An Overview of Studies to Assess the Thermal and Hygrothermal Performance of Highly Insulated and Zero-Energy Ready Wall Assemblies

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#114

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- Introduction, Net Zero Energy Homes
- Field Experiment
- Tested Wall Assemblies
- Numerical Simulation
- Results
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Introduction

Government of Canada,
Federal Sustainability Development Strategy

- GHG (Green House Gases) reductions
  - 17% by 2020
  - 40% by 2030
  - 80% by 2050

…relative to emission levels of 2005 (app.750Mt)

Introduction

Net Zero Energy Homes

- Buildings in Canada account for 20% of GHG emissions

- Homes that on annual basis generate as much energy as they consume.

- High Performance Buildings

  - Proper design, proper workmanship, proper materials, proper maintenance
  - Ecological, economical, local, durable

Net Zero Energy Homes

Example of energy consumption*

Energy consumption, MWh/year	Ottawa	Vancouver
R30, 5.3m^{2}K/W	18.5	13.2
R40, 7.0 m^{2}K/W	14.0	10.1
R50, 8.8 m^{2}K/W	11.1	7.9

* Simple shape home, A = 600m^2

Example of energy generation*

Energy generation, MWh/year	Ottawa	Vancouver
5kWDC	6.2	5.5
10kWDC	12.4	11.0
20kWDC	24.7	21.9

* PVWatts.nrel.gov

Introduction

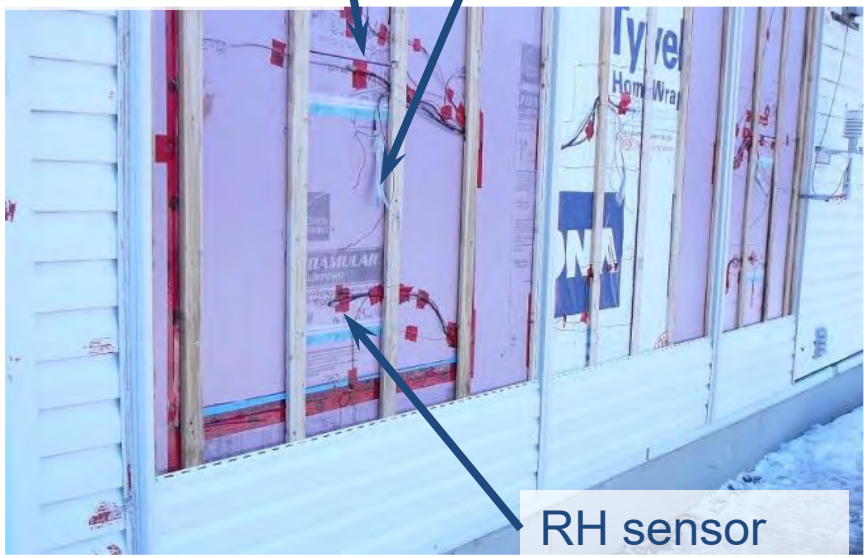
NRC | NRCan | CMHC | CWC

3 year project to develop information on **hygrothermal** behaviour of highly insulated wood frame wall assemblies to:

- Support future code proposals
- Help to meet 2030 targets on net-zero energy practices
- Promote high performance wall assemblies deployment

Field Experiment, Test Facility

Field Exposure of Walls Test Facility, NRC campus in Ottawa, ON



Field Experiment, Instrumentation Examples

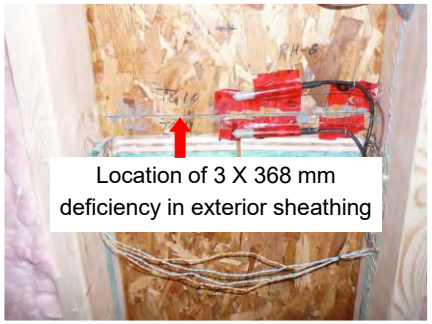
Example 1 - Retrofit

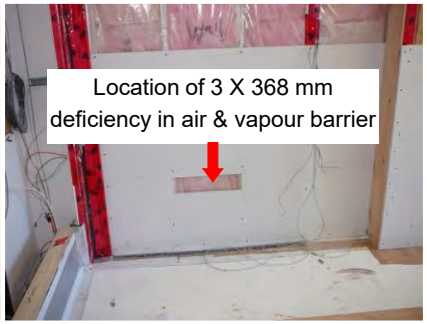
Example 2- New build

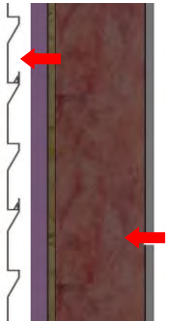
Field Experiment, Test Conditions

Test protocol over monitoring period

Period	Interior conditions				Exterior conditions	
	Temperature (°C)	RH (%)	Pressure (Pa)	Deficiency (3mm slit)	Deficiency (3mm slit)	Temperature/ RH
A (20 days)	21	35	0	Closed	Open	Ambient local
B (20 days)	21	55	50	Open	Open	Ambient local
C (190 days)	21	Variable / natural	0	Open	Open	Ambient local
D (20 days)	21	Variable / natural	0	Closed	Open	Ambient local







