Hygrothermal Analysis of Quik-Therm 936 Connect Wall

Presented to:

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Contents

Introduction

Overview

Evoke Buildings Engineering Inc. (Evoke) was contracted by Quik-Therm Insulation Solutions Inc. (Quik-Therm) to evaluate the hygrothermal performance of the Quik-Therm 936 Connect wall for Vancouver and Winnipeg climates.

The 936 Connect wall has two inches of insulating sheathing called 936 Connect that is installed outboard of 2x4 wood-framed walls with R-12 fiberglass insulation. The 936 Connect insulation has nailing strips embedded in Type 2 expanded polystyrene (EPS) insulation and laminated perforated metalized polymer facers. The system is intended for low-rise wood-framed construction. Figure 1 outlines the 936 Connect wall.

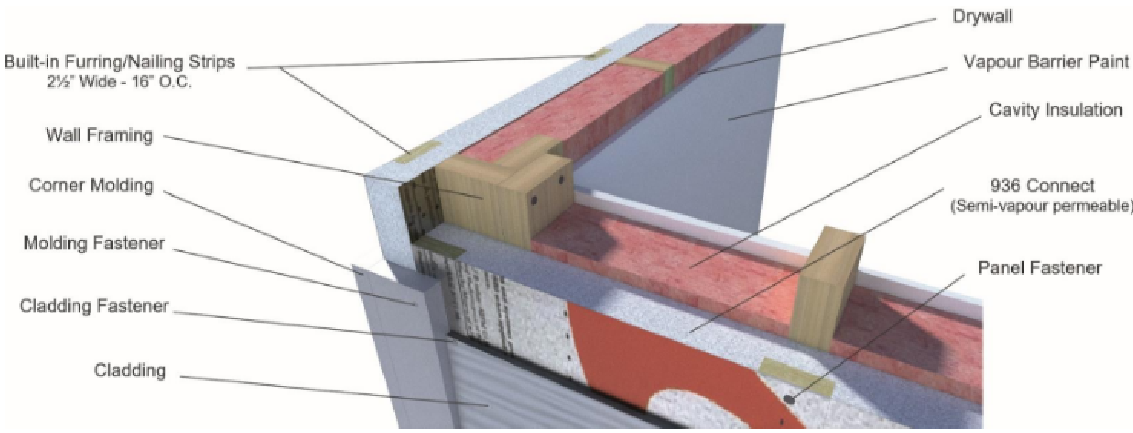

Figure 1: Quik-Therm 936 Connect Wall with Insulating Sheathing and 2x4 Wood-Framed Wall

The 936 Connect insulation has tongue and groove connections at the panel joints that are glued together using spray foam and sealed at perimeter framing (such as top or bottom plate) using gaskets or sealant to maintain air barrier continuity. The requirements for thermal insulation, air barrier, and vapour barrier are provided by the system as outlined in Table 1. The code references are for the 2015 NBC.

Table 1. Components of the 936 Wall System Meeting the Functional Requirements in NBC 2015

Functional Requirement	Code Reference	Components Meeting Functional Requirement	Relevant Standard or Property
Thermal Insulation and Resistance	9.25.2, 5.3.1	936 Connect Insulation	Tested in accordance CAN/ULC-S701-05
Air Barrier System	9.25.3, 5.4.1	936 Connect Insulation with gaskets, sealant, and spray foam	The 936-wall system has an air leakage characteristic less than 0.02 L/s m^2 at 75 Pa when tested in accordance with ASTM E2178
Vapour Barriers	9.25.4, 5.5.1	Vapour barrier coating applied to interior gypsum wall board	Permeance tested in accordance with CAN/CGSB-1.501-M

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Properties and Position of Materials in the Building Envelope

Section 9.25.5. of the 2015 NBC outlines low permeance materials as having the following properties:

1. An air leakage characteristic less than 0.1 L/s m^2 at 75 Pa, and
2. A water vapour permeance less than 60 ng/Pa s m^2.

Two inches (50 mm) of 936 Connect insulation with perforations meets this definition. Therefore, the requirements for the position of low permeance materials and insulation ratios outlined in table 9.25.5.2 would apply, except for the exclusion outlined in sentence in 9.25.5.1.(4). This exclusion applies to insulating sheathings with a vapour permeance greater than 30 ng/Pa s m^2 and thermal resistance greater than R-4 (0.7 RSI) for building locations with heating degrees (HDD18°C) less than 6000. Two inches (50 mm) of 936 Connection insulation with perforations has properties that meet these conditions and table 9.25.5.2 does not have to apply for climates as cold as Winnipeg or warmer.

The 936 Connect Wall with two inches (50 mm) of 936 connect insulation has an outboard to inboard thermal resistance ratio of 0.65. Therefore, the 936 Connect wall meets the minimum ratio for climates with HDD18°C less than 12 000.

Evaluation Objectives

The Quik-Therm 936 Connect wall meets the prescriptive requirements in the 2015 NBC for thermal insulation (9.25.2), air barrier system (9.25.3), vapour barriers (9.25.4), and position of materials in the building envelope (9.25.5). Notwithstanding a wall assembly meeting the minimum requirements set out in the building code, questions often still arise in practice to the hygrothermal limits of specific wall assemblies. The objective of this report is to provide additional insight to the hygrothermal performance of the 936 Connect wall regarding limits to airtightness, indoor humidity, and the ability to dry out incidental moisture from rain leaks.

Methodology

The hygrothermal evaluation of the Quik-therm 936 Connect wall assembly was evaluated using 1D hygrothermal analysis software called WUFI Pro V.6.5. The wall assembly was evaluated under dynamic conditions using published material properties and information provided by Quik-Therm.

The 1D WUFI model that was utilized for this evaluation was first compared to analysis done by Morrison Hershfield (MH) for the Quik-Therm Solar Dry Insulation that utilized a 2D hygrothermal model[1]. The 2D DELPHIN model and approach used in that work was previously validated using field studies that included simulating rain leaks and air leakage[2]. This is relevant because WUFI defaults were not used in this evaluation to simulate air leakage and precalculated moisture sources were used. The 1D WUFI model produced similar results as the reported 2D DELPHIN results when using the approach outlined in this report.

Appendix A outlines the model assumptions and material properties used in the simulations.

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[1] Morrison Hershfield report entitled "Hygrothermal Analysis of Quik-Therm Solar Dry Insulation" dated February 12, 2019.

[2] Lee et al 2019. "Design Limits for Framed Wall Assemblies Dependent on Material Choices for Sheathing Membranes and Exterior Insulation".

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Climate

The wall assembly was evaluated using Environment Canada exterior climatic data for a cold year based on heating degree days since 1980 as outlined in Table 2. Environment Canada climatic data was used to allow for the precalculated moisture sources and indoor humidity to be determined.

WUFI default climatic data and default assumptions were also run to verify that the finding is consistent but are not reported as part of this evaluation, except for the discussion on rain leaks. Rain leaks were simulated using the default weather data for the most severe year for moisture damage as determined by ASHARE RP-1325.

Table 2. Simulated Climatic Data Compared to NBC 2015 Climatic Information

Climate	Climate Zone	Simulated Climatic Data		2015 NBC Climatic Heating Degree Days 18°C
		Weather Year	Heating Degree Days 18°C	
Vancouver, BC	5	1980 (cold and wet)	3,333	2,858
Winnipeg, MB	7	1995-1996 (cold and wet)	6,642	5,670

The indoor humidity was simulated as uncontrolled humidity by applying a vapour pressure elevation (∆VP) to the outdoor air to account for moisture generation from indoor activities and ventilation with outdoor air. The principal reason for applying this approach is the indoor climate model is reinforced by building physics and moisture balances, mirrors monitoring data, and does not have a significant bias for any climate (Roppel et al 2009). This approach is one of the default options found in WUFI for modeling indoor humidity. A ∆VP of 540 was used for the baseline analysis to represent residential occupancy and a medium moisture load.

The indoor temperature was simulated using ASHARE Standard 160-2016 Table 4.2 for Heating only.

A summary of the simulated indoor conditions is presented in Table 3 and Appendix A has graphs showing the simulated hourly indoor and outdoor conditions.

Table 2. Simulated Climatic Data Compared to NBC 2015 Climatic Information

Climate	Heating Season (November to April)			Non-heating Season (April to November)		
	Temperature (°C)	∆VP (Pa)	Average Indoor RH	Temperature (°C)	∆VP (Pa)	Average Indoor RH
Vancouver, BC	21	540	50%	21-25	Varies linearly when outdoor temperature is greater than 0°C	56%
Winnipeg, MB	21		30%	21-33		49%

Air Leakage

A moisture source due to air leakage was simulated at the interior face of the 936 Connect insulation based on hourly climatic conditions and using a baseline airtightness characteristic of 0.02 L/s m² at 75 Pa as referenced by code in 5.4.1.2. (1). The moisture source rate was determined by calculations and inputted into WUFI using a procedure summarized in Appendix A. The hourly moisture source rate is dependent on the calculated air pressure difference that is determined for wind pressure, stack effect, and over pressurization of 10 Pa from mechanical equipment.

Rain Leaks

The default approach to modeling water penetration per ASHARE 160-2016 is to apply 1% of the water reaching the cladding to the exterior surface of the water-resistive barrier. For the 936 Connect wall assembly the water-resistive barrier is outside metalized polymer facer. Nevertheless, for this evaluation rain penetration was applied to the interior face of the 936 Connection insulation to demonstrate the drying potential of the assembly compared to a code minimum wall assembly.

Wetting from rain leaks was considered without air leakage because air exfiltration provides drying and cannot be relied upon to provide drying at the leak location.

Orientation

The wall assemblies were evaluated for the north to evaluate the impact of the indoor humidity and air exfiltration. North orientation has the least solar exposure and drying potential to the exterior.

An east facing wall was used to simulate rain leaks for Vancouver and a north orientation for Winnipeg based on the orientations with the greatest driving rain.

Findings

The Quik-Therm 936 Connect Wall assembly with two inches of 936 Connect insulation., R-12 batt insulation, and a vapour barrier coating on interior gypsum drywall is appropriate for cool marine climate such as Vancouver and a cold continental climate such as Winnipeg from a hygrothermal perspective. However, as is the case for any wall assembly there are indoor humidity and airtightness limits that are essential to minimize the occurrence of condensation. The building code is also concerned about material deterioration and the growth mould and fungi. Nevertheless, controlling the risk of condensation is the critical factor in evaluating performance for the 936 Connect wall assembly.

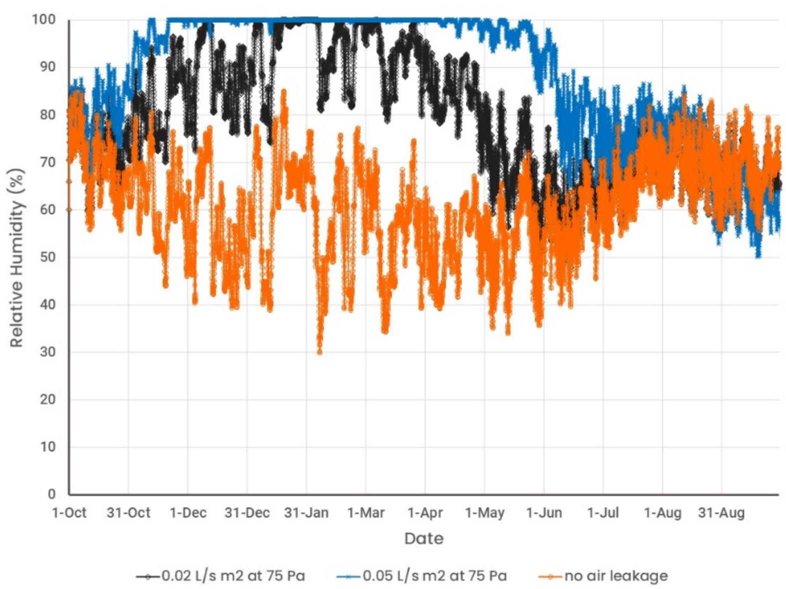
A discussion of the limits follows using Winnipeg results as an example. Similar findings were found for Vancouver unless otherwise indicated and the similar graphs for the Vancouver results can be found in Appendix B.

