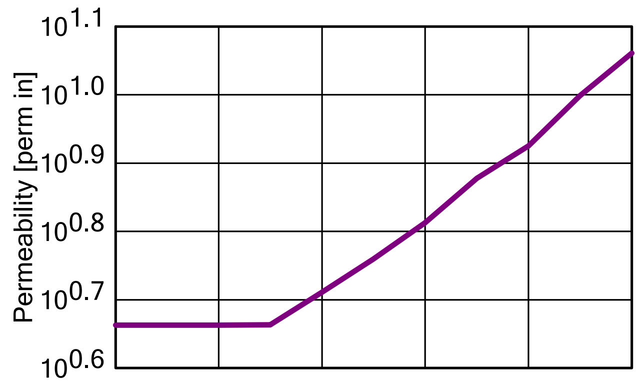
sd-Value Int. [perm]: 1

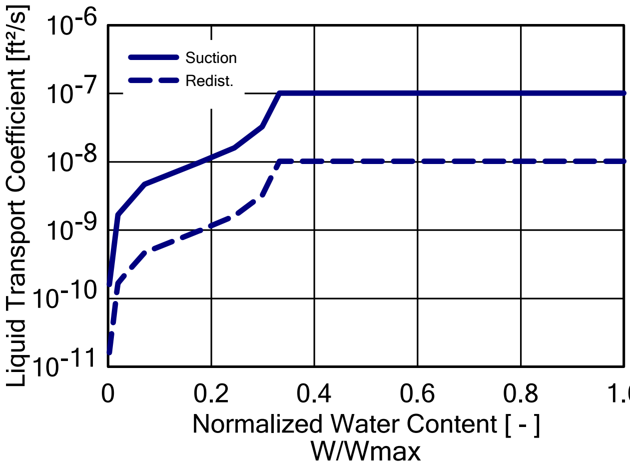
Total Thickness: 6.892 in
R-Value: 23.9 h ft² °F/Btu
U-Value: 0.04 Btu/h ft²°F

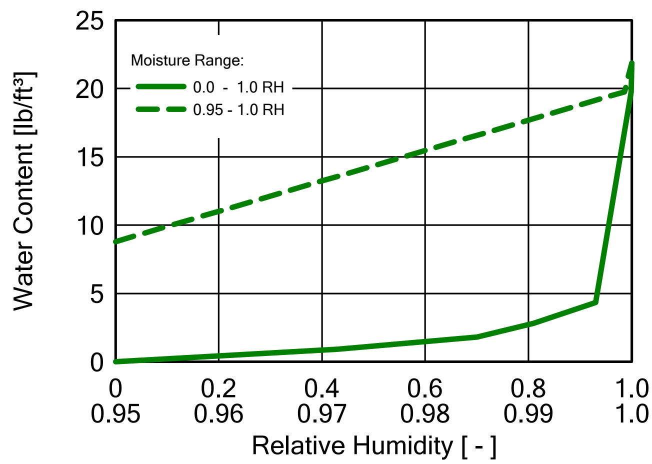
Material: Cement Board

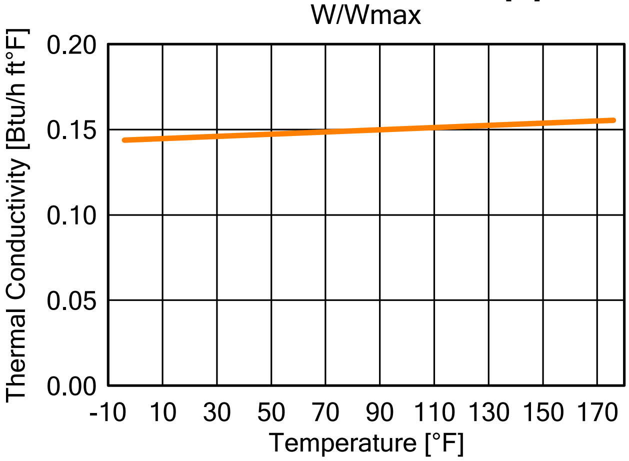
Property	Unit	Value
Bulk density	[lb/ft³]	70.5436
Porosity	[ft³/ft³]	0.48
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2006
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.1473
Permeability	[perm in]	4.6
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642