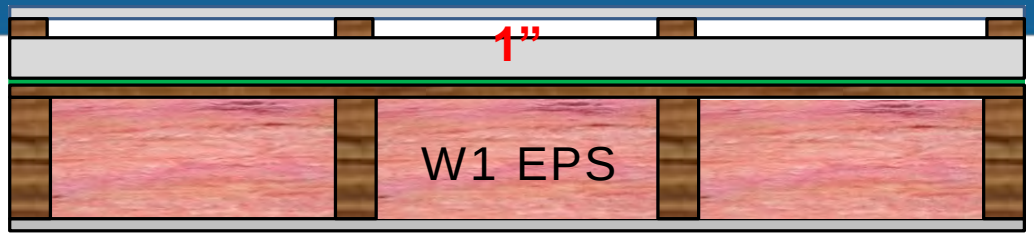
Notes:

Period A: initial stage with no intentional deficiencies in assembly monitoring to observe the response of the wall to local weather conditions.

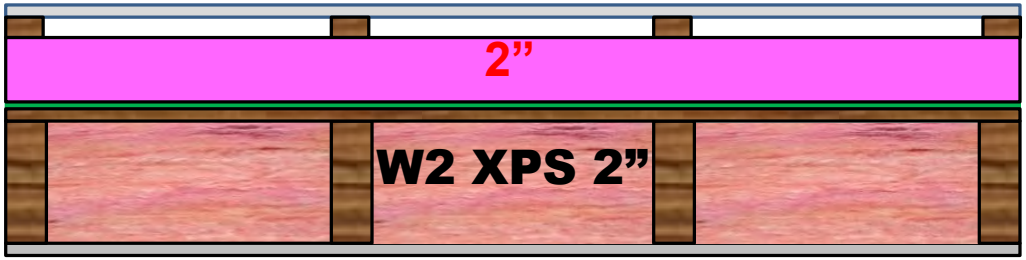
Period B: warm moist air (21°C; 55% RH) exfiltrate through intended deficiencies in the test specimens; exfiltration was induced by applying a pressure up to 50 Pa.

Period C: drying out period with deficiencies in the test specimen present for a certain time and subsequently closed. No pressure applied; natural indoor RH kept.

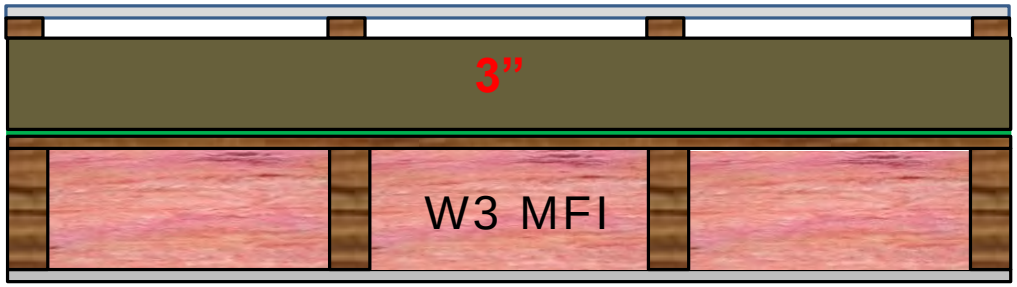
Tested Assemblies- Retrofit Options



RSI	4.8	[m²K/W]
R-value	27	[hr-ft² -°F/BTU]



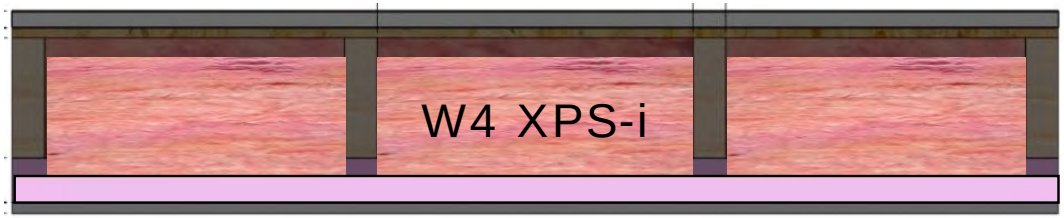
RSI	6.2	[m²K/W]
R-value	35	[hr-ft² -°F/BTU]