Airtightness

The 936 Connect wall can tolerate some air leakage provided the air barrier system has an air leakage characteristic not greater than 0.02 L/s m^2 at 75 Pa as required in Part 5 (NBC 2015 5.4.1.2). Testing done at Red River College shows that this level of airtightness is achievable for 936 Connect Wall when installed per installation Quik-Therm's requirements. An air leakage rate of 0.0084 L/s m^2 at 75 Pa for exfiltration was measured by Red River when the wall system was tested per ASTM E2237-17.

Notes for A-5.4.1.2. (1) reference maximum air leakage rates 0.05, 0.1, and 0.15 L/s m^2 at 75 Pa depending on the indoor humidity and development of Table 9.25.5.2 assumed rates of 0.024 and 0.1 L/s m^2 at 75 Pa as indicated in A-9.25.5.2. However, the findings of this evaluation are that an air leakage rate of 0.05 L/s m^2 at 75 Pa is too high for the 936 Connect wall and moisture accumulation from condensation will be expected for an extended period if the level of airtightness does not meet the 0.02 L/s m^2 at 75 Pa maximum limit. Laboratory testing commissioned by Quik-Therm shows that the 936 Connect wall system can meet this level of airtightness.

Figure 2 shows the impact of air leakage on the risk of condensation of the 936 Connect insulation in Winnipeg. The interior surface of the 936 Connect insulation with leakage rates based on 0.02 L/s m^2 at 75 Pa does have periods where condensation is expected as indicated when the relative humidity reaches 100% at the interior surface of the 936 Connect insulation. Nevertheless, the moisture dries out for the most part within days for many of the wetting events. Two wetting periods were simulated that lasted for two to three weeks during the first winter when the surface was below freezing for an extended period, but the moisture can dry out quickly upon more favourable and less severe conditions. Bear in mind that the simulated year was selected as the coldest winter over a 20-year period using historical Environment Canada climatic data. Therefore, the occurrence and duration of condensing events will be less for normal years. For Vancouver, the RH remains below 92% at the interior surface of the 936 Connect insulation interface for a leakage rate set at 0.02 m^2 at 75 Pa.

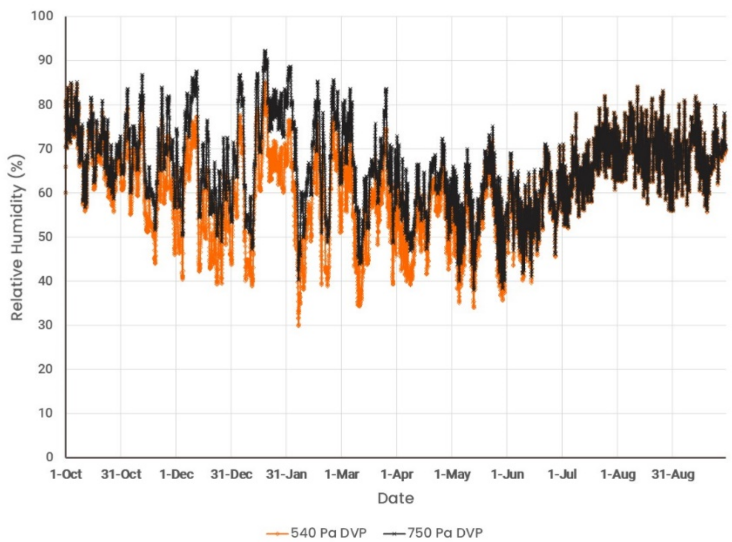


Constant Parameters	
Indoor Humidity	540 Pa ΔVP
Interior Vapour Control	35 ng/m^2 Pa s
Orientation	North
Rain Leaks	None
Variable: Air Leakage	
Blue	0.05 L/s m^2 at 75 Pa
Black	0.02 L/s m^2 at 75 Pa
Orange	No air leakage

Figure 2: Impact of air leakage on the risk of condensation at the interior surface of the 936 Connect Insulation in Winnipeg

Indoor Humidity

A difference in vapour pressure (ΔVP) of 540 was used for the baseline analysis. This represents a medium moisture load that results in indoor humidity levels that are appropriate for residential occupancies. Nevertheless, to evaluate the impact of higher indoor humidity a ΔVP of 750 Pa was simulated for select cases. This value is relevant because the Part 9 notes (A-9.25-5.2.) states that this value was used in the development of Table A-9.25.5.2. This assumption leads to an average indoor humidity 38% in Winnipeg and 53% in Vancouver during the heating season (October to April). Figure 3 shows how the higher indoor humidity raises the moisture levels in the wall cavity but does not result in critical wetting periods.

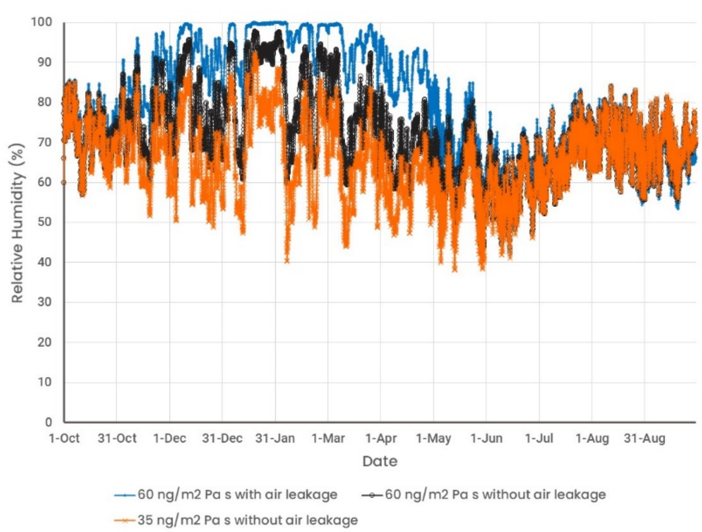


Constant Parameters	
Interior Vapour Control	35 ng/Pa s m^2
Orientation	North
Rain Leaks	None
Air Leakage	None
Variable: Indoor Humidity	
Black	750 Pa ΔVP
Orange	540 Pa ΔVP

Figure 3: Impact of indoor humidity on the risk on condensation risk at the interior surface of the 936 Connect Insulation in Winnipeg

Interior Vapour Control

Vapour barrier coatings are in the range of 35 to 60 ng/Pa s m^2. A permeance of 35 ng/Pa s m^2 was used in the baseline analysis. A coating with a permeance of 35 ng/Pa s m^2 will better control wetting and will still allow enough drying from rain leaks. Nevertheless, a vapour control layer on the warm side of the insulation with a permeance up to 60 ng/Pa s m^2 is sufficient to control wetting related to diffusion of moisture from the indoor environment into the wall cavity. Figure 4 illustrates the findings for a 60 ng/Pa s m^2 vapour control layer compared to 35 ng/Pa s m^2. Ability to dry out the wall assembly from rain leaks is discussed in the next section.



Constant Parameters	
Interior Humidity	750 Pa ΔVP
Orientation	North
Rain Leaks	None
Variable: Interior Vapour Control and Air Leakage	
Black	60 ng/Pa s m^2, no air leakage
Orange	35 ng/Pa s m^2, no air leakage
Blue	60 ng/Pa s m^2, 0.02 L/s m^2 at 75 Pa Air Leakage

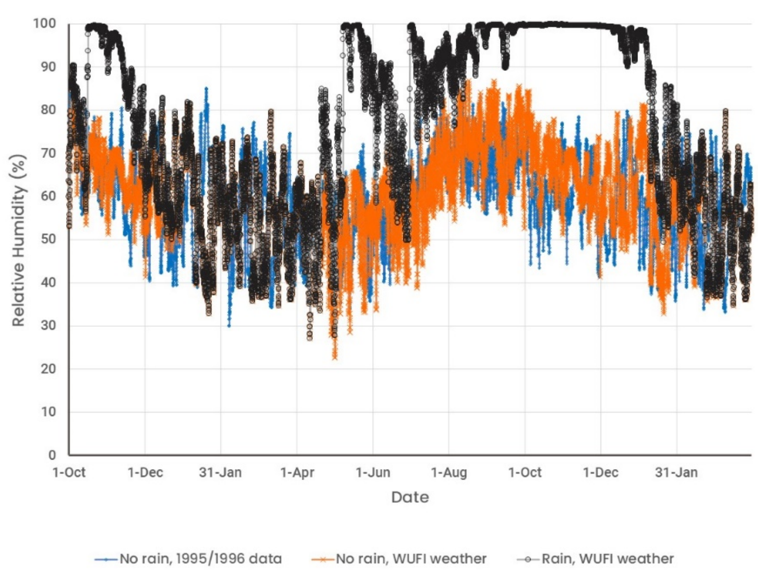
Figure 4: Impact of interior vapour control on the risk of Condensation at the interior surface of the 936 Connect Insulation in Winnipeg

Rain Leaks

The 936 Connect wall can dry out incidental moisture from rain leaks with a vapour barrier coating that is 35 ng/Pa s m^2 or greater. Drying will happen in both directions depending on the vapour pressure of the indoor or outdoor air. The permeance of the 936 Connect with perforations is approximately 86 ng/Pa s m² when measured by wet cup[3], which is greater than the interior vapour control. Therefore, drying is predominantly outward during the heating season when the air is dryer than the indoor air for this assembly in Canadian climates.

Figure 5 illustrates how the 936 Connect wall assembly can dry out from incidental rain leaks and compares the results using the default WUFI weather and the Environment Canada data for 1995 and 1996. Without rain leaks and air leakage, the moisture levels are within the same range and follow the same trends for both climatic years.

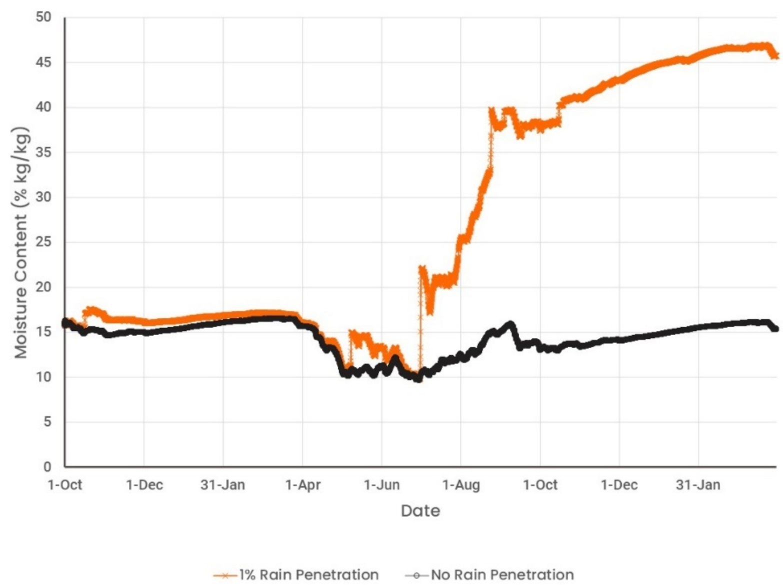
Keep in mind that the moisture source for rain penetration was added to a depth of 5 mm to the exterior fibres of the batt insulation when reviewing the results. The simulated moisture loading is much more stringent than the default assumptions for ASHRAE Standard 160 as result of where the leaks were added to the model. A wall without exterior insulation and plywood sheathing is presented in Figure 6 to provide a sense of how a code minimum wall performs for the same conditions. Details of the code minimum wall are provided in Appendix A. As can be seen the code minimum wall does not dry out and would be subject to deterioration if subject to this level of moisture loading behind the plywood sheathing[4].



