Moisture Performance of Exterior Insulated High-R Wall Systems

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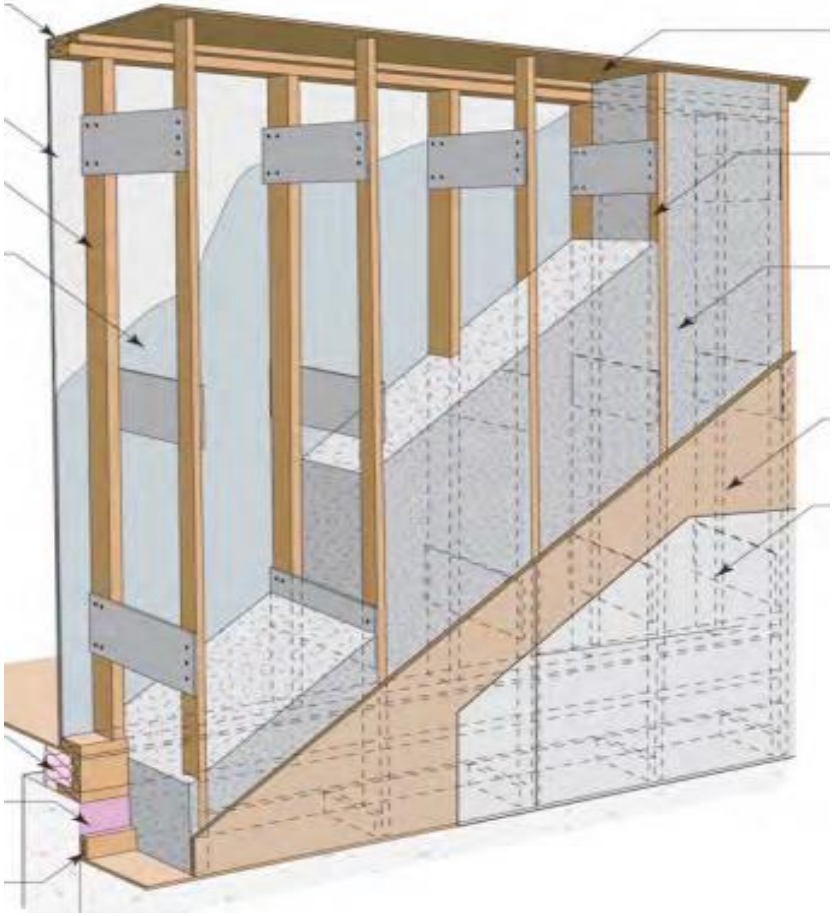
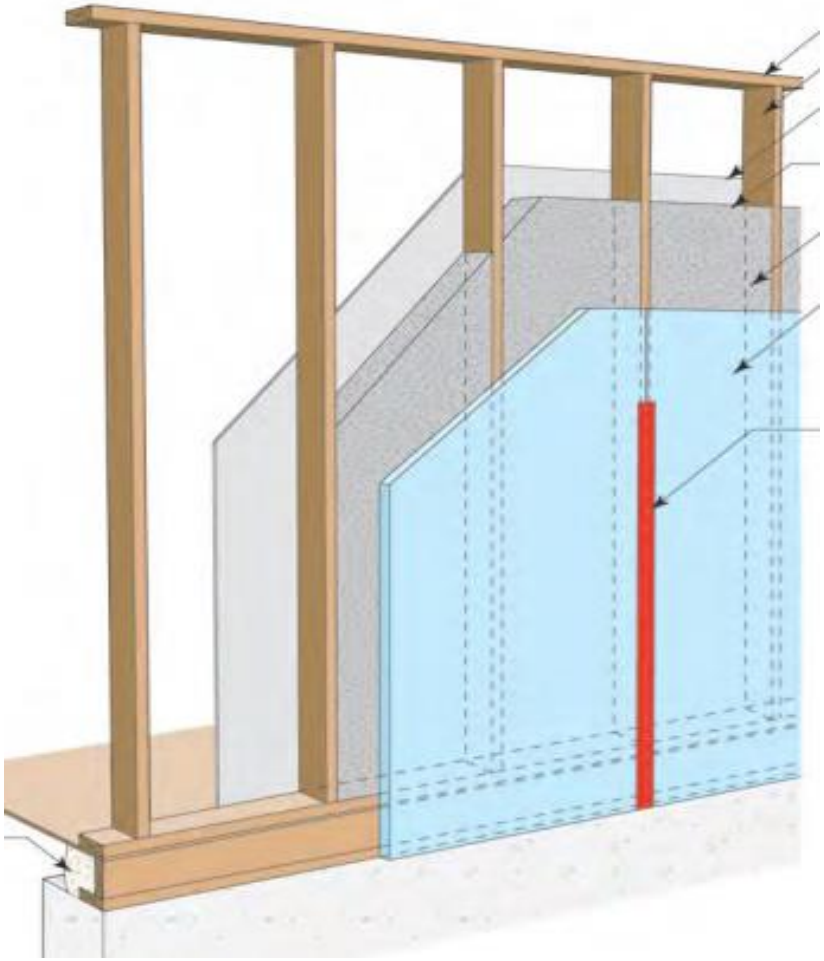
Introduction





(Straube and Smegal, 2009)

Background

Objective: To develop an evidence-based matrix of suitable high-R wall systems for a range of climate zones.

Approach: Validated hygrothermal modelling

Scope: Interpretation of modelled data from six types of high-R walls in 8 different climates and 2 levels of interior RH.