RSI	6.2	[m²K/W]
R-value	35	[hr-ft² -°F/BTU]

- Vinyl siding
- 1.5x0.5-in vertical furring strips
- **INSULATION**
- Sheathing membrane
- 11 mm OSB wood-sheathing
- 1.5x5.5-in. nominal stud cavity
- R24 glass fiber batt insulation for 6-in. cavity
- 6 mil poly air/vapour barrier
- ½-in. painted drywall

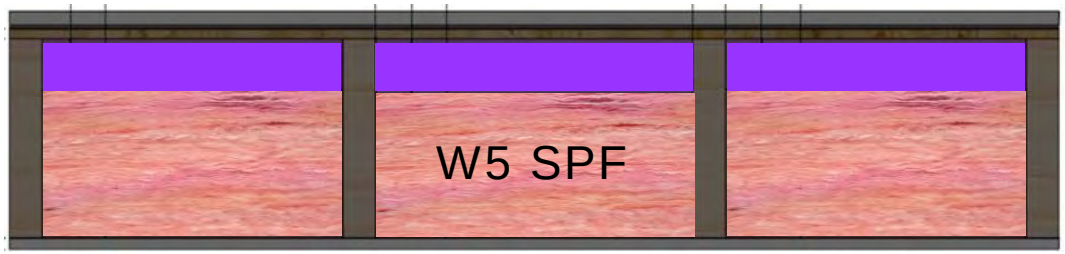
Tested Assemblies, Interior Insulation



RSI	6.0	[m^2K/W]
R-value	34	[hr-ft^2 -°F/BTU]

- Vinyl siding
- Sheathing membrane
- 11 mm OSB wood-sheathing
- 1.5x5.5-in. nominal stud cavity with R24 glass fiber batt insulation
- **51 mm (2 in.) XPS rigid foam insulation**
- 6 mil poly air/vapour barrier
- ½-in. painted drywall

Tested Assemblies



RSI	**7.6**	**[m²K/W]**
R-value	**43**	**[hr-ft² -°F/BTU]**

- Vinyl siding
- Sheathing membrane
- 11 mm OSB wood-sheathing
- 2x10-in. nominal stud cavity
- In Stud cavity
  - **2-in. Spray polyurethane foam insulation**
  - **7-in. R24 glass fiber batt insulation**
- 6 mil poly air/vapour barrier
- ½-in. painted drywall

Tested Assemblies- New Construction

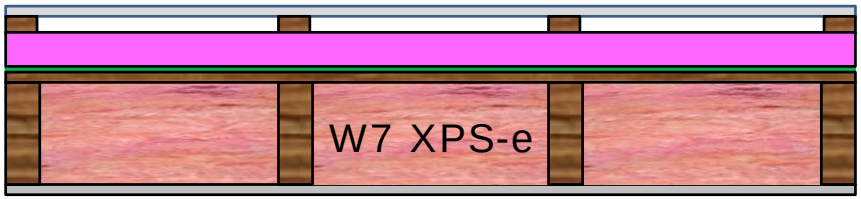
RSI	7.0 [m^2K/W]
R-value	40 [hr-ft^2 -°F/BTU]

- Vinyl siding
- Sheathing membrane
- 11 mm OSB wood-sheathing
- 2x12-in. nominal stud cavity
- **R39 cellulose fiber insulation**
- 6 mil poly air/vapour barrier
- ½-in. painted drywall

RSI	7.6 [m^2K/W]
R-value	43 [hr-ft^2 -°F/BTU]

- Vinyl siding
- 3x0.75-in. nominal vertical furring strip
- Sheathing membrane
- 24mm Diffusion board
- 1.5x9.13-in. nominal wood stud cavity
- **Wood fibre insulation for 10-in. cavity**
- **11 mm OSB wood-sheathing; joints taped**
- 1.5x3.5-in.studs (Service wall interior)
- Wood fibre insulation for 4-in. cavity
- ½-in. painted drywall