Constant Parameters	
Interior Humidity	540 Pa ΔVP (ISO 13788 Class 2)
Interior Vapour Control	35 ng/Pa s m²
Orientation	North
Air Leakage	None
Variable: Rain Leaks and Climate Data	
Black	Rain leaks, WUFI weather file
Orange	No rain leaks, WUFI weather file
Blue	No rain leaks, 1995-1996 Environment Canada data

Figure 5: Impact of 1% rain penetration for the 936 Connect wall assembly in Winnipeg

[3] QAI test report No: T1035-6Rev1 dated September 9, 2019 prepared for Quik-Therm.
[4] This simulation had a lot of convergence errors due to the quantity and location where the moisture as added to the model. Results are presented for illustrative purposes.



Parameters	
Interior Humidity	540 Pa ΔVP (ISO 13788 Class 2)
Interior Vapour Control	6 mil polyethylene
Orientation	North
Air Leakage	None
Variable: Rain Leaks	
Black	No rain leaks, WUFI weather file
Orange	Rain leaks, WUFI weather file

Figure 6: Moisture content of plywood Sheathing for Code minimum wall subject to 1% Rain penetration at the interior face of the plywood sheathing in Winnipeg

Closing

The Quik-Therm 936 Connect wall meets the prescriptive requirements in the 2015 NBC for thermal insulation (925.2), air barrier system (9.25.3), vapour barriers (9.25.4), and position of materials in the building envelope (9.25.5). This evaluation provided additional insight to the hygrothermal performance of the 936 Connect Wall assembly for limits related to airtightness, indoor humidity, and the ability to dry out from rain leaks.

The insulation ratio with two inches of 936 Connect Insulation is adequate for controlling the occurrence of condensation, or frost, for residential occupancies in cool marine climates, such as Vancouver, and cold continental climates, such as Winnipeg. However, achieving an airtightness of at least 0.02 L/s m^2 is critical. This level of airtightness is achievable as shown by the air lekage testing that Quik-Therm commissioned at Red River College provided that same installation procedures are followed as outlined by Quik-Therm installation guidelines.

Please do not hesitate to contact us with any questions regarding this evaluation.

Evoke Buildings Engineering Inc.

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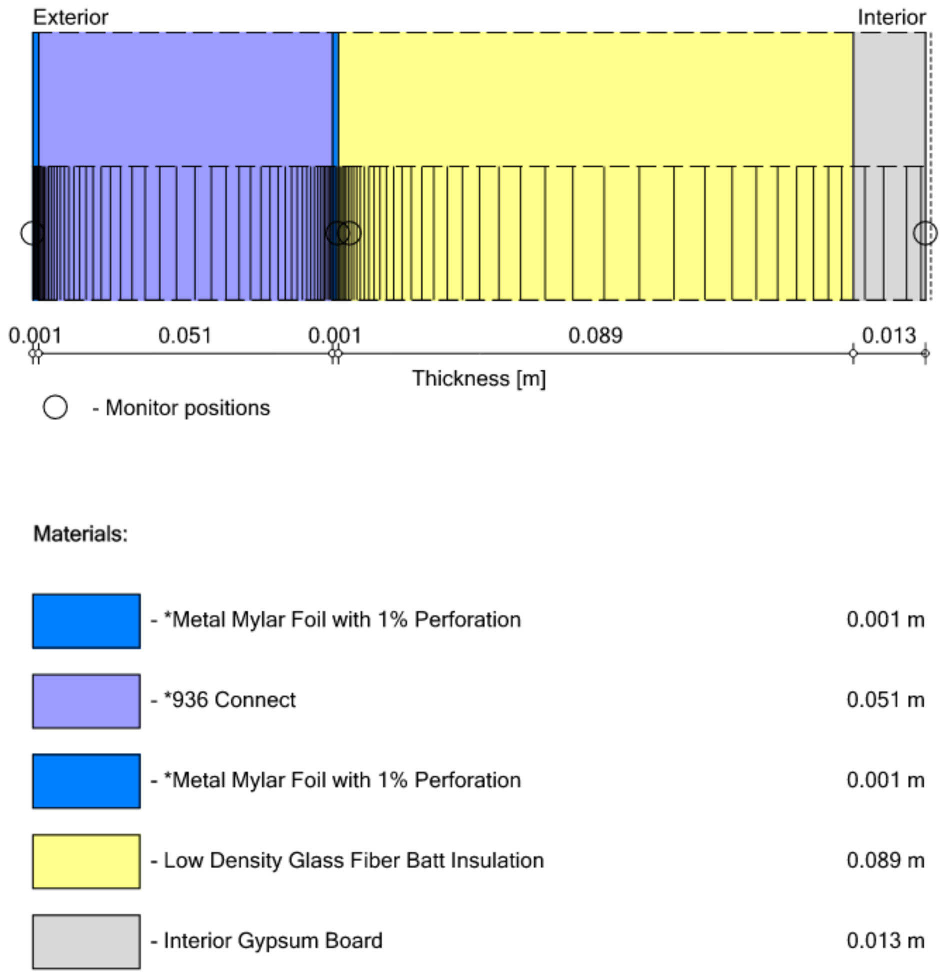
Appendix A: Model Assumptions and Material Properties

936 Connect Wall Assembly



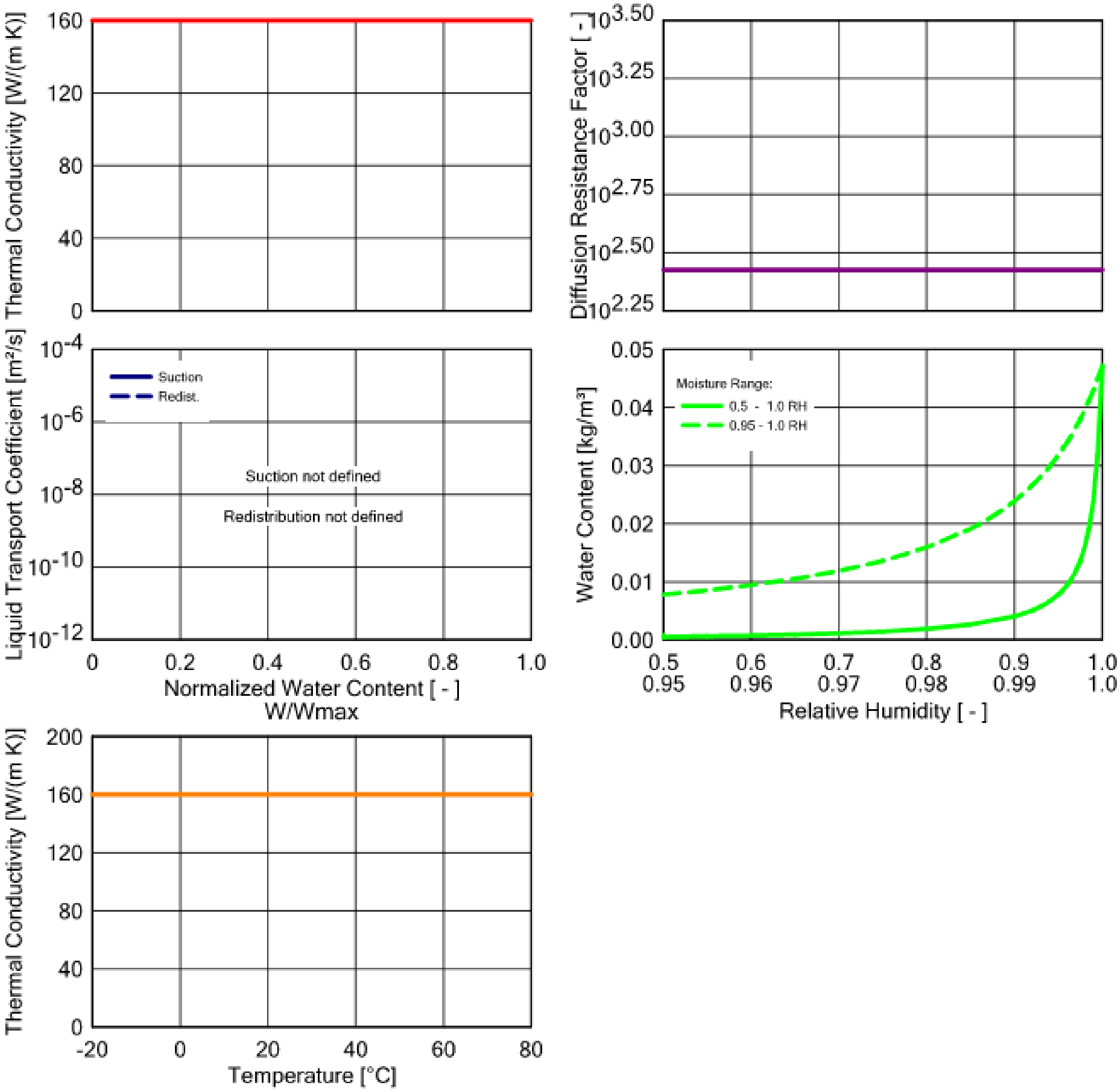
Boundary Conditions

Boundary	Heat Transfer Coefficient ($W/m^2 K$)	Vapour Exchange Coefficient ($ng/Pa\ m^2\ s$)
Exterior Surface	7.75	Generated by WUFI based on heat transfer coefficient
Interior Surface	7.75	35

Material Properties

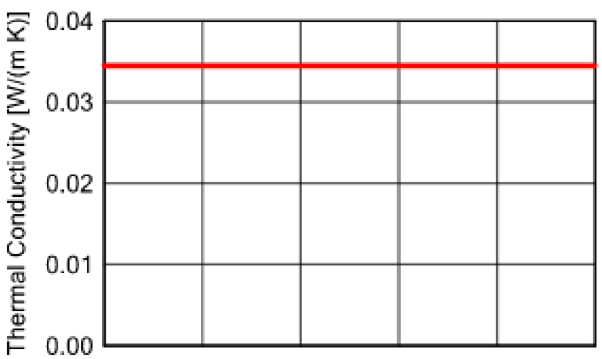
Material: *Metal Mylar Foil with 1% Perforation

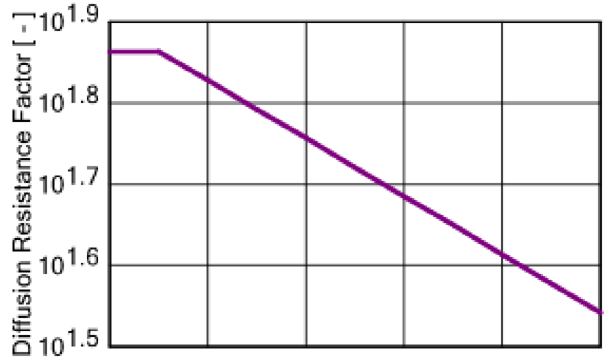
Property	Unit	Value
Bulk density	[kg/m³]	130
Porosity	[m³/m³]	0.001
Specific Heat Capacity, Dry	[J/(kg K)]	2300
Thermal Conductivity, Dry, 10°C	[W/(m K)]	160
Water Vapour Diffusion Resistance Factor	[-]	267
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	0.0002