Review of Literature:
High-R Wall Monitoring Studies

→ The air control layer is very important in cold climates - even small deficiencies can lead to moisture damage

→ An interior vapor control layer should not be required where there is sufficient exterior insulation

→ Using higher permeance exterior insulation products may help reduce the moisture durability risk

→ Interior relative humidity is a critical factor in the long term moisture durability of typical residential wall assemblies.

Hygrothermal Models: Assemblies

→ WUFI Pro 5.1

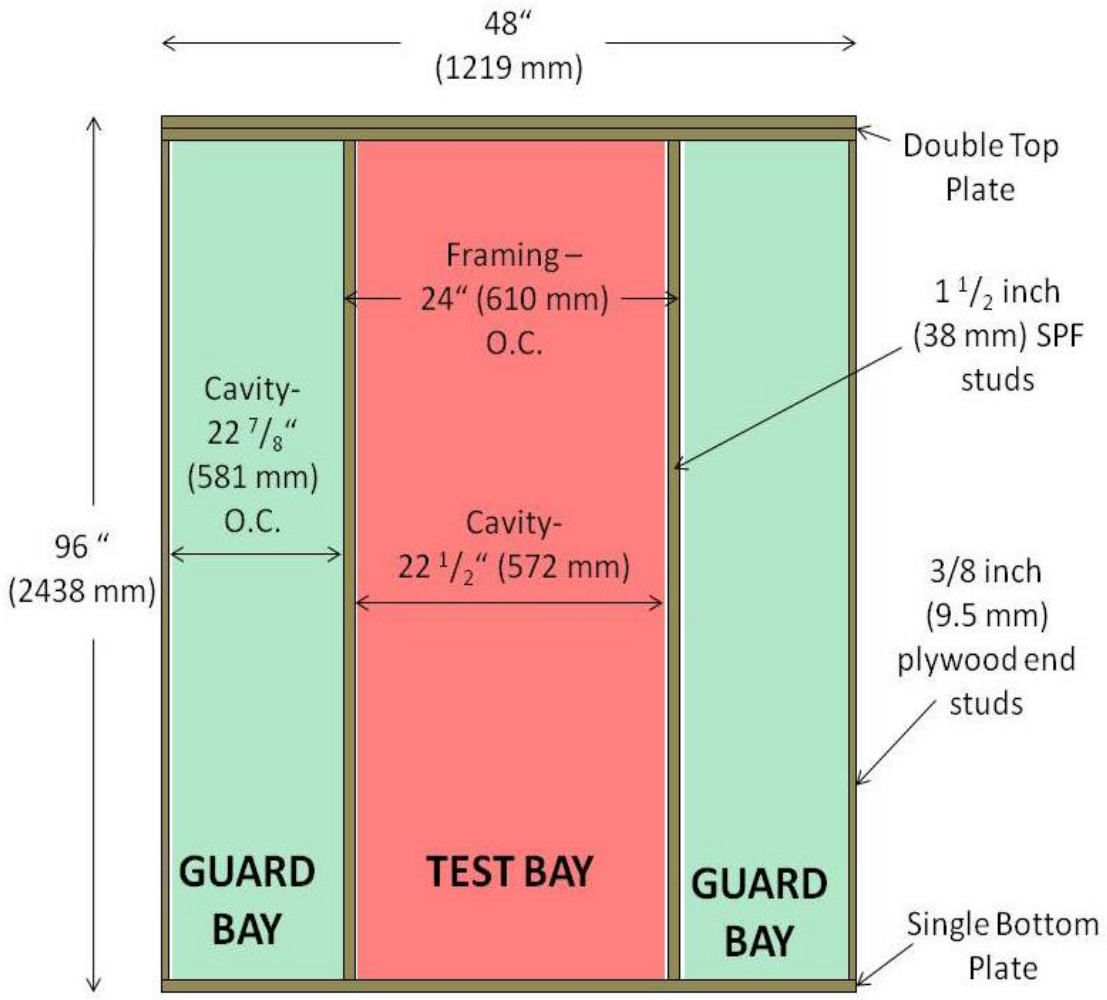
WALL	Datum	Double Stud	Polyisocyanurate (PIC)	Extruded Polystyrene (XPS)	Mineral wool Insulated Sheathing (MW)	Expanded Polystyrene (EPS)
ASSEMBLY LAYERS	■ Cladding ■ Air Gap ■ SBPO Membrane ■ OSB Sheathing ■ Fiberglass Insulation ■ 6 mil Poly ■ Drywall/ Latex Paint	■ Cladding ■ Air Gap ■ SBPO Membrane ■ OSB Sheathing ■ Cellulose Insulation ■ 6 mil Poly ■Drywall/Latex Paint	■ Cladding ■ Air Gap ■ PIC Insulation ■ SBPO Membrane ■ OSB Sheathing ■ Fiberglass Insulation ■Drywall/Latex Paint	■ Cladding ■ Air Gap ■ XPS Insulation ■ SBPO Membrane ■ OSB Sheathing ■ Fiberglass Insulation ■Drywall/Latex Paint	■ Cladding ■ Air Gap ■ Rockwool Insulation ■ SBPO Membrane ■ OSB Sheathing ■ Fiberglass Insulation ■ 6 Mil Poly ■Drywall/Latex Paint	■ Cladding ■ Air Gap ■ EPS Insulation ■ SBPO Membrane ■ OSB Sheathing ■ Fiberglass Insulation ■Drywall/Latex Paint

Validating the Model

→ To validate the hygrothermal model, it was compared to field monitoring data

→ Used 2 years of data from the NewBuilds-NSERC/ University of Waterloo High-R Wall Study