Tested Assemblies, XPS variations



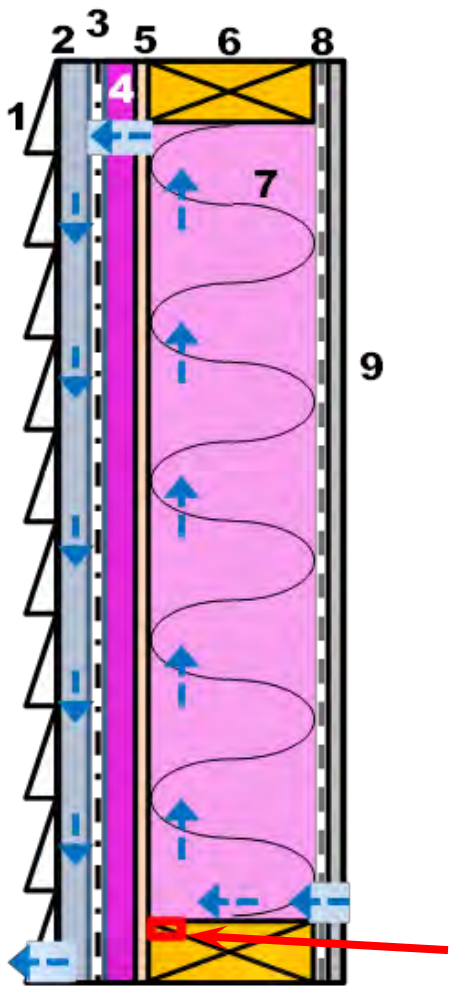
RSI	**5.1**	**[m²K/W]**
R-value	**29**	**[hr-ft² -°F/BTU]**

- Vinyl siding
- 3x0.75-in. nominal vertical furring strip
- **1-in. XPS rigid foam insulation**
- Sheathing membrane
- 11 mm OSB wood-sheathing
- 1.5x5.5-in. nominal wood stud cavity
- R24 glass fiber batt insulation for 6-in. cavity
- 6 mil poly air/vapour barrier
- ½-in. painted drywall

RSI	**5.1**	**[m²K/W]**
R-value	**29**	**[hr-ft² -°F/BTU]**

- Vinyl siding
- 3x0.75-in. nominal vertical furring strip
- 1-in. XPS rigid foam insulation
- 1.5x5.5-in. nominal wood stud cavity
- R24 glass fiber batt insulation for 6-in. cavity
- **11 mm OSB wood-sheathing; joints taped**
- ½-in. painted drywall