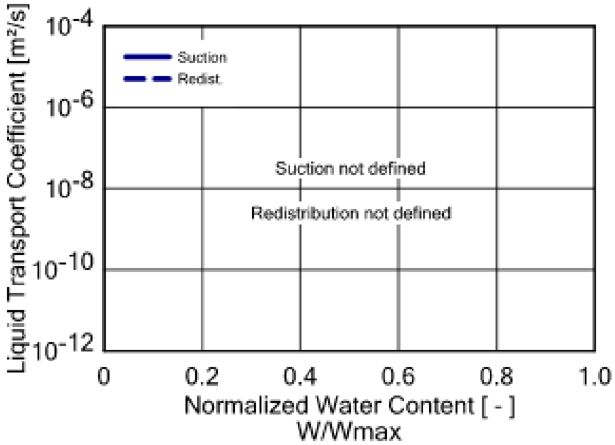


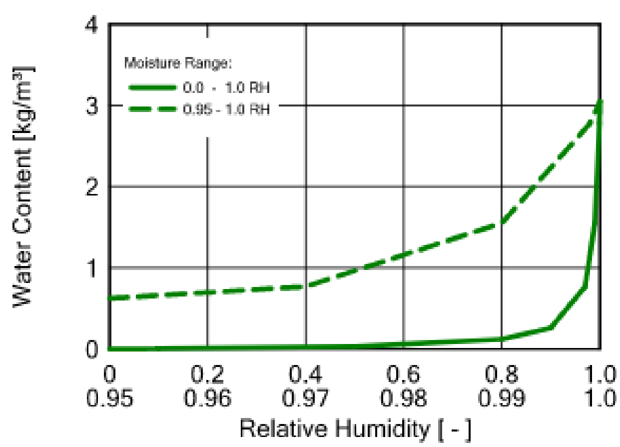
Material: *936 Connect

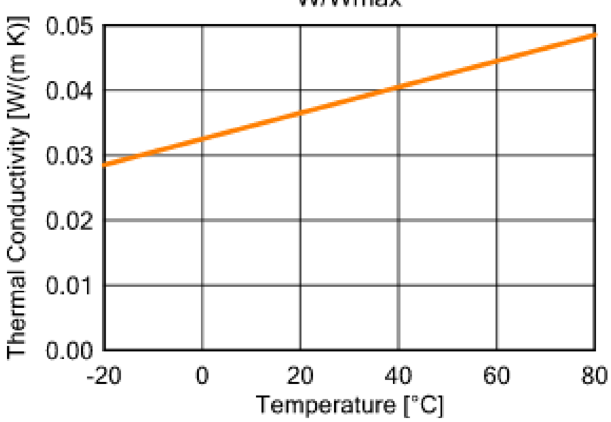
Property	Unit	Value
Bulk density	[kg/m³]	14.8
Porosity	[m³/m³]	0.99
Specific Heat Capacity, Dry	[J/(kg K)]	1470
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.0345
Water Vapour Diffusion Resistance Factor	[-]	73.01
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	0.0002





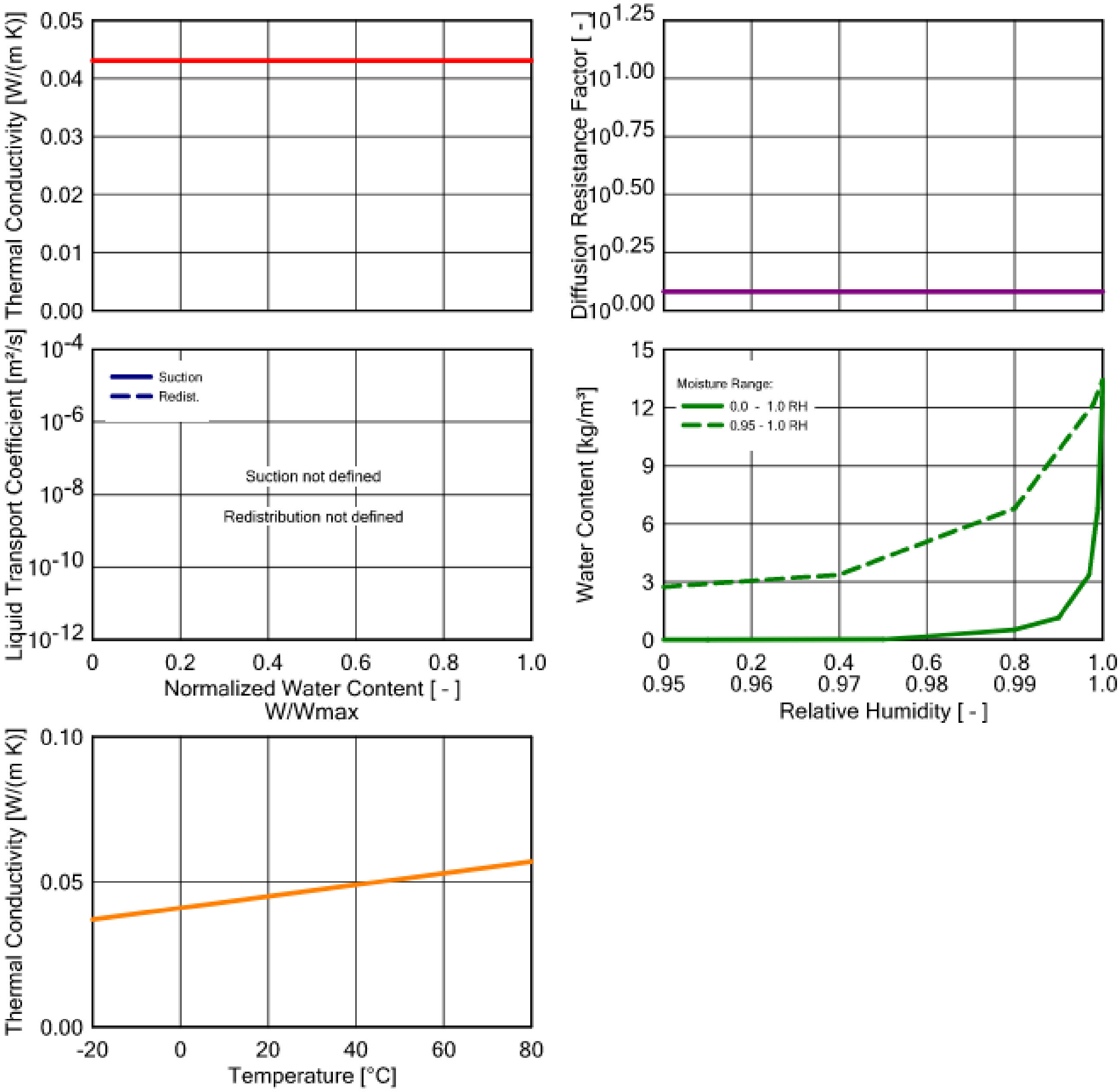






Material: Low Density Glass Fiber Batt Insulation

Property	Unit	Value
Bulk density	[kg/m³]	8.8
Porosity	[m³/m³]	0.999
Specific Heat Capacity, Dry	[J/(kg K)]	840
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.043
Water Vapour Diffusion Resistance Factor	[-]	1.21
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4



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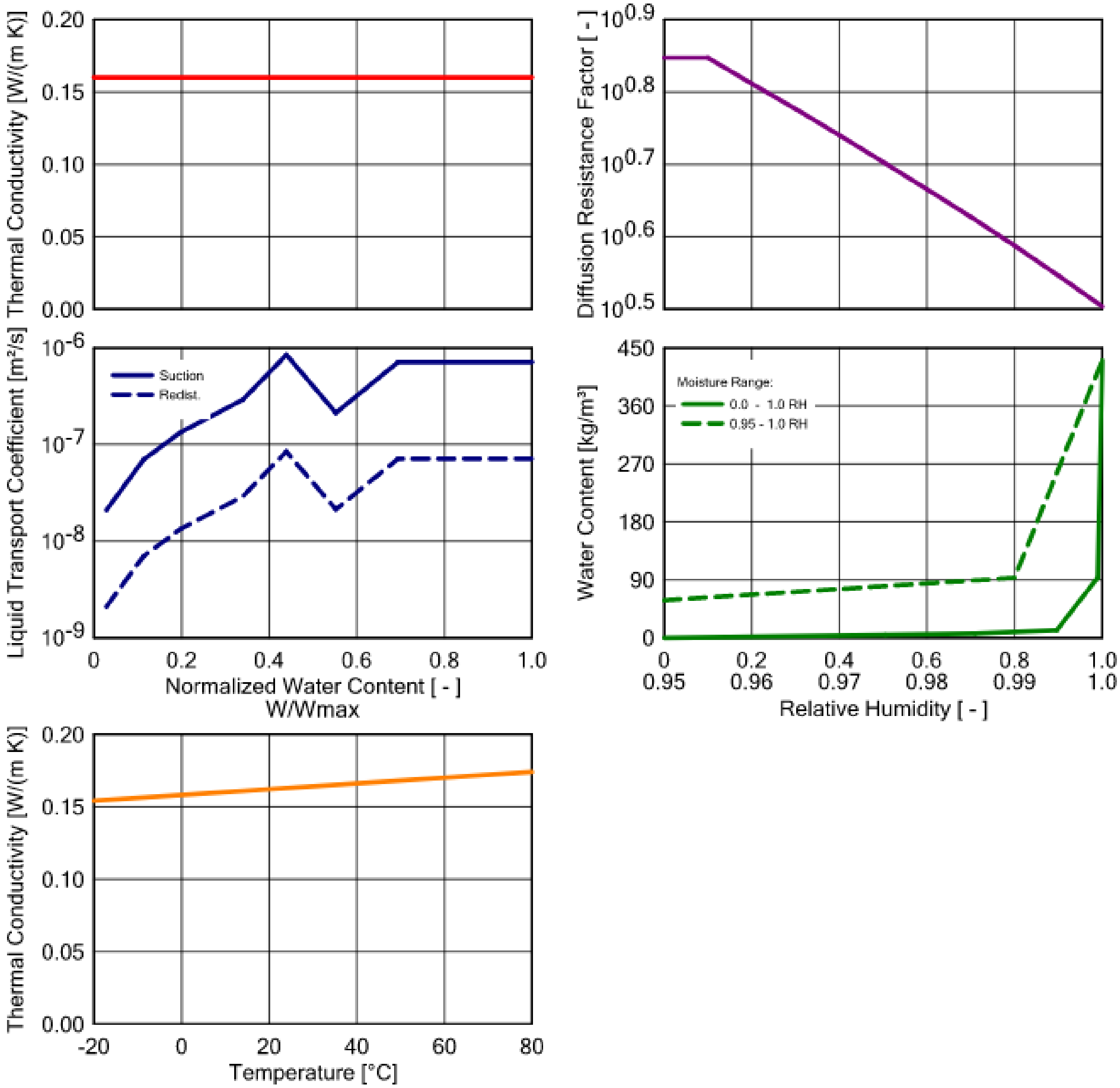
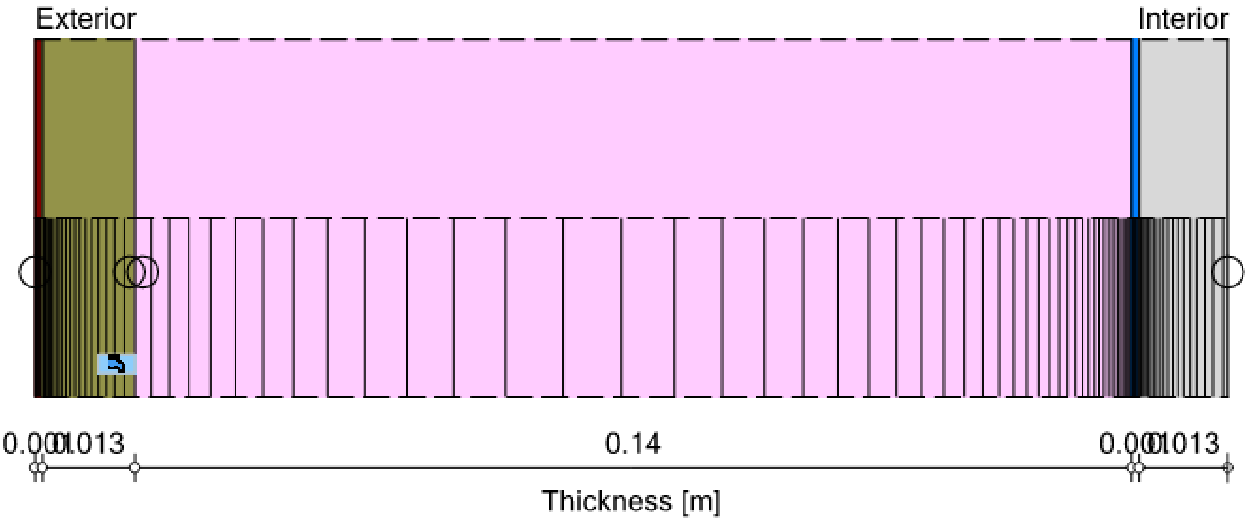
Material: Interior Gypsum Board