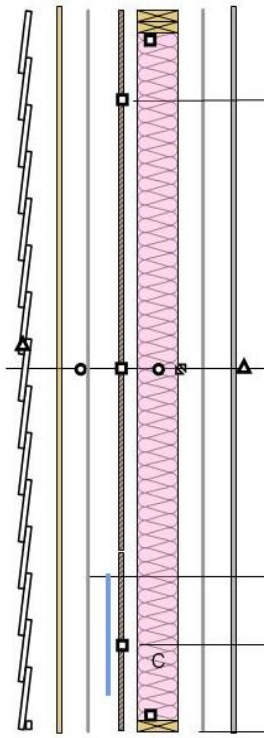
UW High-R Wall Monitoring Study



Framing pattern:
All Test Walls

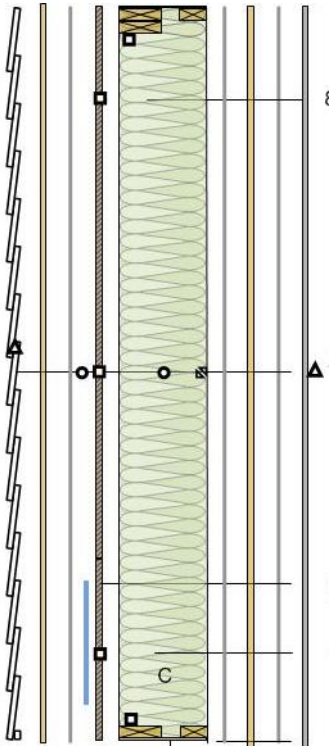
UW High-R Wall Monitoring Study

Datum Wall



R-24
(installed)

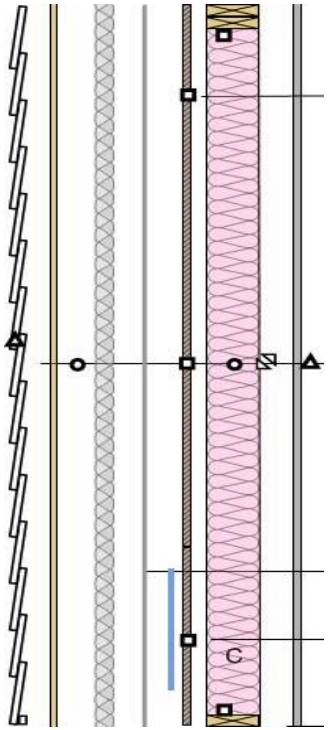
Double Stud Wall



R-35
(installed)

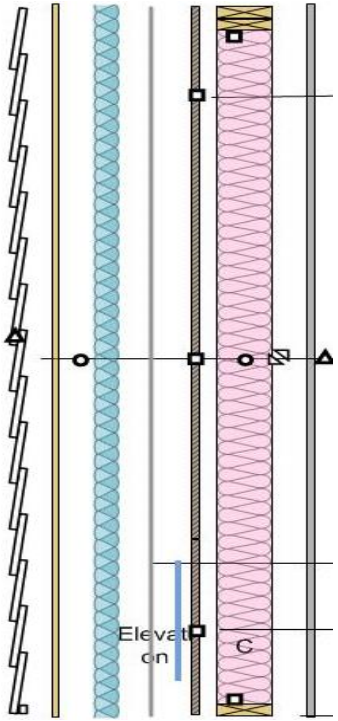
UW High-R Wall Monitoring Study:

PIC



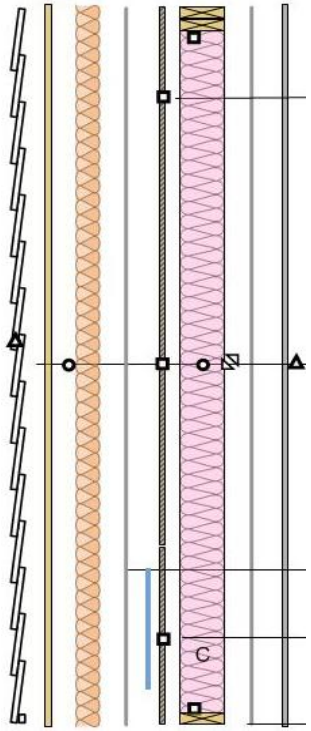
R-35
(installed)

XPS



R-35
(installed)

MW



R-34
(installed)

Exterior Insulated Walls

UW High-R Wall Monitoring Study:

Instrumentation

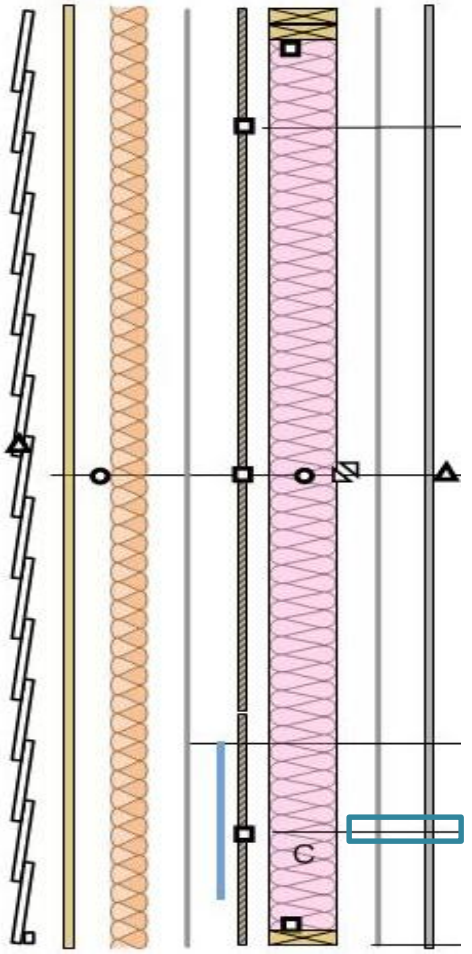
2- Temperature Sensors

2- Relative Humidity/ Temperature Sensors

5- Moisture Content/ Temperature Sensors

Wetting Mat

Air Injection Port

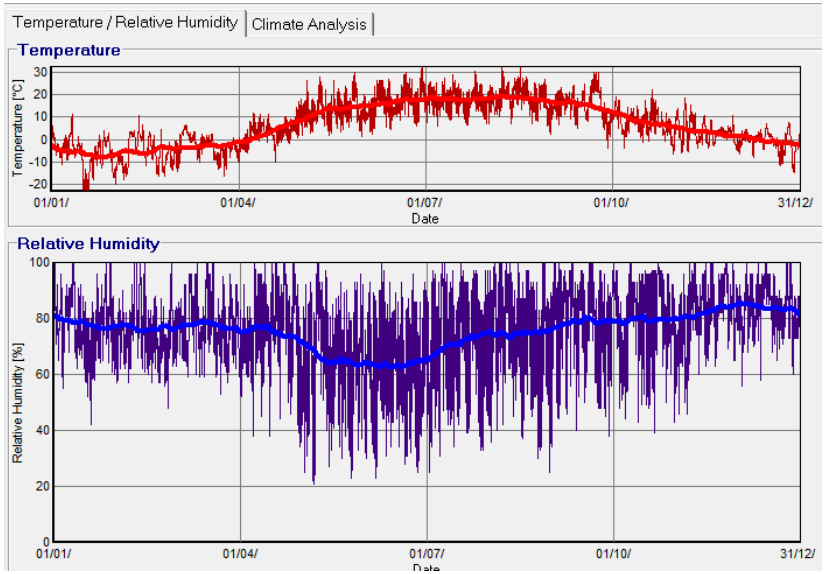


The BEG Hut

- North and south elevations were used for testing
- Natural weather exposure (Waterloo, Ontario)
- Interior Conditions- 21 ˚C, 40% RH (winter)

Hygrothermal Models: Validation

- → Comparing UW Monitoring Data to WUFI Model Data
  - → Compared over a 2 year period
  - → Using custom weather file in WUFI
  - → Using custom OSB moisture storage function – based on FP Innovations pressure plate data



Hygrothermal Models: Validation

- → Validated cladding temperatures
- → Validated sheathing temperatures
- → Validated sheathing moisture contents

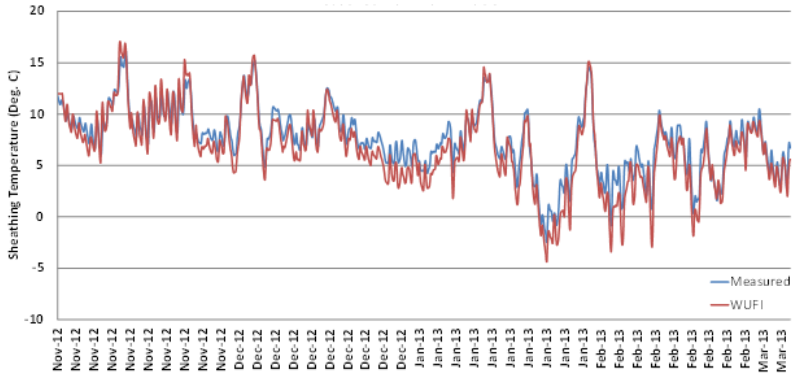


Figure 21- Temperature Plot for RW Wall Comparing Measured OSB Temperature to WUFI Model over the First 125 days