Numerical Simulations, Model Description



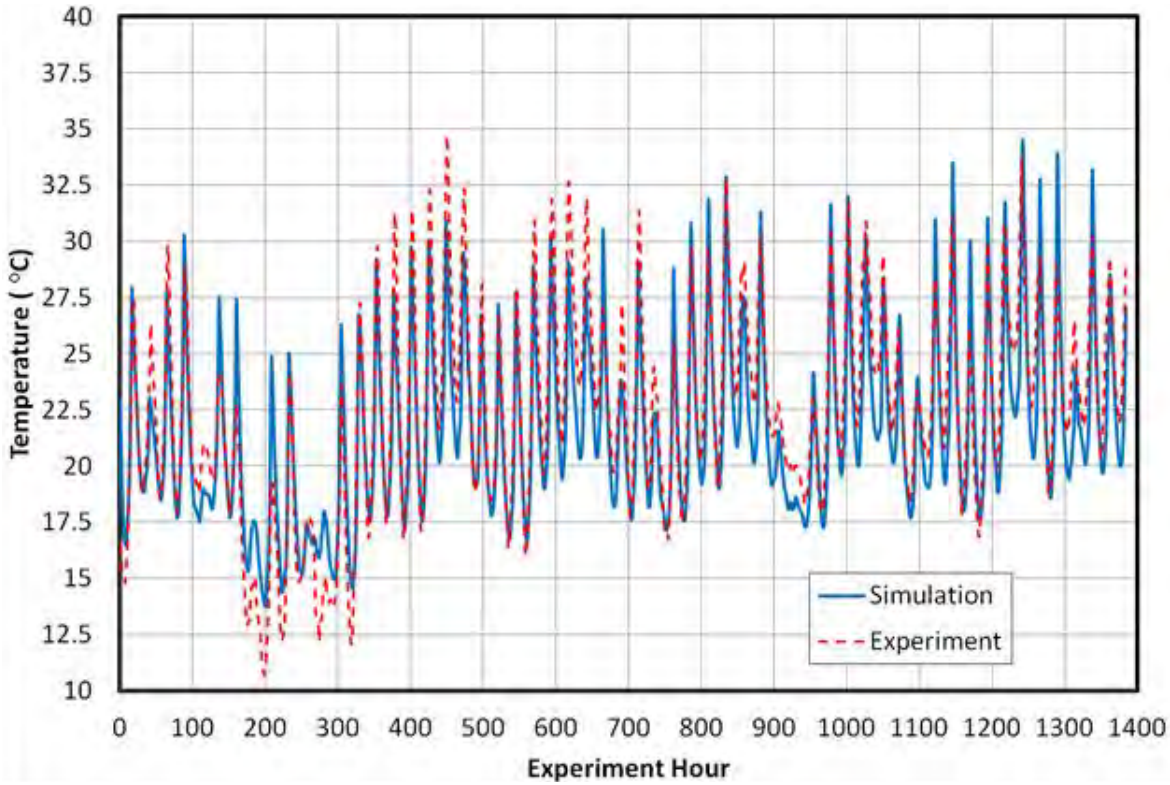
Region of focus

As Constructed	As Modeled	Label
Vinyl Siding (3mm)	Vinyl Siding (3mm)	1
19mm Strapping & air space	Airspace (19mm)	2
XPS (25mm)	XPS (25mm)	3
Sheathing membrane	Spunbonded Olefin (0.15mm)	4
OSB Sheathing (11mm)	OSB Sheathing (11mm)	5
Wood Studs (5.5in)	Pine (140mm)	6
R24 Glass-fibre insulation (Stud cavity insulation)	Low Density Glass Fibre (140mm)	7
6 mil poly air/vapour barrier	Polyethylene (0.15mm)	8
1/2in –painted drywall	Primed Gypsum (12.7mm)	9

Used software: hygIRC 2D

Numerical Simulations, Benchmarking

Comparison example of measured and calculated temperatures inside region of focus, Ottawa 2016



Used software: hygIRC 2D

Numerical Simulations, Parametric Analysis

Annual hygrothermal analysis for Canadian locations:

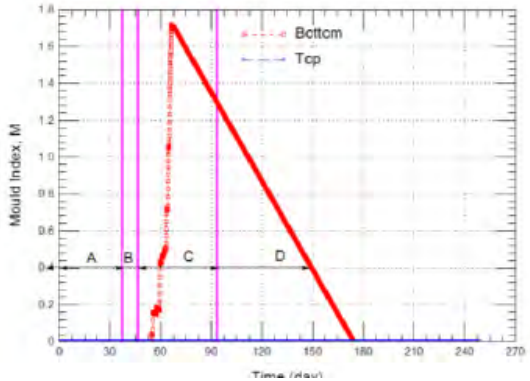
- Ottawa, ON
- Vancouver, BC
- Yellowknife, NWT
- Edmonton, AB
- St. Johns, NL

Mould growth calculated using model developed by Viitanen and Ojanen*

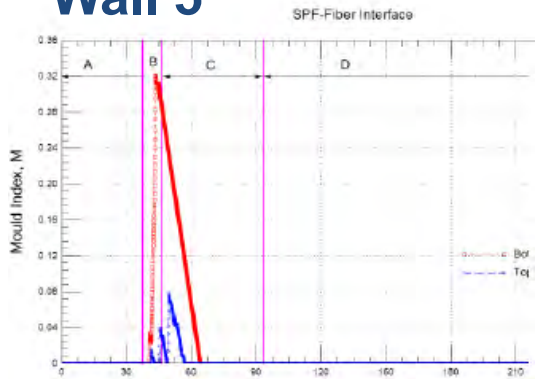
*Viitanen, H.A., and Ojanen, T.: Improved model to predict mould growth in building materials, 2007.