Property	Unit	Value
Bulk density	[kg/m³]	625
Porosity	[m³/m³]	0.706
Specific Heat Capacity, Dry	[J/(kg K)]	870
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.16
Water Vapour Diffusion Resistance Factor	[-]	7.03
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	0.0002



Code Minimum Wall



○ - Monitor positions

- Heat/Moisture source/sink positions

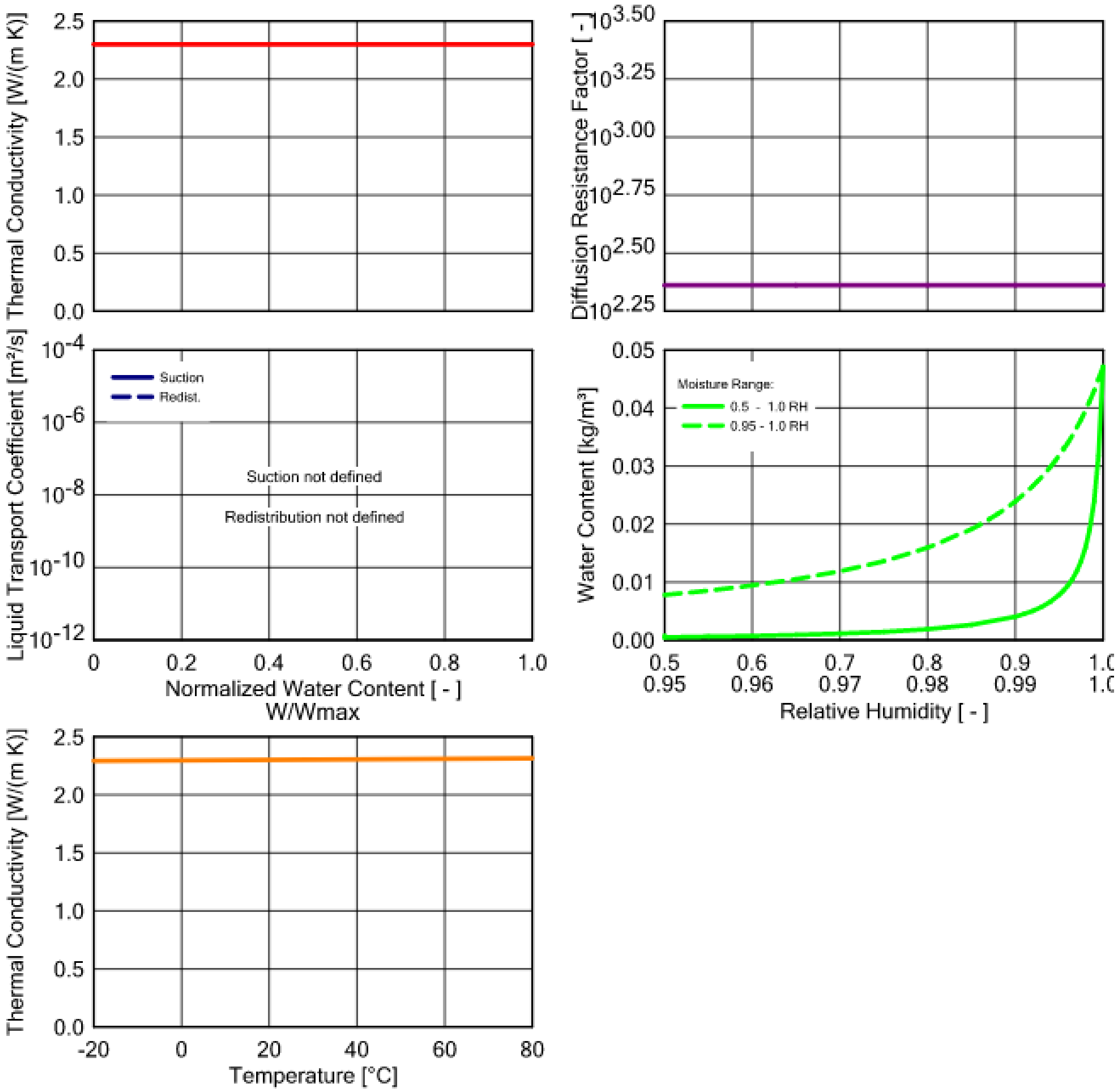
Materials:

- *15 Perm membrane	0.001 m
- *Plywood #1 IRC	0.013 m
- *R19 Fiberglass Batt	0.14 m
- *6 mil Poly	0.001 m
- Interior Gypsum Board	0.013 m

Material Properties

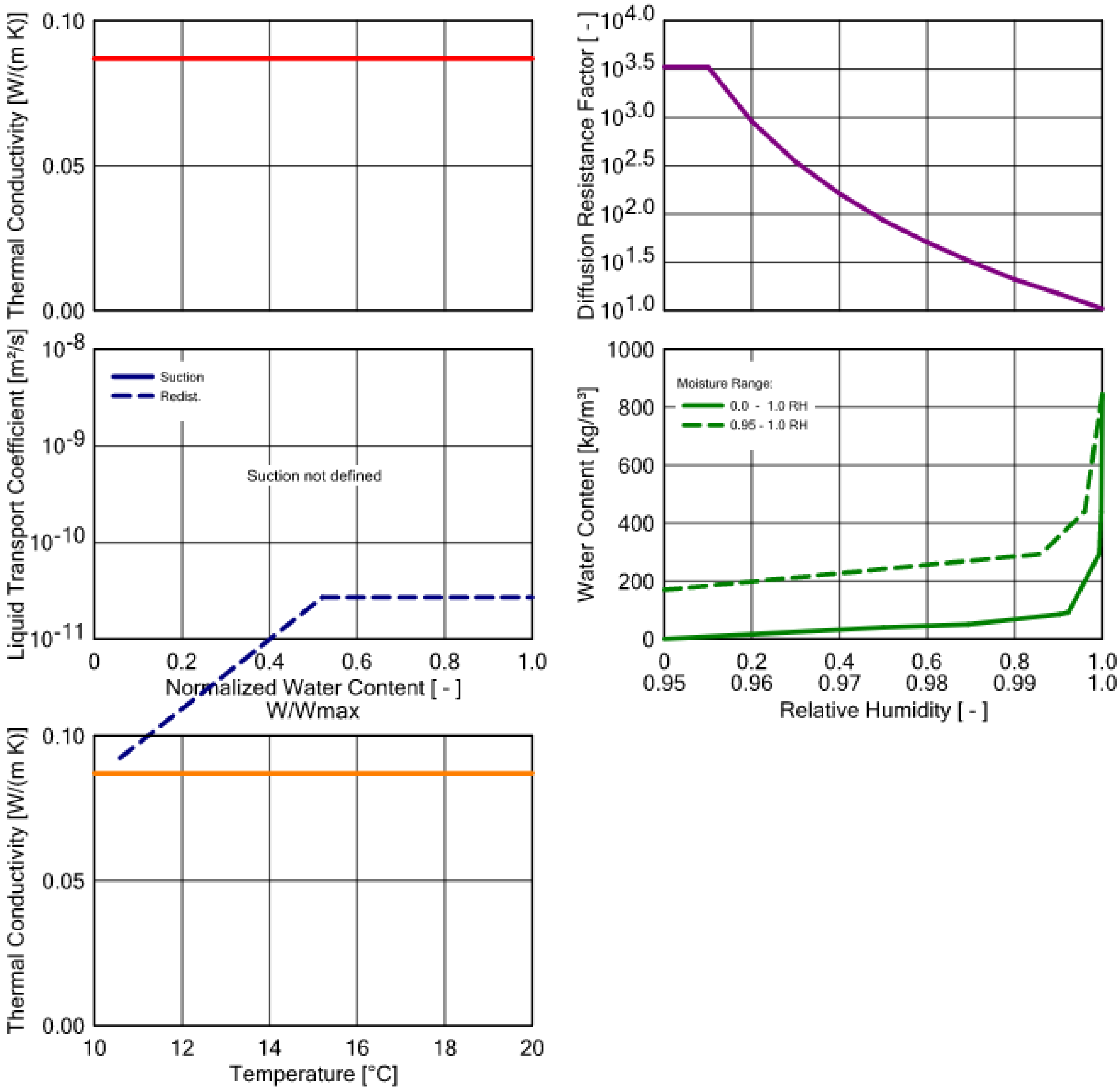
Material: *15 Perm membrane

Property	Unit	Value
Bulk density	[kg/m³]	280
Porosity	[m³/m³]	0.001
Specific Heat Capacity, Dry	[J/(kg K)]	1500
Thermal Conductivity, Dry, 10°C	[W/(m K)]	2.3
Water Vapour Diffusion Resistance Factor	[-]	230
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	0.0002



Material: *Plywood #1 IRC

Property	Unit	Value
Bulk density	[kg/m³]	445
Porosity	[m³/m³]	0.8455
Specific Heat Capacity, Dry	[J/(kg K)]	1880
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.087
Water Vapour Diffusion Resistance Factor	[-]	3317
Reference Water Content	[kg/m³]	49.84
Free Water Saturation	[kg/m³]	440
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.0037



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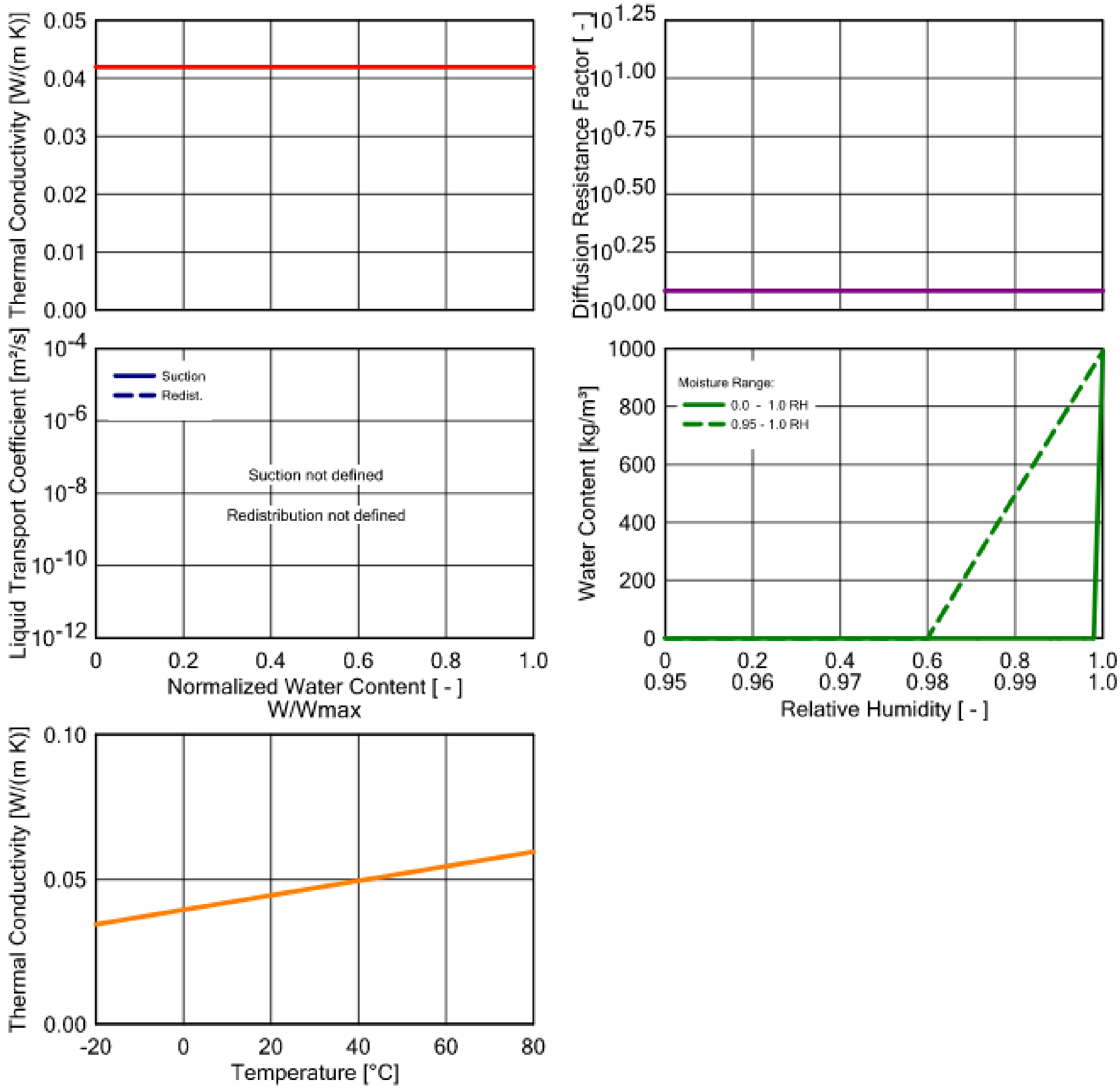
Material: *R19 Fiberglass Batt