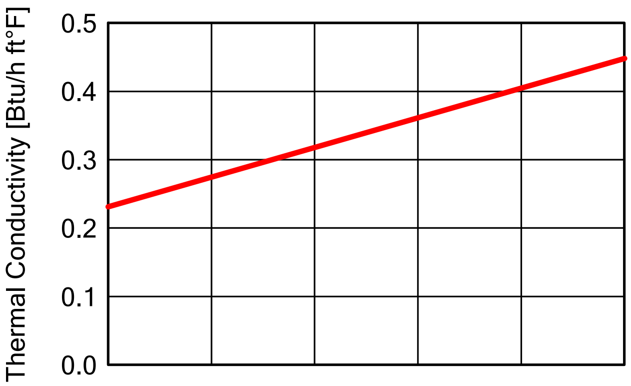


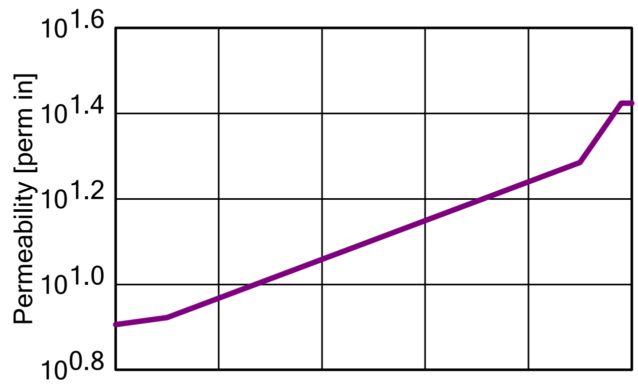


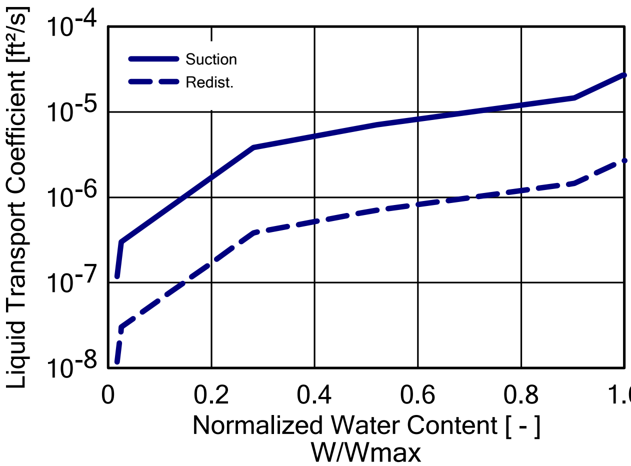


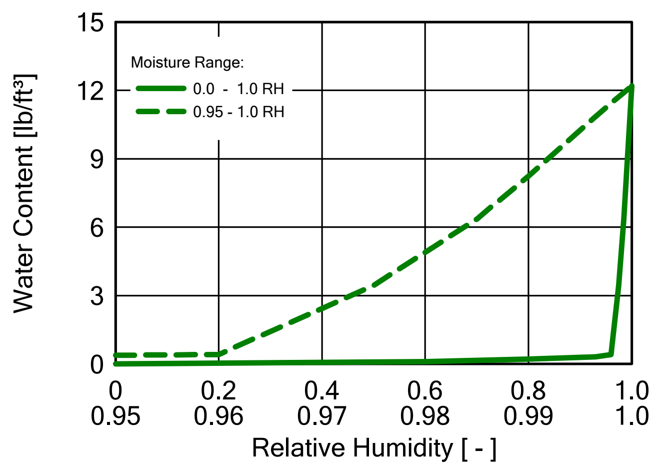
Material: *1% DR Condensation Film

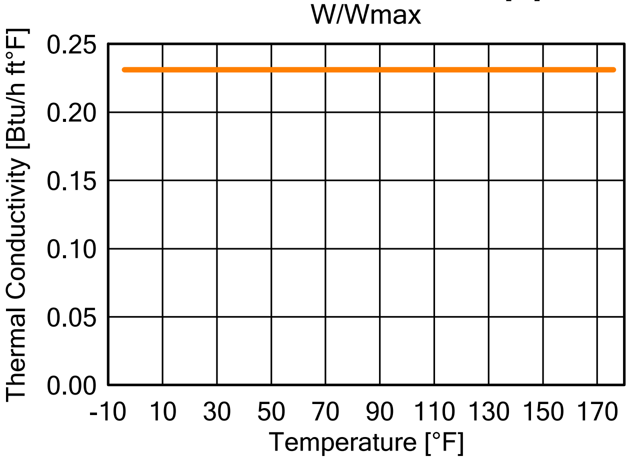
Property	Unit	Value
Bulk density	[lb/ft³]	104.2547
Porosity	[ft³/ft³]	0.196
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2006
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.2311
Permeability	[perm in]	8.05
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8.0
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0