Field Test and Simulation Results

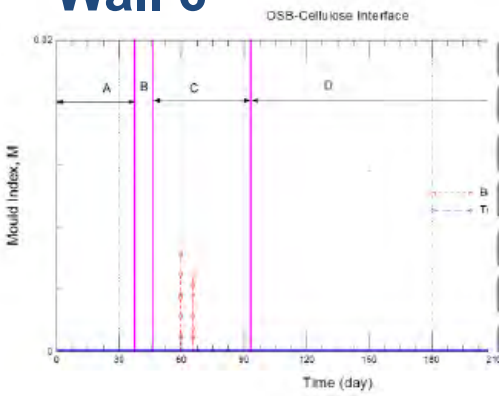
Wall 4



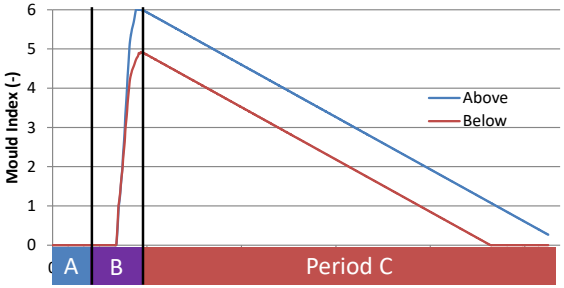
Wall 5



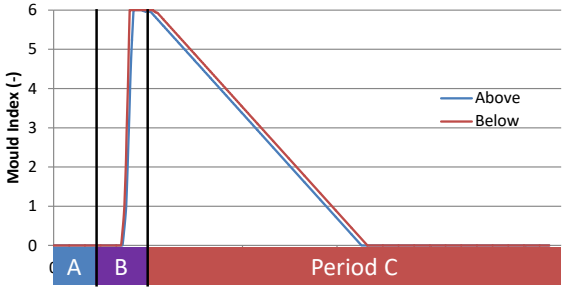
Wall 6



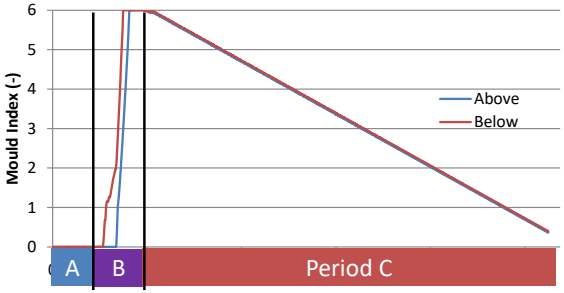
Wall 7



Wall 8



Wall 9



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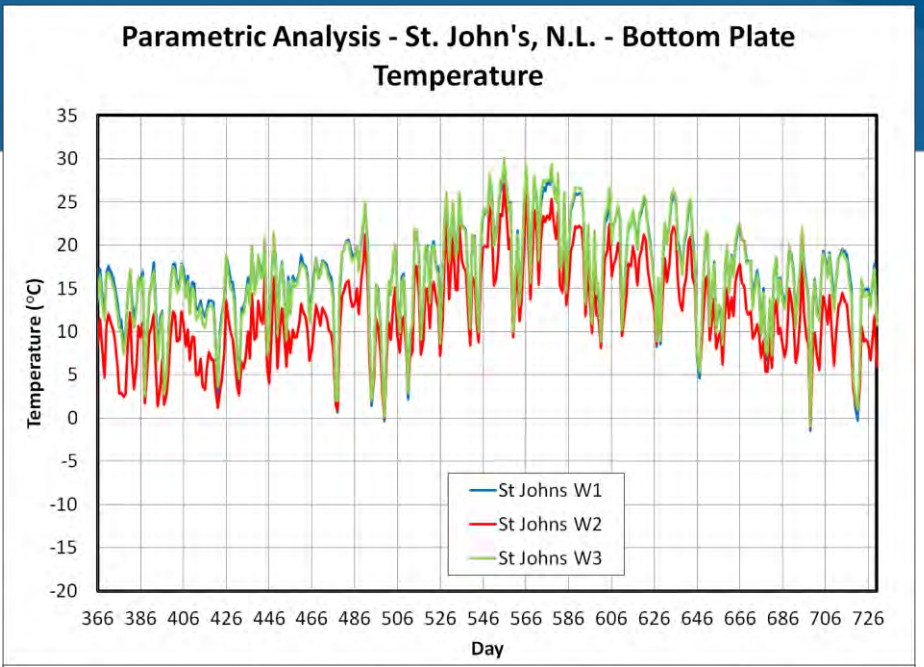