Property	Unit	Value
Bulk density	[kg/m³]	11.5
Porosity	[m³/m³]	0.999
Specific Heat Capacity, Dry	[J/(kg K)]	840
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.042
Water Vapour Diffusion Resistance Factor	[-]	1.21
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	0.00025



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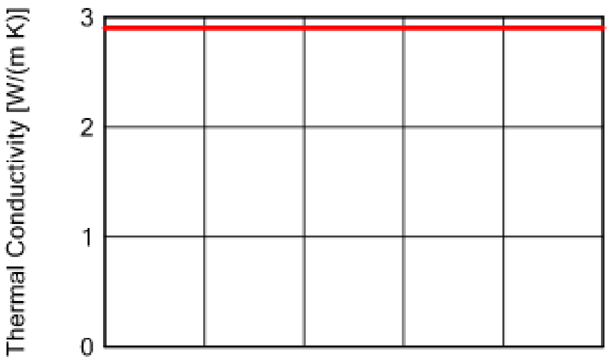
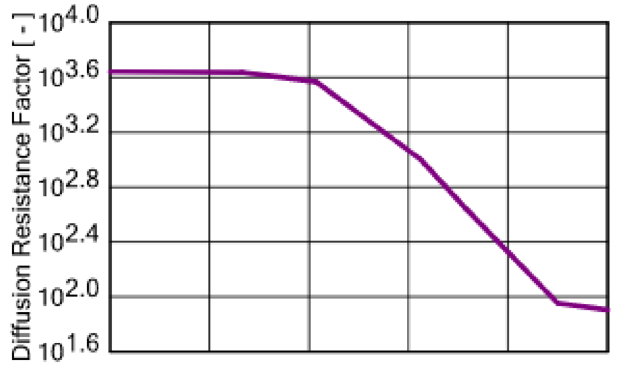
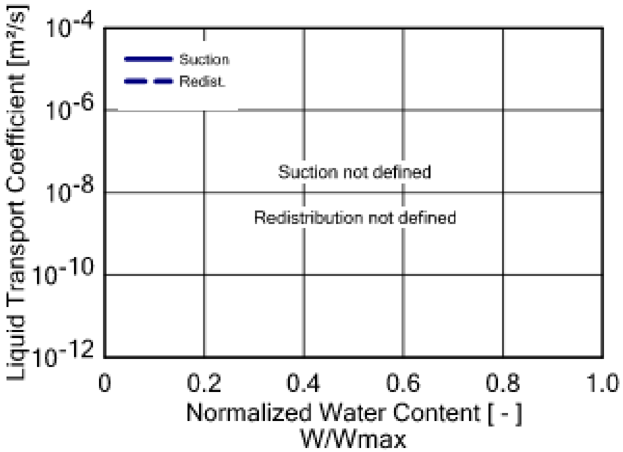
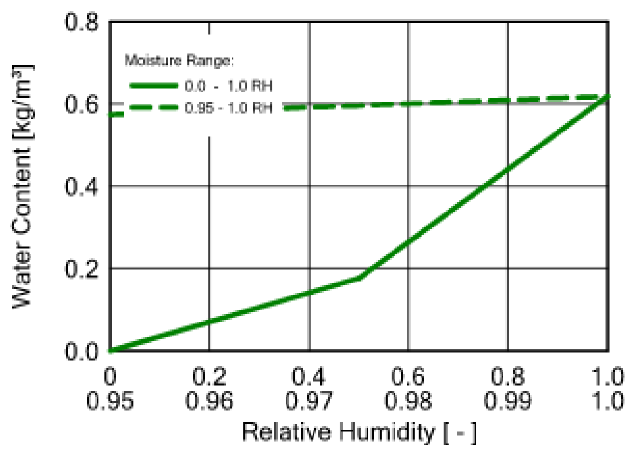
Material: *6 mil Poly

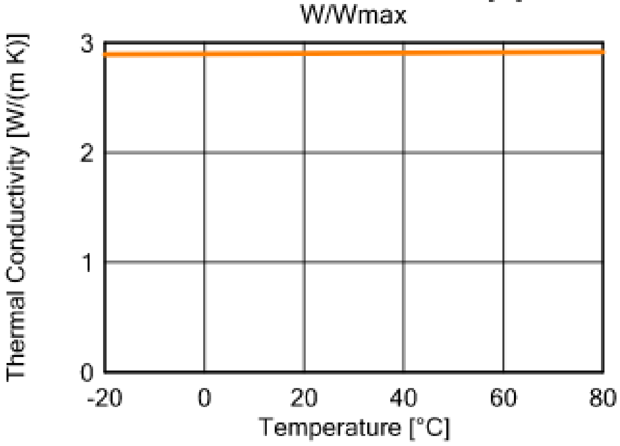
Property	Unit	Value
Bulk density	[kg/m³]	65
Porosity	[m³/m³]	0.001
Specific Heat Capacity, Dry	[J/(kg K)]	2300
Thermal Conductivity, Dry, 10°C	[W/(m K)]	2.9
Water Vapour Diffusion Resistance Factor	[-]	4380
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





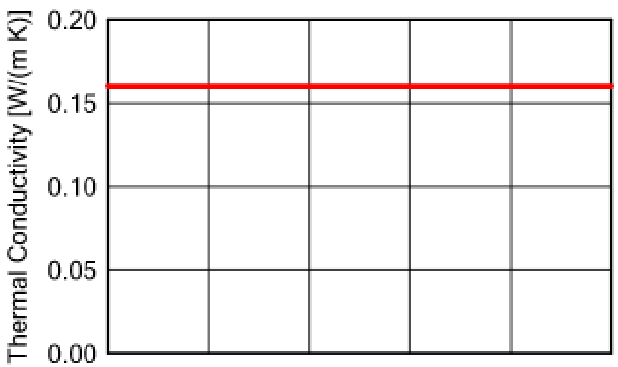


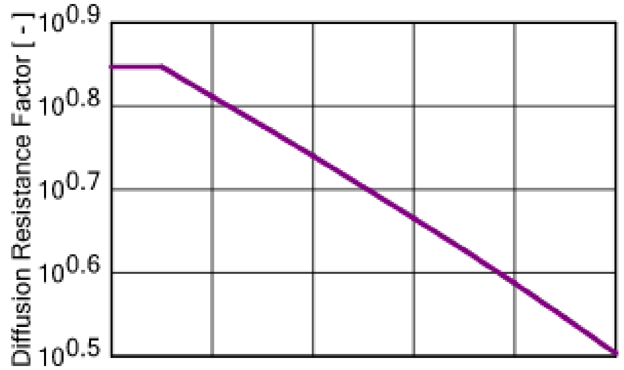


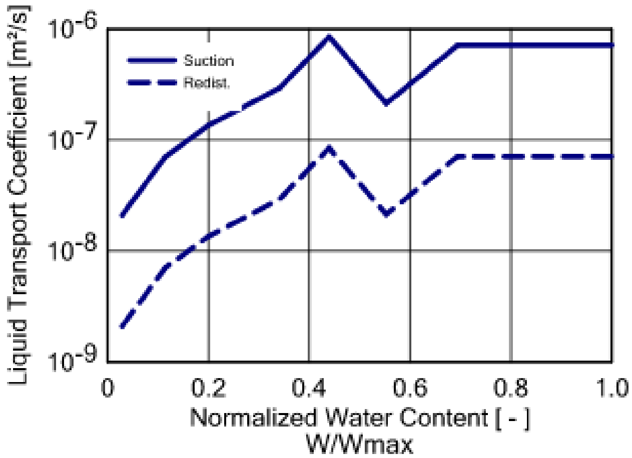


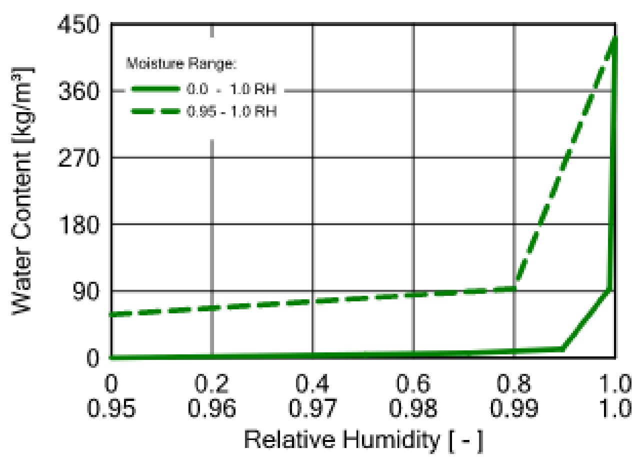
Material: Interior Gypsum Board

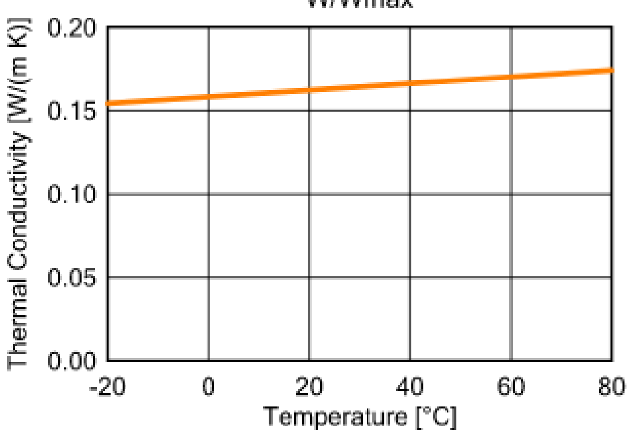
Property	Unit	Value
Bulk density	[kg/m³]	625
Porosity	[m³/m³]	0.706
Specific Heat Capacity, Dry	[J/(kg K)]	870
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.16
Water Vapour Diffusion Resistance Factor	[-]	7.03
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	0.0002