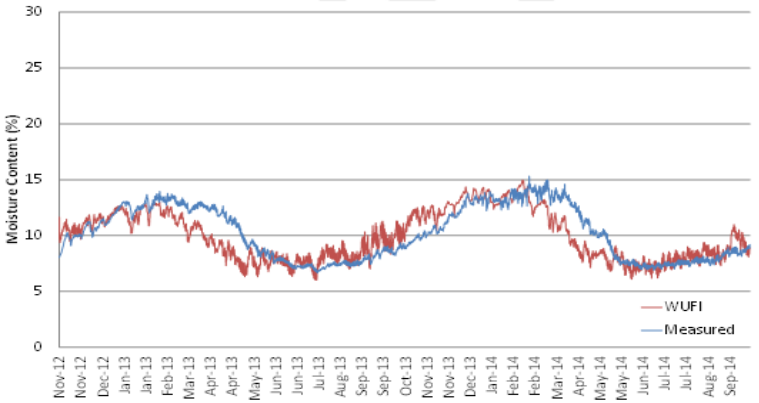
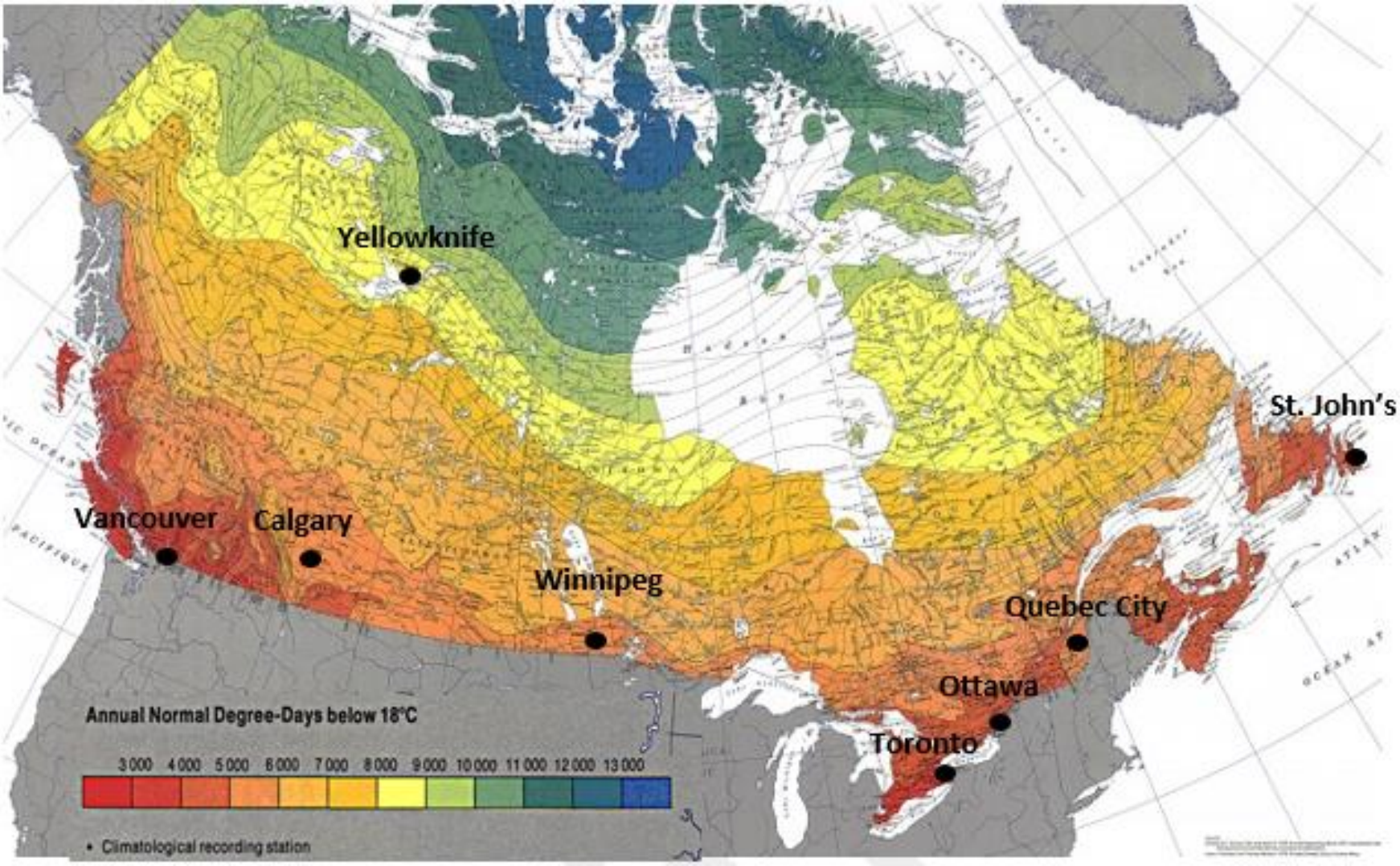


Figure 24- Moisture Content Plot for Double Stud Wall- Comparing Measured Data to WUFI Model over 2 Year Span