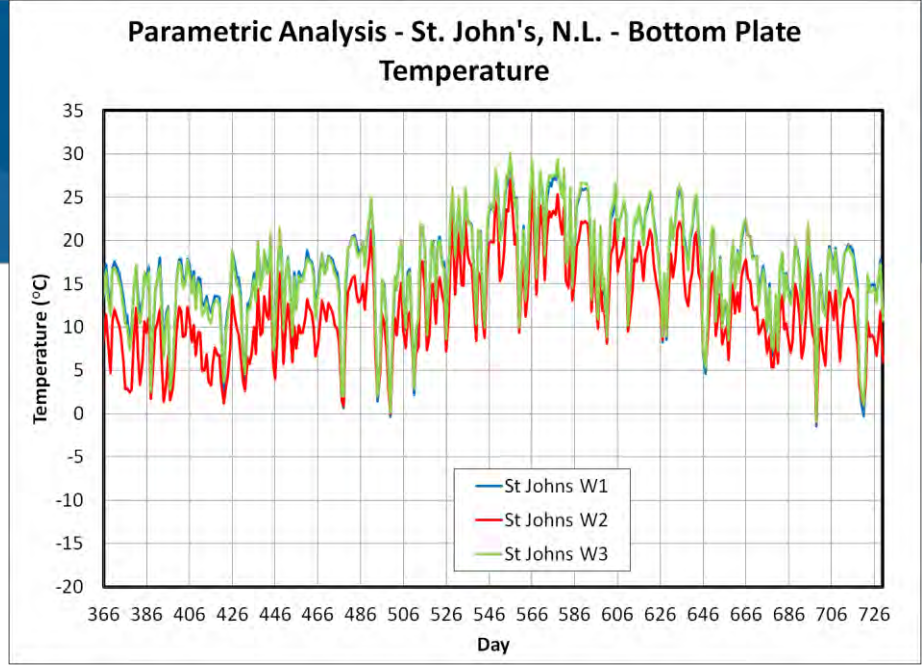
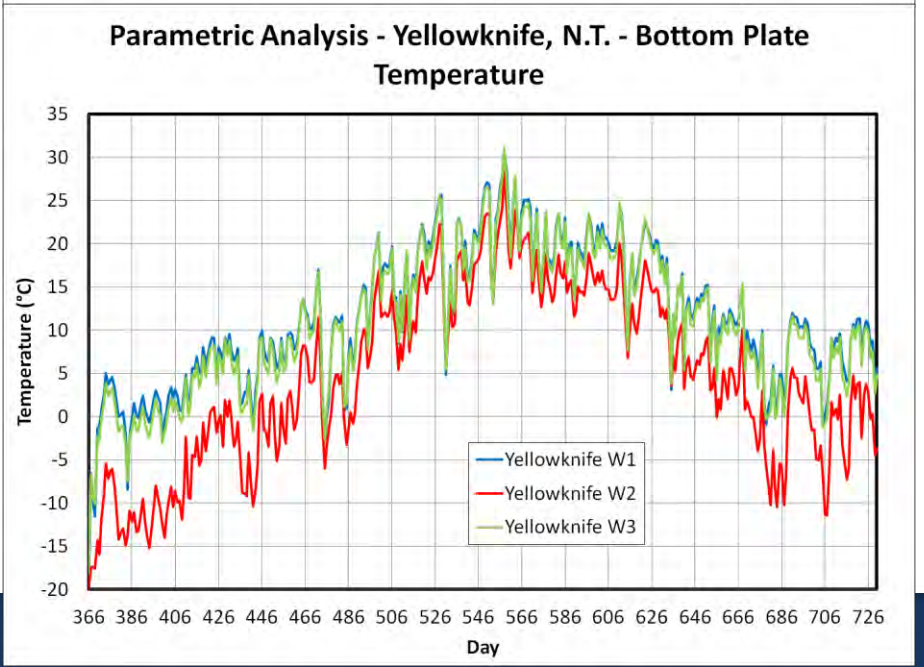
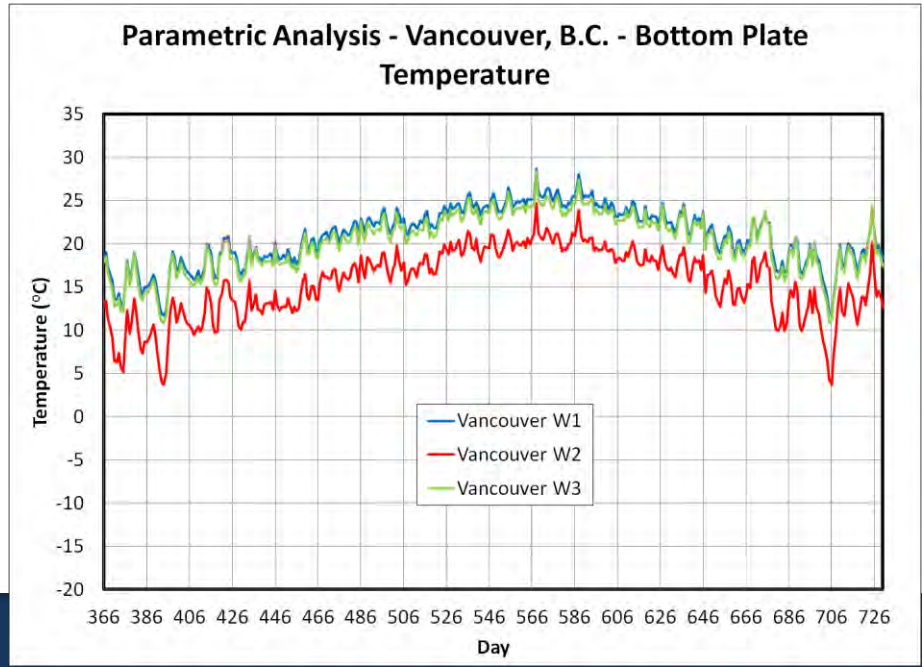
Period C: drying out period with deficiencies in the test specimen present for a certain time and subsequently closed. No pressure applied; natural indoor RH kept.