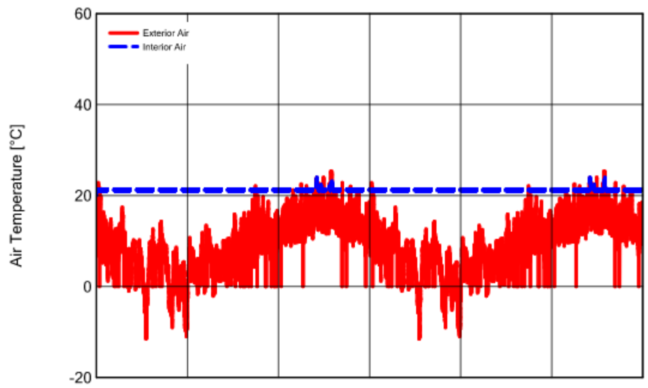


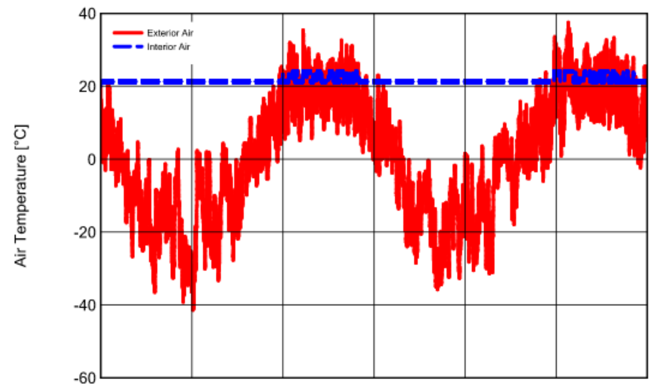




Environment Canada Climatic Data

Temperature

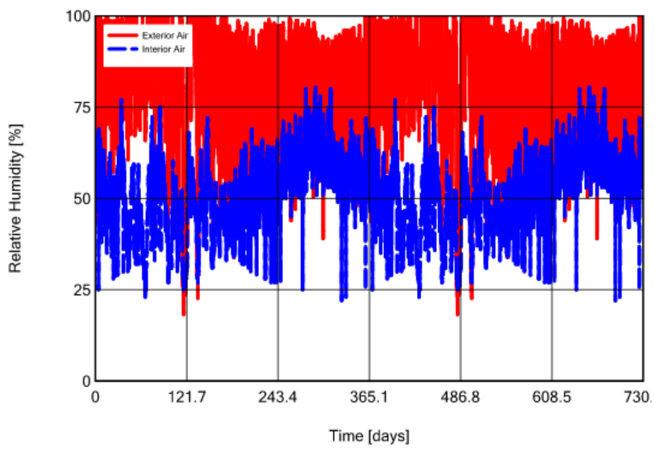


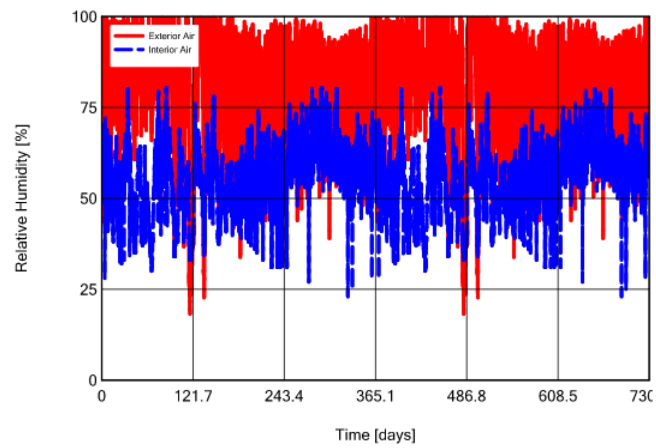


Vancouver 1980

Winnipeg 1995-1996

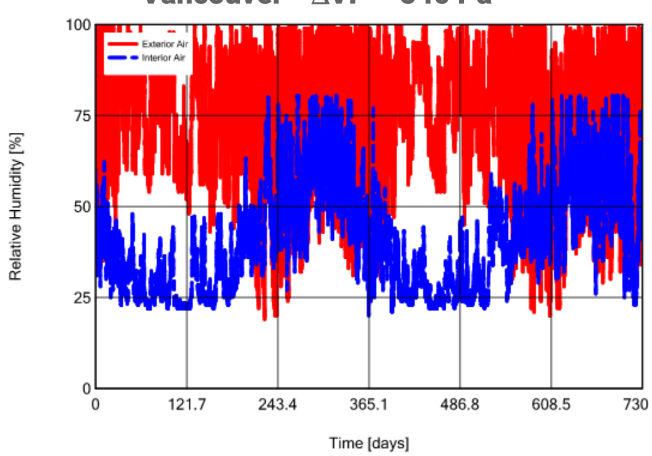
Relative Humidity

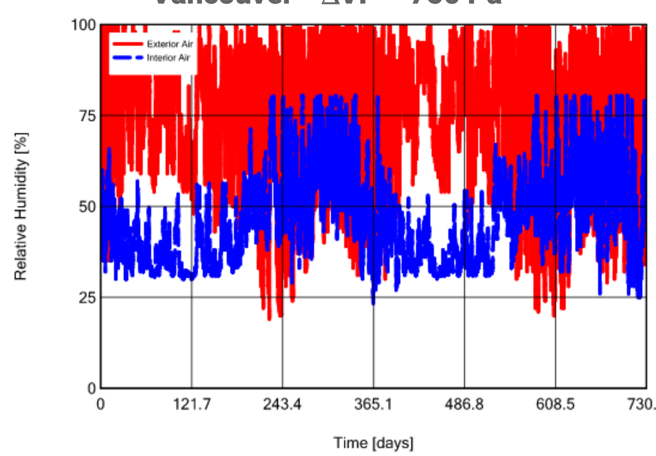




Vancouver - ΔVP = 540 Pa

Vancouver - ΔVP = 750 Pa



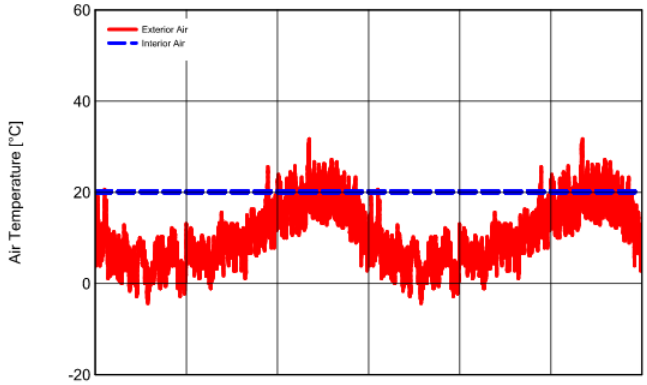


Winnipeg - ΔVP = 540 Pa

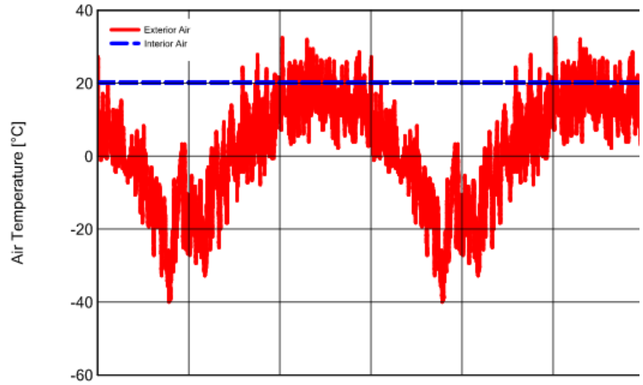
Winnipeg - ΔVP = 750 Pa

ASHARE Year 1 (WUFI File)

Temperature

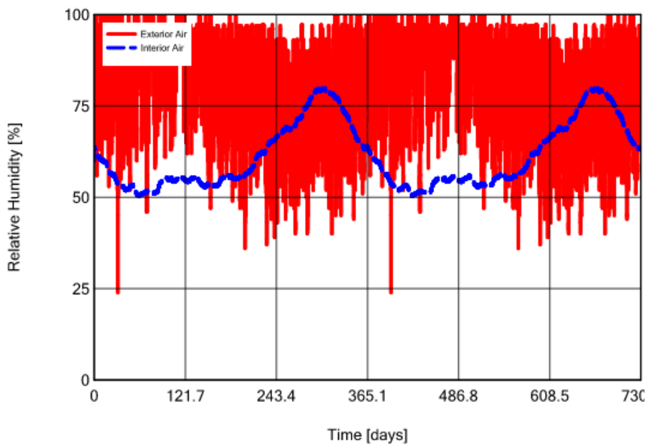


Vancouver

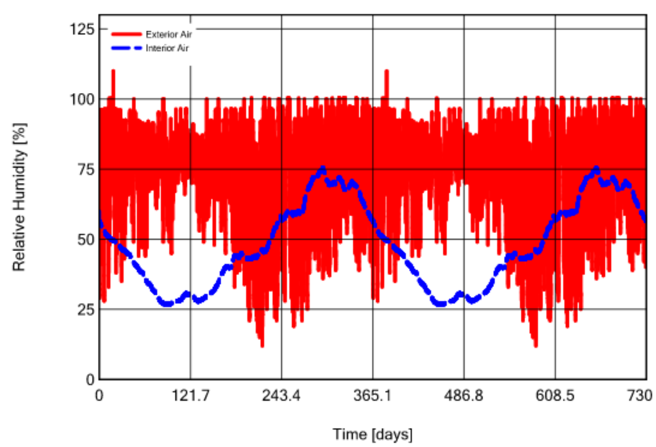


Winnipeg

Relative Humidity

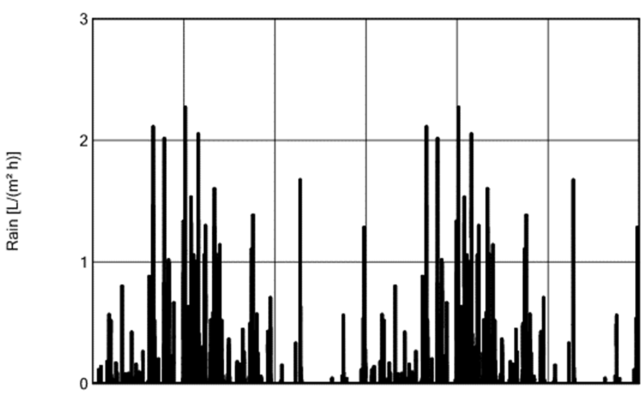


Vancouver

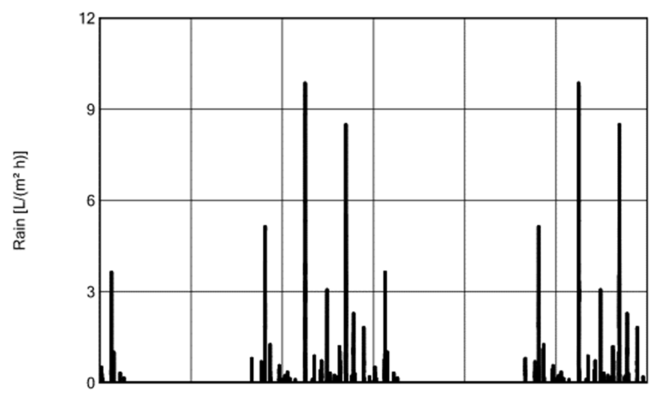


Winnipeg

Rain

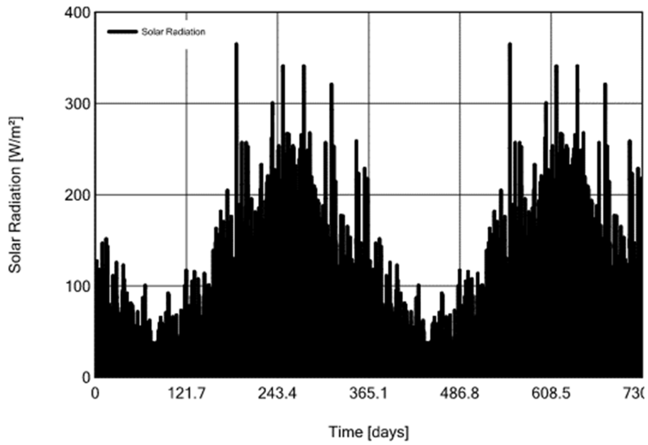


Vancouver

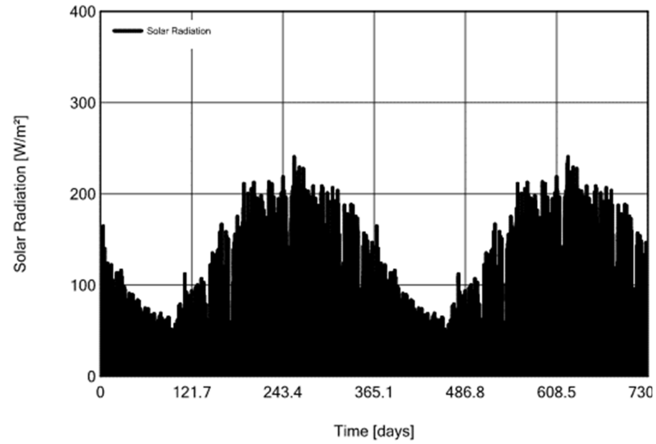


Winnipeg

Solar Radiation



Vancouver



Winnipeg

Air Leakage Rates

In the model, the air leakage is simulated by adding a moisture source to the interior face of the 936 connect insulation based on the following equation:

$$m = Q \cdot (W_{indoor} - W_{surface})$$

Where

m = moisture source rate (kg/s m²)

Q = the air leakage rate (m³/s)

W_{indoor} = the moisture content of the indoor air (kg/m³)

$W_{surface}$ = the moisture content of the air at the insulation interface (kg/m³)

The air leakage rate is calculated using a sharp-edge orifice equation as follows:

$$Q = C_d \cdot A \cdot \left(\frac{2\Delta P}{\rho}\right)^{0.5}$$

Where

Q = the air leakage rate (m³/s)

C_d = the discharge coefficient $(\frac{\pi}{\pi+2})$

A = the area of the orifice (m²)

ΔP = the pressure difference (Pa)

ρ = the density of air (kg/m³)

Using this formula, the equivalent orifice area was calculated for the characteristic leakage rate (for example 0.02 L/s m² at 75 Pa). Then the same equation is used to calculate the airflow for a pressure difference produced by hourly wind pressure, stack effect and mechanical ventilation.