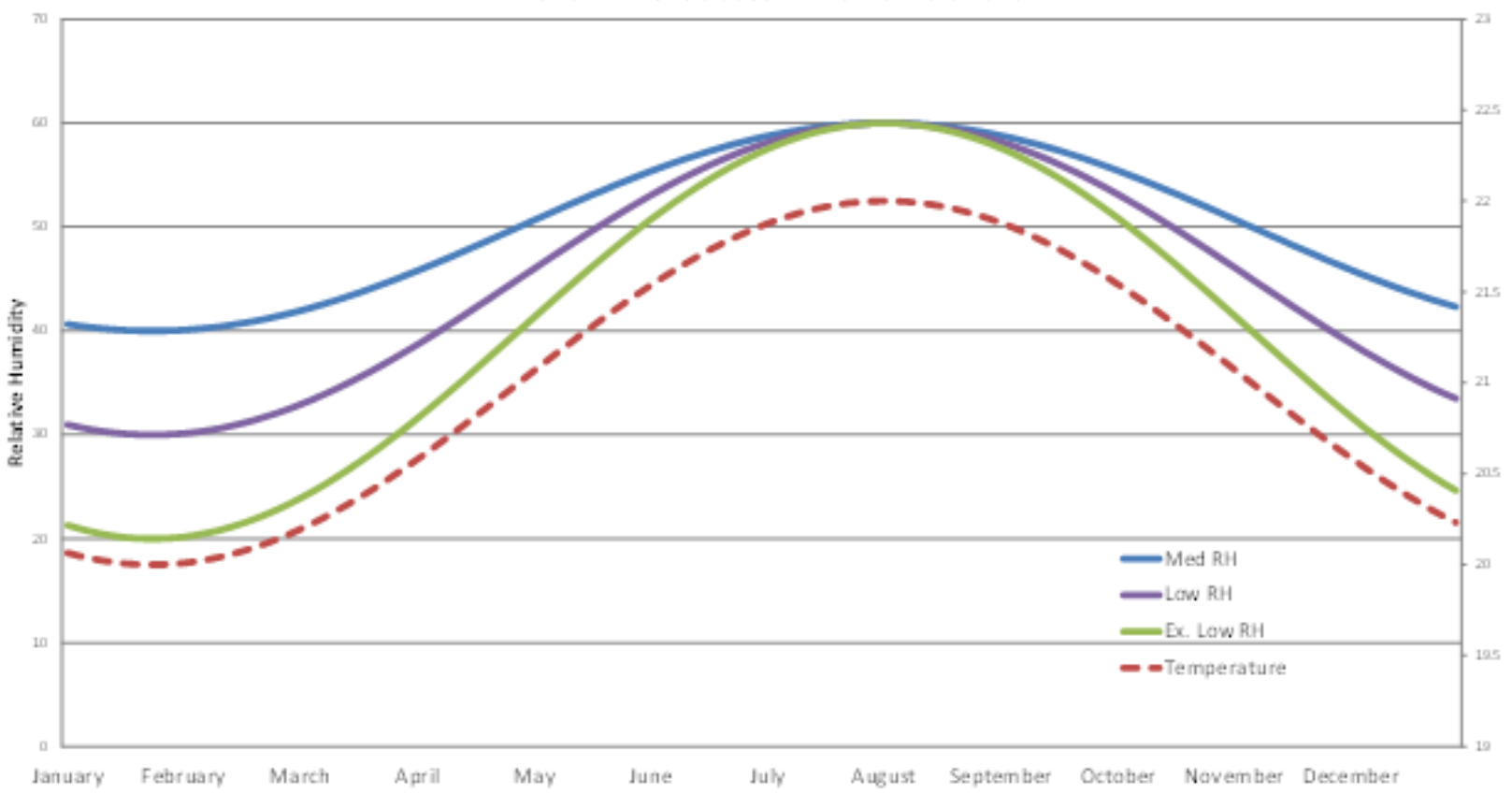
Hygrothermal Models: Weather



Hygrothermal Models: Weather

Location Modeled	2% Design Temp.		Heating Degree Days		Precipitation		Driving Rain		Comparable US City
	°C	°F	°C	°F	mm	Inches	mm	Inches	
Vancouver, BC	-7 °C	19 °F	2910	5238	1196	47	950	37	Seattle, WA
St. John's NL	-15 °C	5 °F	4881	8786	914	36	900	35	Bangor, ME
Toronto, ON	-20 °C	-4 °F	3800	6840	606	24	225	9	Buffalo, NY
Ottawa, ON	-25 °C	-13 °F	4440	7992	586	23	400	16	Montpellier, VT
Quebec City, QC	-25 °C	-13 °F	5080	9144	807	32	375	15	Burlington, VT
Calgary, AB	-30°C	-22 °F	5000	9000	304	12	250	10	Billings, MO
Winnipeg, MB	-33 °C	-27 °F	5670	10206	309	12	200	8	Grand Forks, ND
Yellowknife, NWT	-41 °C	-42 °F	8170	14706	289	11	N/A		Fairbanks, AK

Hygrothermal Models: Interior Conditions



Results – Baseline Simulations

= MC < 20%, no mold growth

= MC is 20 to 28%, potential for mold growth

= MC > 28%, moisture problems expected, this design is NOT recommended

	Wall Construction					Vancouver		St. John's		Toronto		Ottawa		Quebec City		Calgary		Winnipeg			Yellowknife		
						2.5% Temp. = -7		2.5% Temp. = -15		2.5% Temp. = -20		2.5% Temp. = -25		2.5% Temp. = -25		2.5% Temp. = -30		2.5% Temp. = -33			2.5% Temp. = -41		
						HDD 2910		HDD 4881		HDD 3800		HDD 4440		5080		HDD 5000		HDD 5670			HDD 8170		
Wall	Cavity Insulation	Cavity Depth	Exterior Insulation	Ext. Insul. Thickness	Vapour Control	Low RH 30/55%	Med. RH 40/60%	Low RH 30/55%	Med. RH 40/60%	Low RH 30/55%	Med. RH 40/60%	Low RH 30/55%	Med. RH 40/60%	Low RH 30/55%	Med. RH 40/60%	Low RH 30/55%	Med. RH 40/60%	Ex.Low RH 20/50%	Low RH 30/55%	Med. RH 40/60%	Ex.Low RH 20/50%	Low RH 30/55%	Med. RH 40/60%
Datum	Fiberglass	5.5 "	none	0	Polyethylene sheet	10%	11%	11%	11%	11%	11%	10%	10%	11%	11%	8%	8%	10%	10%	10%	11%	11%	12%
PIC	Fiberglass	5.5"	polyiso-cyanurate	2"	Latex paint+primer	10%	11%	12%	15%	11%	13%	12%	18%	13%	19%	14%	21%	12%	20%	30%	15%	30%	35+%
					Polyethylene sheet												7%			8%		7%	
XPS	Fiberglass	5.5"	extruded polystyrene	2.5 "	Latex paint+primer	10%	11%	12%	15%	11%	13%	12%	14%	13%	19%	14%	21%	12%	20%	30%	15%	30%	35+%
					Polyethylene sheet												7%			8%		7%	
EPS	Fiberglass	5.5"	expanded polystyrene	3.0"	Latex paint+primer	10%	11%	12%	17%	11%	14%	13%	20%	14%	20%	15%	24%	12%	21%	34%	17%	34%	35+%
					Polyethylene sheet								8%		8%		7%			8%		7%	
MW	Fiberglass	5.5"	mineral wool insulated sheathing	3.0"	Latex paint+primer		12%						12%		15%		16%	12%	17%	25%	13%	25%	35+%
					Polyethylene sheet	8%	9%	8%	8%	9%	9%	8%	8%	9%	9%	7%	7%	7%	8%	8%	7%	7%	8%
Double Stud	Cellulose	11.25"	none	0	Polyethylene sheet	12%	13%	13%	14%	13%	13%	14%	14%	14%	14%	13%	13%	15%	15%	14%	16%	16%	16%