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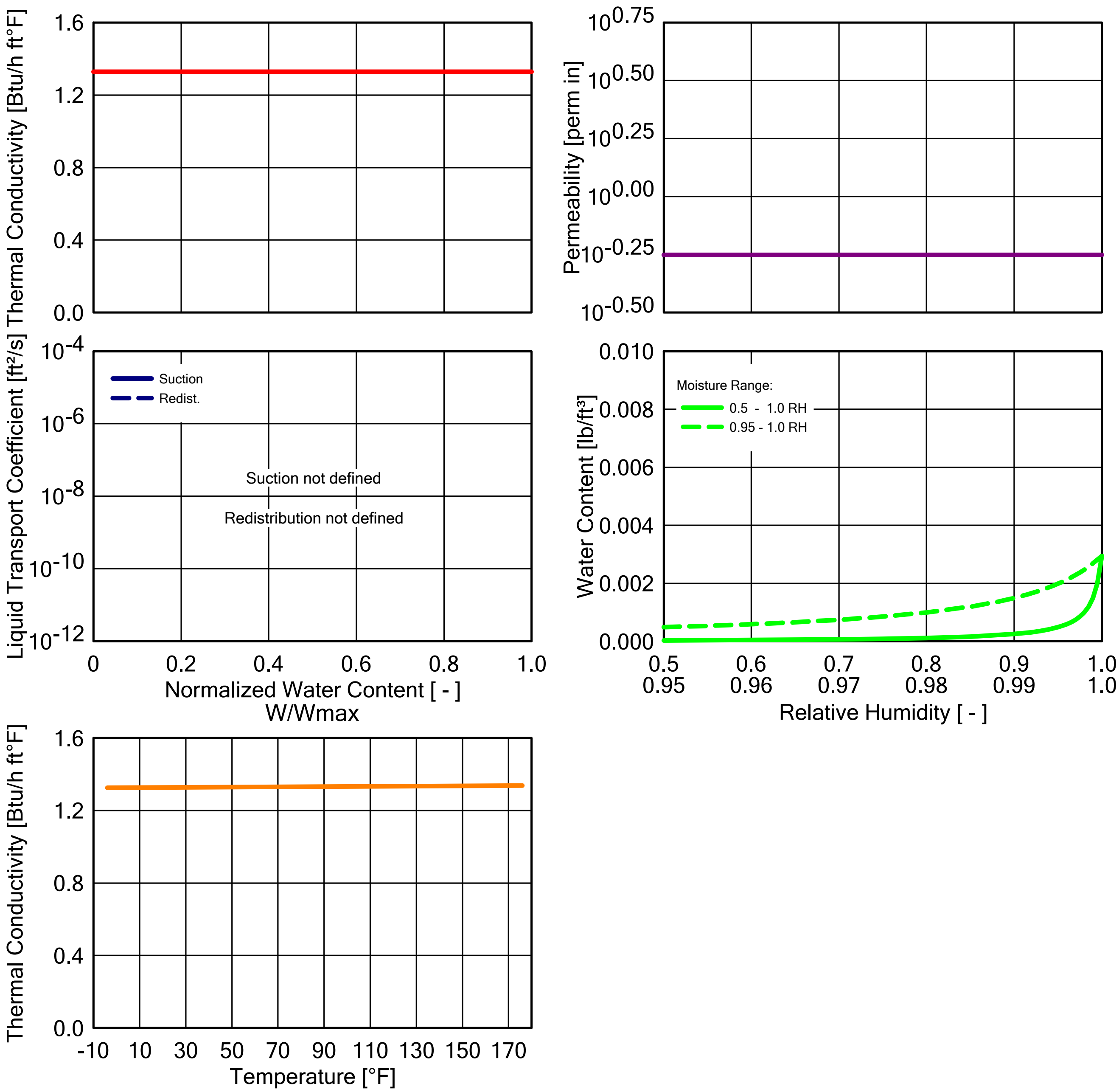
Material: *OSB-Integrated WRB (14 perm)

Property	Unit	Value
Bulk density	[lb/ft³]	8.11563
Porosity	[ft³/ft³]	0.001
Specific Heat Capacity, Dry	[Btu/lb°F]	0.549346
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	1.32892
Permeability	[perm in]	0.56
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41988E-5