The wind pressure difference is calculated using the stagnation pressure equation (from Bernoulli's equation) as follows:

$$\Delta P = \frac{1}{2} \cdot C_p \cdot \rho \cdot v^2$$

where

ΔP = the pressure difference (Pa)

C_d = the wind surface pressure coefficient (-)

ρ = the density of air (kg/m^3)

V = the wind speed (m/s)

The average wind pressure coefficient was utilized as VTT reported (1994[5]) by the following equation:

$$C_a = \sum_{0}^{4} C_i \theta^i$$

where

C_o = 0.587888

C_1 = 6.47584×10^{-3}

C_2 = -4.48640×10^{-4}

C_3 = 3.68668×10^{-6}

C_4 = -8.65351×10^{-9}

θ = the angle between window direction and normal to the wall surface (degrees)

The stack effect pressure difference is calculated using the following formulae (ASHRAE Handbook of Fundamentals (2017):

$$.\Delta P = \rho_o \cdot \left(\frac{T_O - T_I}{T_I}\right) \cdot g \cdot (H_{NPL} - H)$$

where

ΔP = the pressure difference (Pa)

ρ = the density of air (kg/m^3)

T_o = the outdoor temperature (°C)

T_i = the indoor temperature (°C)

g = the gravitational acceleration (9.81 m/s^2)

H = the height above the reference plane (m)

H_{NPL} = the height of the neutral pressure level above the reference plane (m)

The mechanical ventilation pressure difference is set to the depressurization value of 10 Pa as per previous work done by Brown et al 2007[6], NRC and VTT to support the provisions in 9.25.5.

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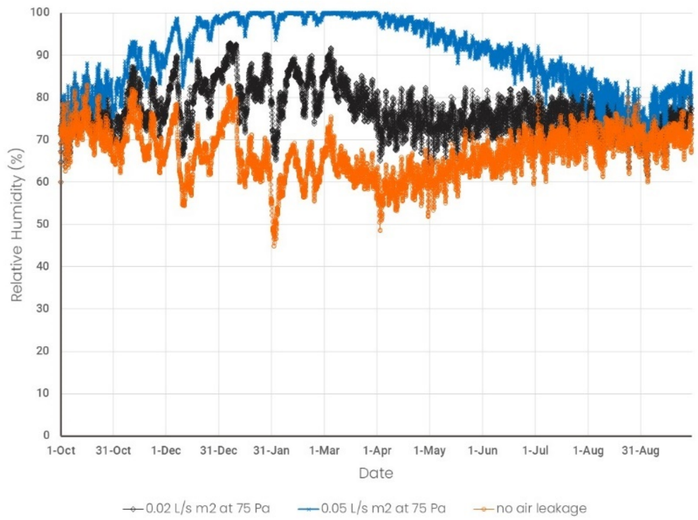
[5] VTT. 1994. TCC2D – Simulations on the Performance of Air Barriers in Ottawa, An Interim Report.

[6] Brown, W., P. Roppel, M. Lawton. 2007. Developing a Design Protocol for Low Air and Vapour Permeance Insulating Sheathing in Cold Climates. Proceedings of the Thermal Performance of the Exterior Envelopes of Whole Buildings X International Conference.

Appendix B: Vancouver Results

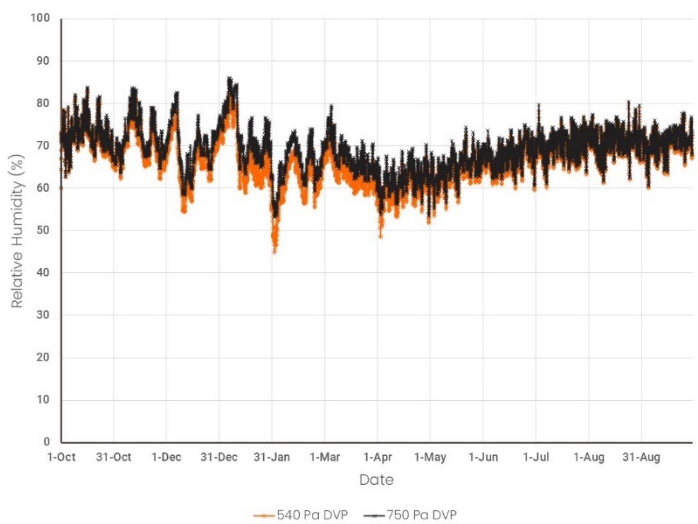
Airtightness



Constant Parameters	
Indoor Humidity	540 Pa ΔVP
Interior Vapour Control	35 ng/m² Pa s
Orientation	North
Rain Leaks	None
Variable: Air Leakage	
Blue	0.05 L/s m² at 75 Pa
Black	0.02 L/s m² at 75 Pa
Orange	No air leakage

Figure A1: Impact of air leakage on the risk of condensation at the interior surface of the 936 Connect Insulation in Vancouver

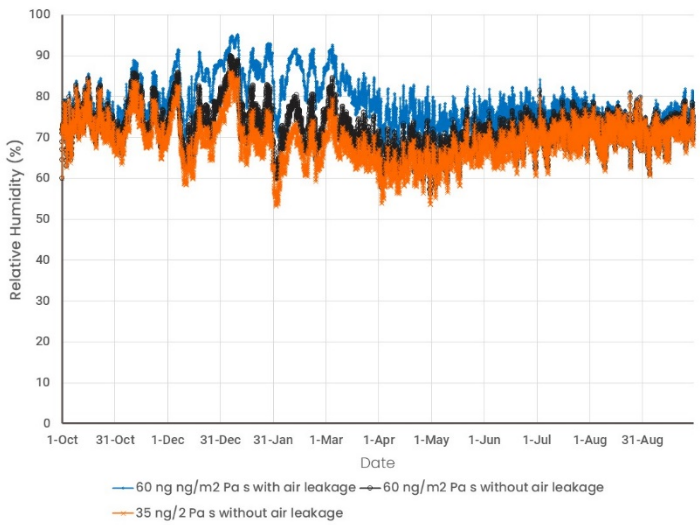
Indoor Humidity



Constant Parameters	
Interior Vapour Control	35 ng/Pa s m²
Orientation	North
Rain Leaks	None
Air Leakage	None
Variable: Indoor Humidity	
Black	750 Pa ΔVP
Orange	540 Pa ΔVP

Figure A2: Impact of indoor humidity on the risk on condensation risk at the interior surface of the 936 Connect Insulation in Vancouver

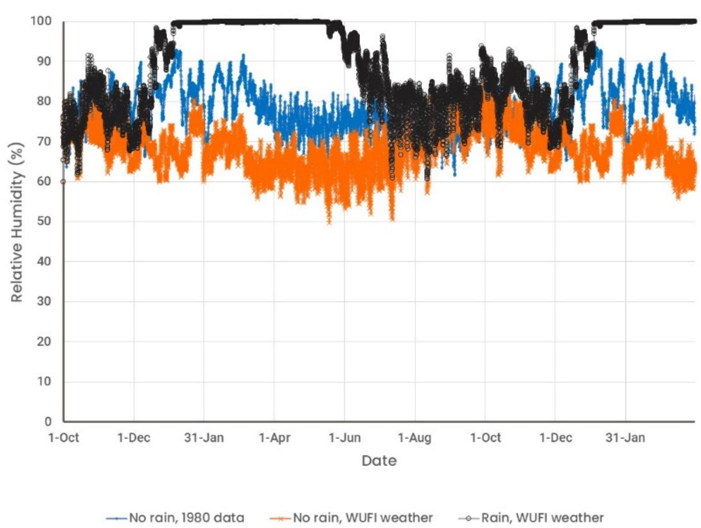
Interior Vapour Control



Constant Parameters	
Interior Humidity	750 Pa ΔVP
Orientation	North
Rain Leaks	None
Variable: Interior Vapour Control and Air Leakage	
Black	60 ng/Pa s m^2, no air leakage
Orange	35 ng/Pa s m^2, no air leakage
Blue	60 ng/Pa s m^2, 0.02 L/s m^2 at 75 Pa Air Leakage

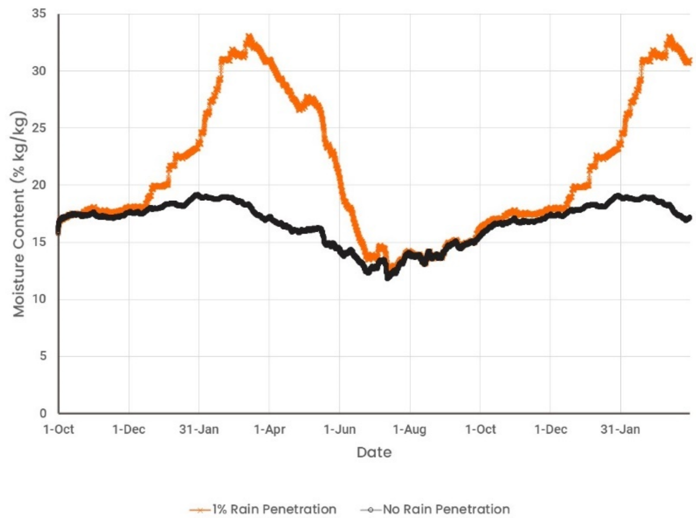
Figure A3: Impact of interior vapour control on the risk of Condensation at the interior surface of the 936 Connect Insulation in Vancouver

Rain Leaks



Constant Parameters	
Interior Humidity	540 Pa ΔVP (ISO 13788 Class 2)
Interior Vapour Control	35 ng/Pa s m^2
Orientation	North
Air Leakage	None
Variable: Rain Leaks and Climate Data	
Black	Rain leaks, WUFI weather file
Orange	No rain leaks, WUFI weather file
Blue	No rain leaks, 1980 Environment Canada data

Figure A4: Impact of 1% rain penetration for the 936 Connect wall assembly in Vancouver



Parameters	
Interior Humidity	540 Pa ΔVP (ISO 13788 Class 2)
Interior Vapour Control	6 mil polyethylene
Orientation	North
Air Leakage	None
Variable: Rain Leaks	
Black	No rain leaks, WUFI weather file
Orange	Rain leaks, WUFI weather file

Figure A5: Moisture content of plywood Sheathing for Code minimum wall subject to 1% Rain penetration at the interior face of the plywood sheathing in Vancouver