General Notes:

a. 2.5% Design Temperature and Heating Degree Days (HDD) from NBCC 2010
b. Walls are residential wood frame with light-colored, thin cladding facing north: this is a worse-case scenario for cold-weather diffusion wetting
c. Results are for OSB sheathing. Plywood sheathing values will be equal or lower. OSB permeance is always over 60 ng/Pa·s·m² in exterior sheathing applications.
d. Sheathings of DensGlas, FiberBoard, and Gypsum Board are all very vapor permeable and hence will have lower moisture contents
e. Thicker exterior insulation will always result in lower wintertime sheathing moisture contents
f. Effective Air Barrier is assumed to be installed, as is proper rain control
g. MC values are for inner 3 mm OSB sheathing

Results – Increased Insulation Ratio

= MC < 20%, no mold growth = MC is 20 to 28%, potential for mold growth = MC > 28%, moisture problems expected, this design is NOT recommended

						Winnipeg R-12 HDD 5777		Winnipeg R-18 HDD 5777		Winnipeg R-24 HDD 5777		Yellowknife R-12 HDD 8166		Yellowknife R-18 HDD 8166		Yellowknife R-24 HDD 8166	
	Wall Construction																
Wall	Cavity Insulation	Cavity Depth	Exterior Insulation	Ext. Insul. Thickness	Vapour Control	Low RH 30/55%	Med. RH 40/60%	Low RH 30/55%	Med. RH 40/60%	Low RH 30/55%	Med. RH 40/60%	Low RH 20/50%	Med. RH 30/60%	Low RH 20/50%	Med. RH 30/60%	Low RH 20/50%	Med. RH 30/60%
PIC	Fiberglass	5.5"	polyiso-cyanurate	2.0" 3.0" 4.0"	Latex paint+primer	20%	30%	15%	23%		18%		35+%	15%	30%	12%	15%
					Polyethylene sheet		8%		8%		8%		7%		7%		7%
XPS	Fiberglass	5.5"	extruded polystyrene	2.5" 5.0"	Latex paint+primer	20%	30%	15%	23%		18%		35+%	15%	30%	12%	15%
					Polyethylene sheet		8%		8%		8%		7%		7%		7%
EPS	Fiberglass	5.5"	expanded polystyrene	3.0" 4.5" 6.0"	Latex paint+primer	21%	34%	17%	24%		19%		35+%	17%	34%	12%	17%
					Polyethylene sheet		8%		8%		8%		7%		7%		7%
MW	Fiberglass	5.5"	Mineral wool Insulated Sheathing	3.0" 4.5" 6.0"	Latex paint+primer	17%	25%	12%	19%		14%		35+%	13%	25%	10%	13%
					Polyethylene sheet	8%	8%		8%		8%		8%		7%	7%	7%

Results – Decreased Insulation Ratio

RDH

= MC < 20%, no mold growth = MC is 20 to 28%, potential for mold growth = MC > 28%, moisture problems expected, this design is NOT recommended

	Wall Construction					Vancouver R-12 (RSI 2.1) HDD 2910		Vancouver R-6 (RSI 1.0) HDD 2910		Toronto R-12 (RSI 2.1) HDD 3800		Toronto R-6 (RSI 1.0) HDD 3800		Ottawa R-12 (RSI 2.1) HDD 4440		Ottawa R-6 (RSI 1.0) HDD 4440	
Wall	Cavity Insulation	Cavity Depth	Exterior Insulation	Ext. Insul. Thickness	Vapour Control	Low RH 30/55%	Med. RH 40/60%	Low RH 30/55%	Med. RH 40/60%	Low RH 30/55%	Med. RH 40/60%	Low RH 30/55%	Med. RH 40/60%	Low RH 30/55%	Med. RH 40/60%	Low RH 30/55%	Med. RH 40/60%
PIC	Fiberglass	5.5"	polyiso-cyanurate	2.0" 1.0"	Latex paint+primer	10%	11%	12%	14%	11%	13%	13%	19%	12%	18%	16%	26%
					Polyethylene sheet								9%				9%
XPS	Fiberglass	5.5"	extruded polystyrene	2.5" 1.0"	Latex paint+primer	10%	11%	12%	12%	11%	13%	13%	20%	12%	14%	18%	26%
					Polyethylene sheet								9%				9%
EPS	Fiberglass	5.5"	expanded polystyrene	3.0" 1.5"	Latex paint+primer	10%	11%	12%	12%	11%	14%	13%	20%	13%	20%	18%	26%
					Polyethylene sheet								9%		8%		9%
MW	Fiberglass	5.5"	Min. wool Insulated Sheathing	3.0" 1.5"	Latex paint+primer			9%	12%			12%	16%		12%	15%	24%
					Polyethylene sheet	8%	9%			9%	9%		9%	8%	8%	8%	9%

General Notes:

a. 2.5% Design Temperature and Heating Degree Days (HDD) from NBCC 2010
b. Walls are residential wood frame with light-colored, thin cladding facing north: this is a worse-case scenario for cold-weather diffusion wetting
c. Results are for OSB sheathing. Plywood sheathing values will be equal or lower. OSB permeance is always over 60 ng/Pa·s·m^2 in exterior sheathing applications.
d. Sheathings of DensGlas, FiberBoard, and Gypsum Board are all very vapor permeable and hence will have lower moisture contents
e. Thicker exterior insulation will always result in lower wintertime sheathing moisture contents
f. Effective Air Barrier is assumed to be installed, as is proper rain control
g. MC values are for inner 3 mm OSB sheathing

Results – Rain Leakage

= MC < 20%, no mold growth = MC is 20 to 28%, potential for mold growth = MC > 28%, moisture problems expected, this design is NOT recommended