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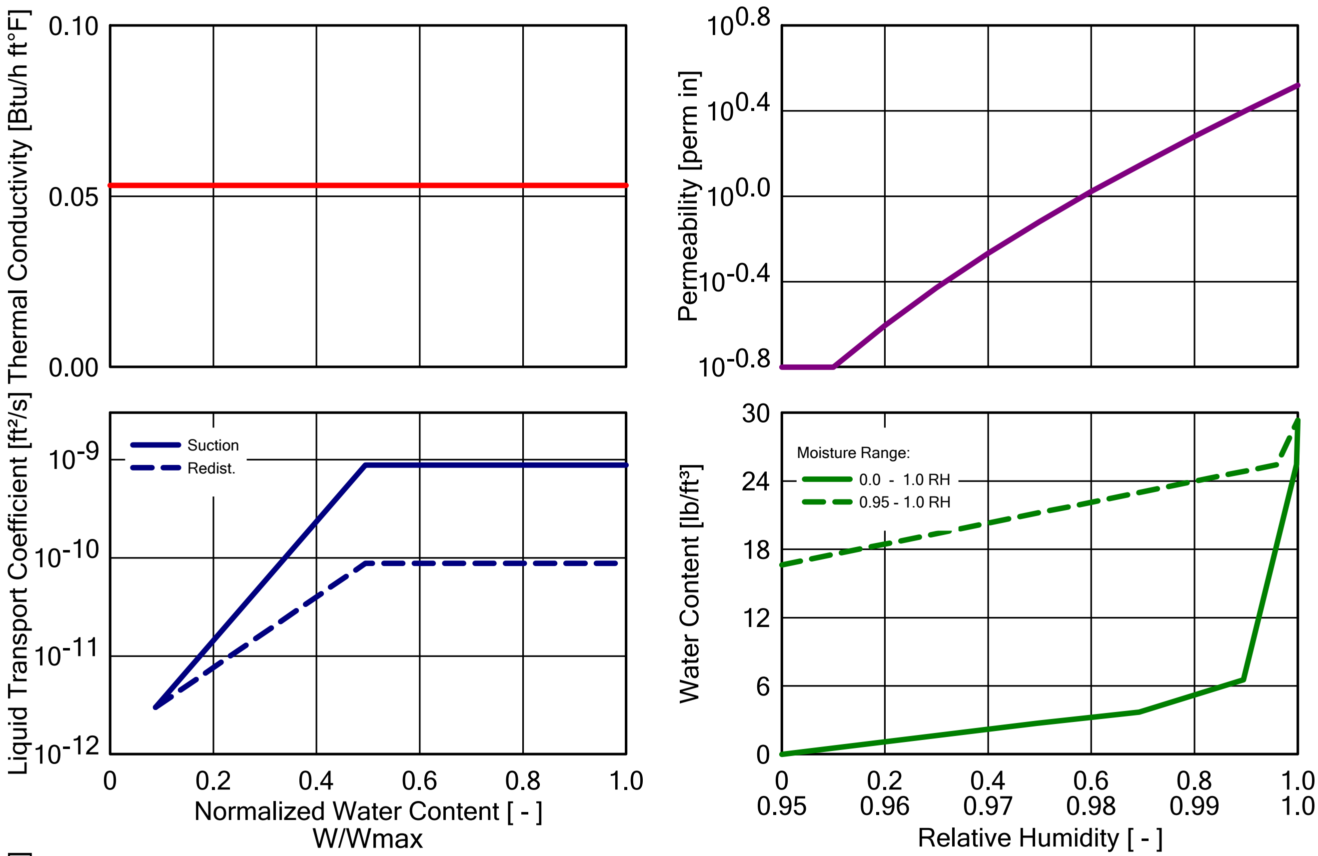
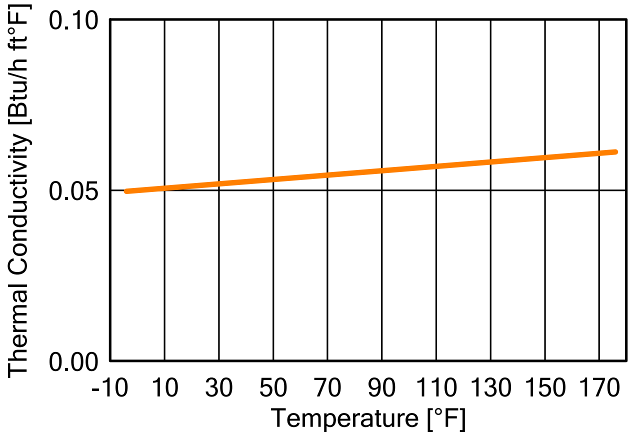
Material: *ZIP Sheathing (inner)

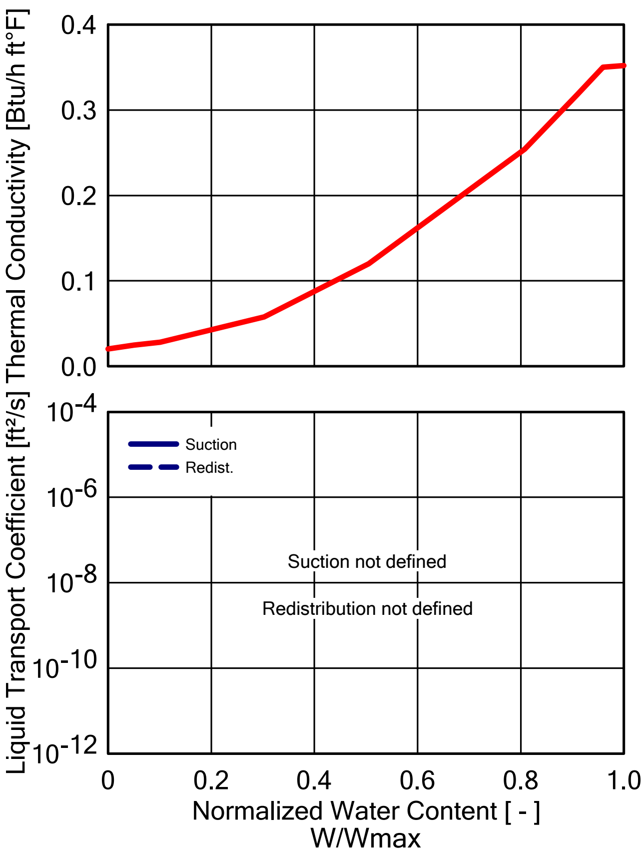
Property	Unit	Value
Bulk density	[lb/ft³]	40.5782
Porosity	[ft³/ft³]	0.95
Specific Heat Capacity, Dry	[Btu/lb°F]	0.449
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.0532
Permeability	[perm in]	0.1585
Reference Water Content	[lb/ft³]	5.2003
Free Water Saturation	[lb/ft³]	29.3411
Water Absorption Coefficient	[lb/in²s^0.5]	0.0000031
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642

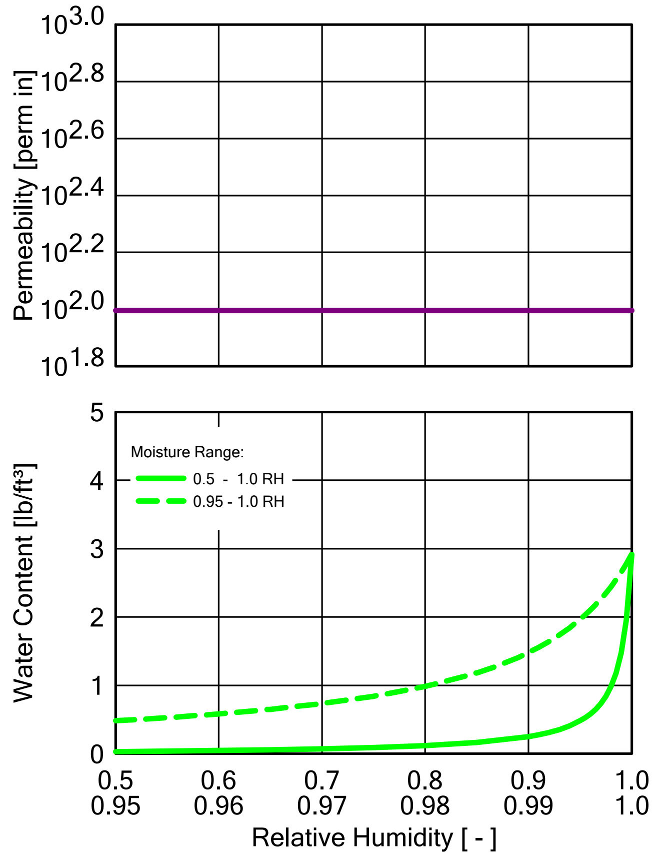


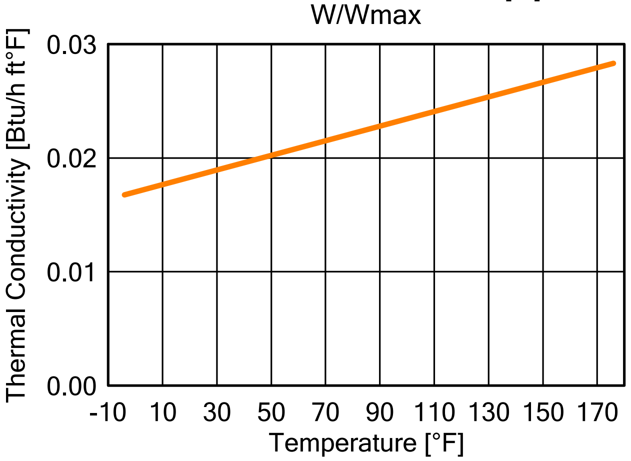


Material: Fiber Glass

Property	Unit	Value
Bulk density	[lb/ft³]	1.9
Porosity	[ft³/ft³]	0.99
Specific Heat Capacity, Dry	[Btu/lb°F]	0.201
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.02022
Permeability	[perm in]	99
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	6.41990E-5