Wall Construction						Vancouver Ave. Annual Temp 9 °C HDD 2910, 304 mm Driving Rain			Toronto Ave. Annual Temp 7 °C HDD 3800, 77 mm Driving Rain				St. Johns Ave. Annual Temp 4 °C HDD 4881, 291 mm Driving Rain		
Wall	Cavity Insulation	Cavity Depth	Exterior Insulation	Ext. Insul. Thickness	Vapour Control	No Leakage	1% Rain leak	2% Rain leak	No Leakage	1% Rain leak	2% Rain leak	5% Rain leak	No Leakage	1% Rain leak	2% Rain leak
Datum	Fiberglass	5.5 "	none	0	Polyethylene sheet	11%	15%	22%	11%	11%	12%	15%	11%	15%	22%
PIC	Fiberglass	5.5"	polyiso-cyanurate	2"	Latex paint+primer	11%	16%	24%	13%	13%	17%	23%	15%	25%	35+%
					Polyethylene sheet		35+%	35+%		11%	15%	35+%		35+%	35+%
XPS	Fiberglass	5.5"	extruded polystyrene	2.5 "	Latex paint+primer	11%	16%	24%	13%	13%	17%	23%	15%	25%	35+%
					Polyethylene sheet		35+%	35+%			15%	35+%		35+%	35+%
EPS	Fiberglass	5.5"	expanded polystyrene	3.0"	Latex paint+primer	11%	17%	27%	14%	15%	18%	25%	17%	26%	35+%
					Polyethylene sheet		35+%	35+%			20%	35+%		35+%	35+%
MW	Fiberglass	5.5"	mineral wool insulated sheathing	3.0"	Latex paint+primer		13%	18%			12%	16%		13%	20%
					Polyethylene sheet	9%	12%	18%	9%	9%	9%	13%	8%		20%
Double Stud	Cellulose	11.25"	none	0	Polyethylene sheet	13%	15%	20%	13%	13%	16%	19%	14%	17%	20%

General Notes:

a. Walls are residential wood frame with light-colored, thin cladding facing north: this is a worse-case scenario for cold-weather diffusion wetting
b. Results are for OSB sheathing. Plywood sheathing values will be equal or lower. OSB permeance is always over 60 ng/Pa·s·m^2 in exterior sheathing applications.
c. Sheathings of DensGlas, FiberBoard, and Gypsum Board are all very vapor permeable and hence will have lower moisture contents
d. Thicker foam will always result in lower wintertime sheathing moisture contents
e. Effective Air Barrier is assumed to be installed, as is proper rain control
f. MC values are for inner 3 mm OSB sheathing

Results – Air Leakage

= MC < 20%, no mold growth = MC is 20 to 28%, potential for mold growth = MC > 28%, moisture problems expected, this design is NOT recommended

Wall Construction						Vancouver 2.5% Temp. = -7 HDD 2926, 304 mm Driving Rain			Toronto 2.5% Temp. = -20 HDD 4065, 77 mm Driving Rain			St. Johns 2.5% Temp. = -15 HDD 5777, 291 mm Driving Rain		
Wall	Cavity Insulation	Cavity Depth	Exterior Insulation	Ext. Insul. Thickness	Vapour Control	No Exfiltration	Air Exfil. 0.5 ACH	Air Exfil. 2.0 ACH	No Exfiltration	Air Exfil. 0.5 ACH	Air Exfil. 2.0 ACH	No Exfiltration	Air Exfil. 0.5 ACH	Air Exfil. 2.0 ACH
Datum	Fiberglass	5.5 "	none	0	Polyethylene sheet	11%	17%	29%	11%	22%	35+%	11%	24%	35+%
PIC	Fiberglass	5.5"	polyiso-cyanurate	2"	Latex paint+primer	11%	12%	13%	13%	15%	17%	15%	18%	20%
					Polyethylene sheet			13%			16%			
XPS	Fiberglass	5.5"	extruded polystyrene	2.5 "	Latex paint+primer	11%	12%	13%	13%	14%	16%	15%	18%	20%
					Polyethylene sheet									
EPS	Fiberglass	5.5"	expanded polystyrene	3.0"	Latex paint+primer	11%	12%	13%	14%	18%	19%	17%	20%	22%
					Polyethylene sheet									
MW	Fiberglass	5.5"	mineral wool insulated sheathing	3.0"	Latex paint+primer									15%
					Polyethylene sheet	9%	10%	12%	9%	10%	13%	8%	11%	13%
Double Stud	Cellulose	11.25"	none	0	Polyethylene sheet	13%	25%	28%	13%	25%	29%	14%	31%	35+%

General Notes:

a. Walls are residential wood frame with light-colored, thin cladding facing north: this is a worse-case scenario for cold-weather diffusion wetting
b. Results are for OSB sheathing. Plywood sheathing values will be equal or lower. OSB permeance is always over 60 ng/Pa·s·m^2 in exterior sheathing applications.
c. Sheathings of DensGlas, FiberBoard, and Gypsum Board are all very vapor permeable and hence will have lower moisture contents
d. Thicker foam will always result in lower wintertime sheathing moisture contents
e. Effective Air Barrier is assumed to be installed, as is proper rain control
f. MC values are for inner 3 mm OSB sheathing

Conclusions

- → Exterior insulation strategies can be used to safely create High R-value walls
  - → effective at resisting the air leakage condensation issues that are common in cold climates.
- → Low permeance exterior insulation show a higher risk of moisture issues under rain leakage conditions
  - → if an appropriate insulation ratio is used then the interior poly layer can be omitted, reducing the risk significantly.
- → If driving rain exposure and penetration is a major concern, vapour permeable exterior insulation products can be used to further reduce the risk.