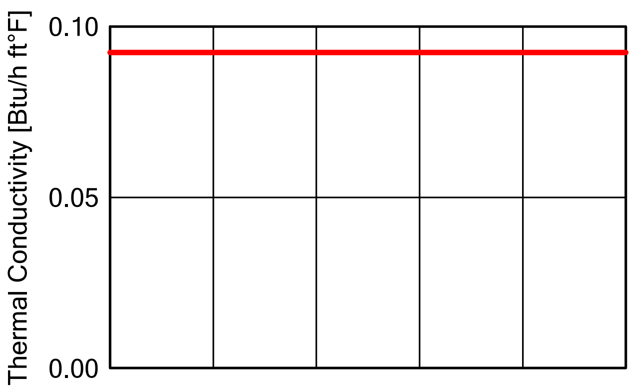


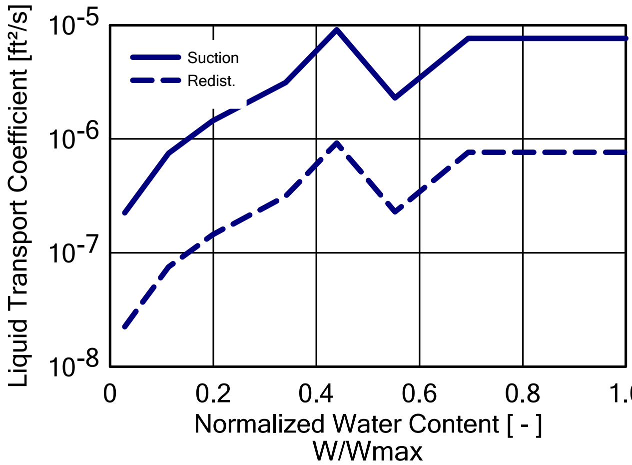


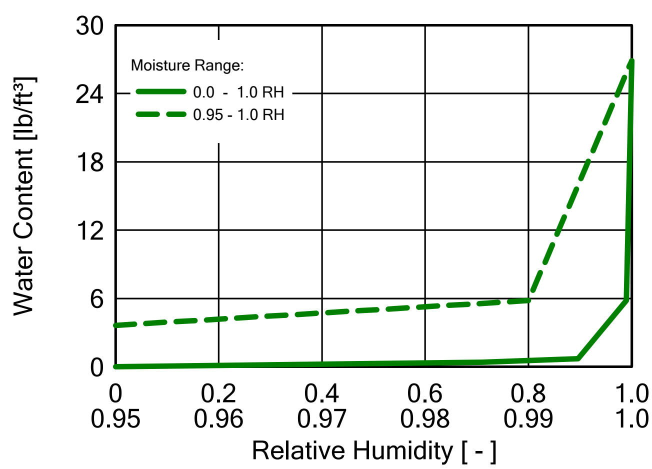


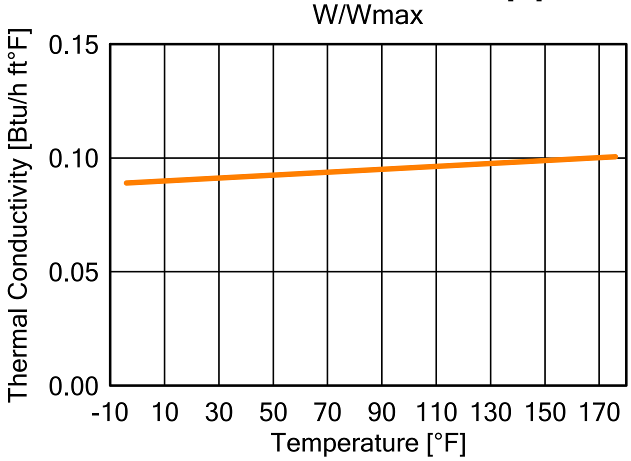
Material: Interior Gypsum Board

Property	Unit	Value
Bulk density	[lb/ft³]	39.0175
Porosity	[ft³/ft³]	0.706
Specific Heat Capacity, Dry	[Btu/lb°F]	0.2078
Thermal Conductivity, Dry, 50°F	[Btu/h ft°F]	0.0924
Permeability	[perm in]	18.3215
Temp-dep. Thermal Cond. Supplement	[Btu/h ft°F²]	0.0000642









Boundary Conditions

Exterior (Left Side)

Location: Boise, ID; ASHRAE Year 3
Temperature Shift: 0.0 °F
Orientation / Inclination: North / 90 °

Interior (Right Side)

Indoor Climate: EN 15026
Medium Moisture Load (EN/WTA)

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	Bright	[-]	0.2
Long-Wave Radiation Emissivity	Bright	[-]	----
Adhering Fraction of Rain	Depending on inclination o	[-]	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]	1

Sources, Sinks

*1% DR Condensation Film

Name	Type		
1% ASHRAE160	*Moisture Source; Fraction of Rain Load*		
	Whole Layer		
	Cut-Off at Free Water Saturation	[lb/ft³]	
	User-Defined	[%]	1

Results from Last Calculation

Status of Calculation

Calculation: Time and Date	12/11/2016 1:04:33 PM
Computing Time	1 min,18 sec.
Begin / End of calculation	10/1/2017 / 10/1/2022
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[lb/ft²]	14.75 -15.94
Integral of fluxes, right side (kr,dr)	[lb/ft²]	1.1E-7 -0.52
Balance 1	[lb/ft²]	-0.18
Balance 2	[lb/ft²]	-0.18

Water Content [lb/ft²]

	Start	End	Min.	Max.
Total Water Content	0.36	0.18	0.13	0.81

Water Content [lb/ft³]

Layer/Material	Start	End	Min.	Max.
Cement Board	2.73	0.86	0.36	20.98
*1% DR Condensation Film	0.21	0.07	0.03	12.03
*OSB-Integrated WRB (14 perm)	0.00	0.00	0.00	0.00
*ZIP Sheathing (outer)	5.20	2.90	1.74	6.19
*ZIP Sheathing (core)	5.20	3.25	2.26	5.78
*ZIP Sheathing (inner)	5.20	3.29	2.47	6.80
Fiber Glass	0.12	0.04	0.02	0.12
Interior Gypsum Board	0.54	0.26	0.06	0.54

Time Integral of fluxes

Heat Flux, left side	[Btu/ft²]	-1.5E+0005
Heat Flux, right side	[Btu/ft²]	-33872.52
Moisture Fluxes, left side	[lb/ft²]	-1.19
Moisture Fluxes, right side	[lb/ft²]	-0.52

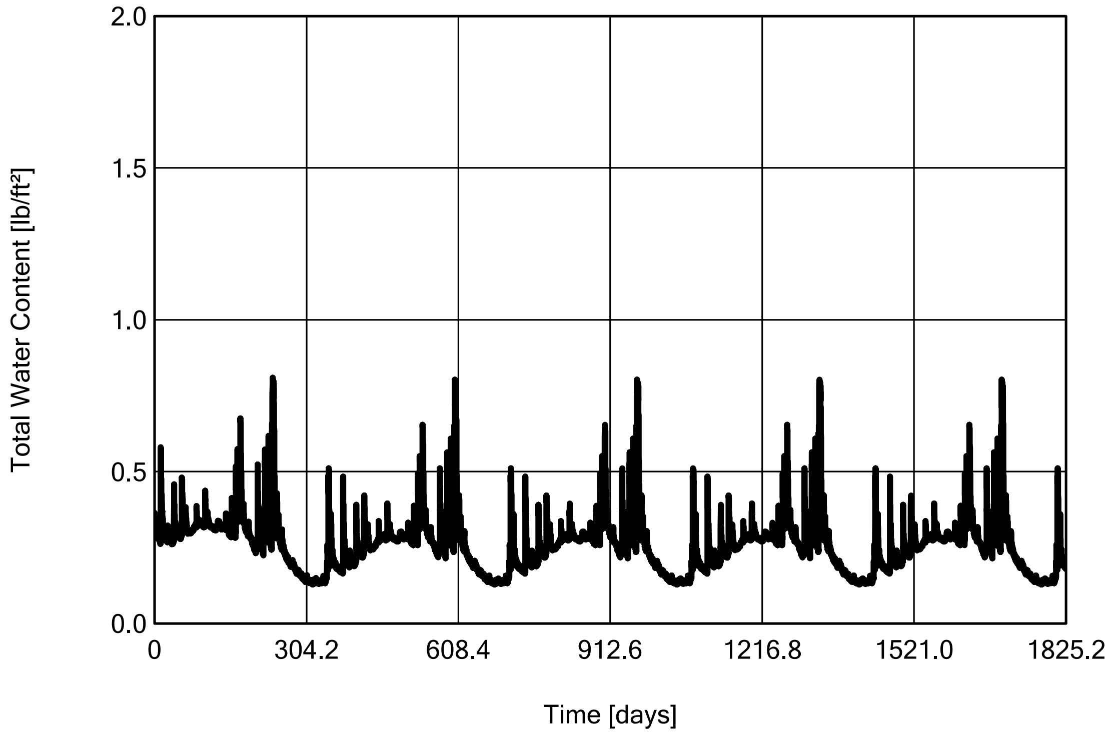
Hygrothermal Sources

Heat Sources	[Btu/ft²]	0.0
Moisture Sources	[lb/ft²]	0.491

Hygrothermal Sources (Continue)

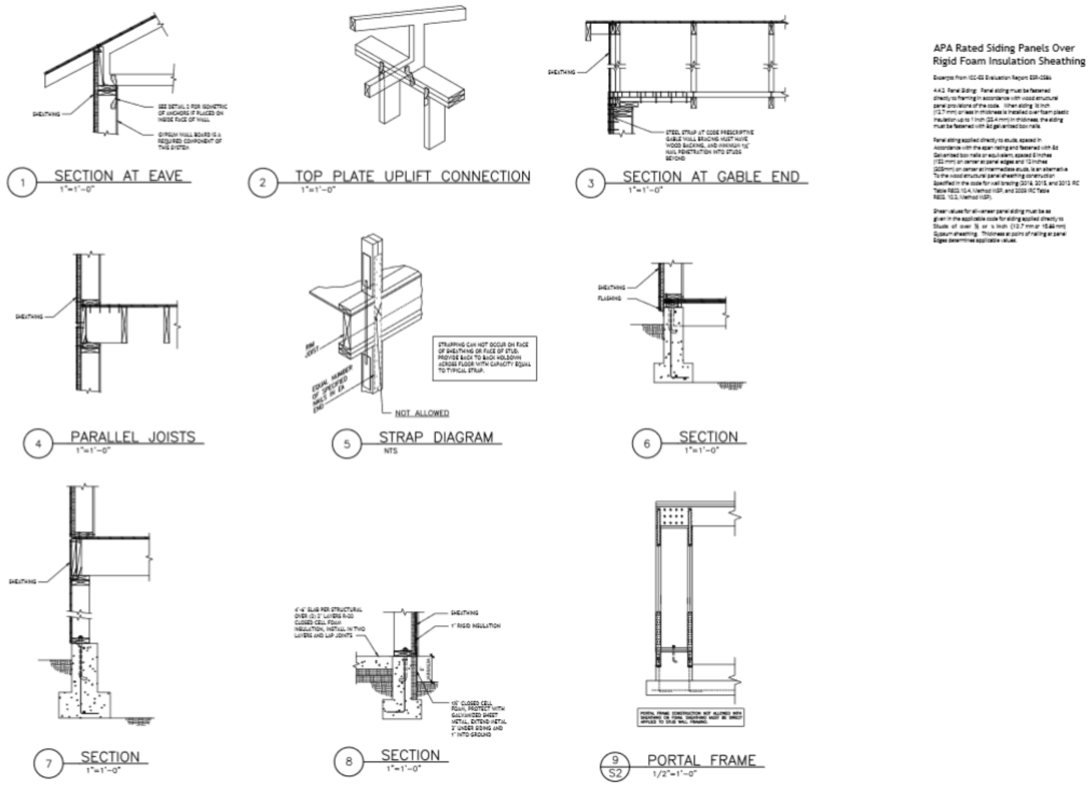
Unreleased Moisture Sources (due to cut-off)	[lb/ft²]	0.0
1% ASHRAE160 (Moisture Source)	[lb/ft²]	0.491

Total Water Content in Construction

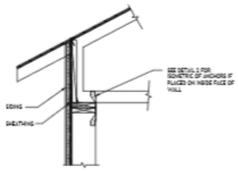


Appendix D – Wall Assembly Details - CAD files

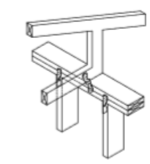
TBS Wall Drawings - CAD files available upon request.



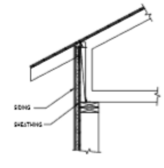
Exterior Rigid Insulation Wall Drawings - CAD files available upon request.



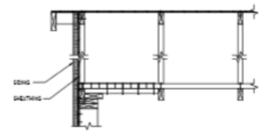
1 SECTION AT EAVE
1"=1'-0"



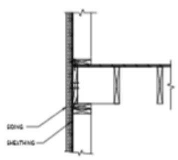
2 TOP PLATE UPLIFT CONNECTION
1"=1'-0"



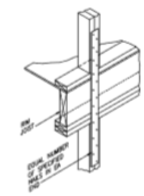
3 SECTION AT EAVE
1"=1'-0"



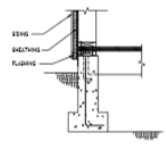
4 SECTION AT GABLE END
1"=1'-0"



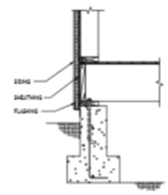
5 PARALLEL JOISTS
1"=1'-0"



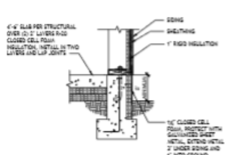
6 STRAP DIAGRAM
NTS



7 SECTION
1"=1'-0"



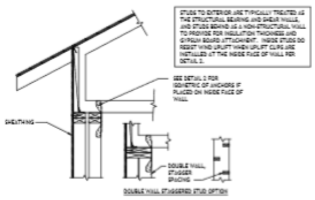
8 SECTION
1"=1'-0"



9 SECTION
1"=1'-0"

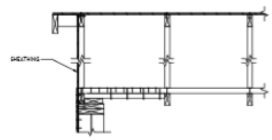
10 PORTAL FRAME
1/2"=1'-0"

Double Stud Wall Drawings - CAD files available upon request.

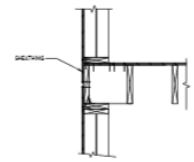


1 SECTION AT EAVE
1"=1'-0"

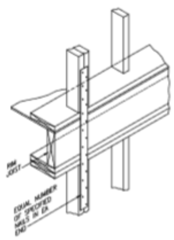
2 TOP PLATE UPLIFT CONNECTION
1"=1'-0"



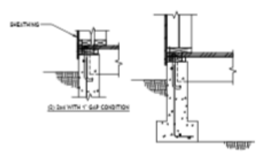
3 SECTION AT GABLE END
1"=1'-0"



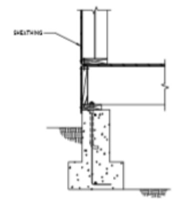
4 PARALLEL JOISTS
1"=1'-0"



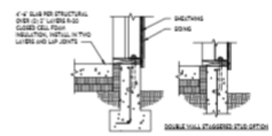
5 STRAP DIAGRAM
NTS



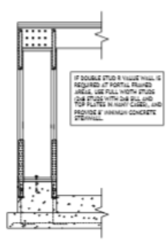
6 SECTION
1"=1'-0"



7 SECTION
1"=1'-0"



8 SECTION
1"=1'-0"



9 PORTAL FRAME
1/2"=1'-0"

Appendix E – Quantifying Benefits Advanced Codes

A 2016 meta study estimates the market value of non-energy benefits of green certified homes. The excerpt from the study below notes that 60% of the increased market value of these higher performing homes (4.3% premium) can be attributed to non-energy benefits such as comfort and durability.

https://www.researchgate.net/publication/294090858_The_green_premium_for_environmentally_certified_homes_a_meta-analysis_and_exploration

Housing has a large environmental impact. Certification programs such as LEED and Energy Star endeavor to reduce this impact with homes that, among other things, perform above code requirements. However, the voluntary nature of certification implies the need for a price premium, where certified homes sell for more than similar uncertified homes. Does this premium exist? And if so, what are buyers paying for?

We conducted a systematic review and meta-analysis of existing studies of the premium for certified homes. Over 20 studies worldwide, the mean weighted premium was 4.3% ± 0.6% SD. This finding was robust, changing little over numerous variations in the analysis, and was considerably less than the 9% figure used in some certification marketing.

Next, we explored several possible sources of value behind the premium, in a sample of 43 certified homes in Portland, Oregon USA. We compared the financed yearly cost of the premium to the market values of the utility savings and carbon mitigation associated with those homes. On average per year, the premium cost the owner $891, while the home provided utility savings of $327, and carbon mitigation with a market value of $24. Many other purchases and lifestyle options available to consumers deliver bigger carbon benefits at lower prices per ton.

These results suggest that while certified homes do provide environmental and financial benefits, those benefits are often limited in scope. Nonetheless, surveys indicate buyers of certified homes are satisfied with their purchases, in part due to tangible but hard-to-quantify characteristics such as comfort and quality. In our Portland sample, 60% of the premium's value came from such sources, while 3% came from carbon mitigation and 37% from utility savings.

The premium for certified homes seems to represent a collection of benefits for the buyer. Currently the values of individual benefits are not well quantified, and open to question. As real estate markets and green building techniques continue to evolve, home certification programs may need to evolve as well, to continue to prove their homes are distinctive enough to merit a higher price. # # #