Temperatures

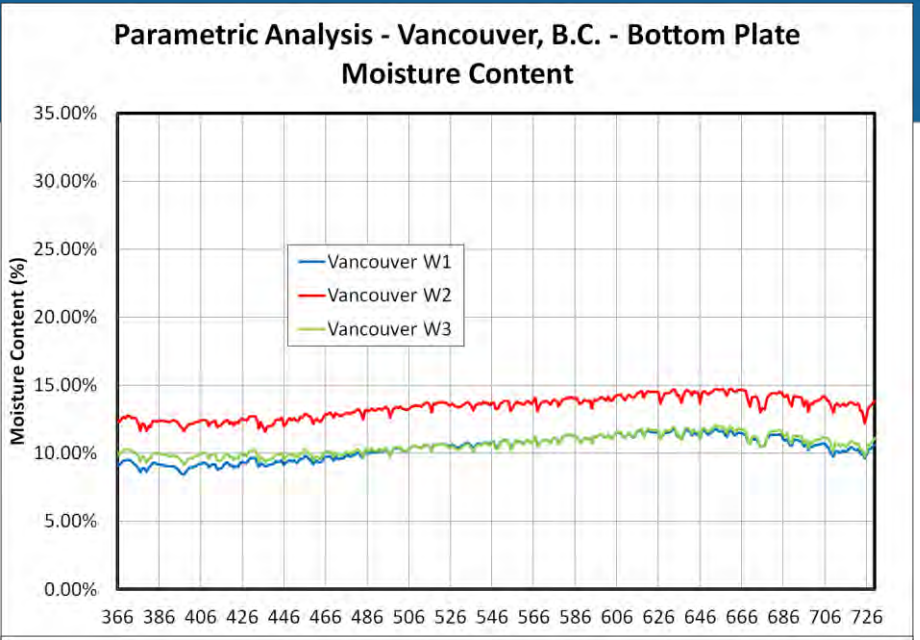


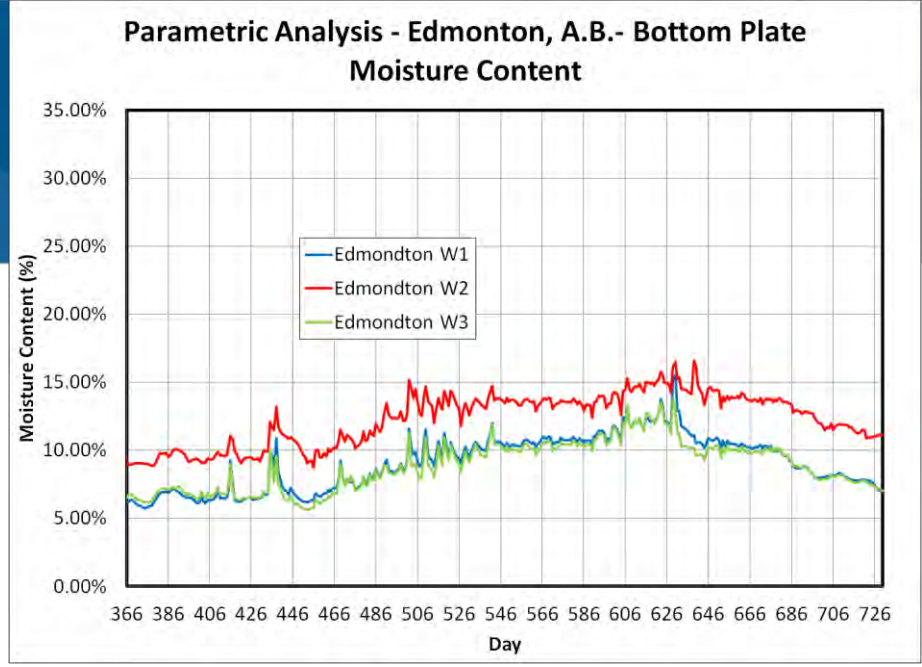


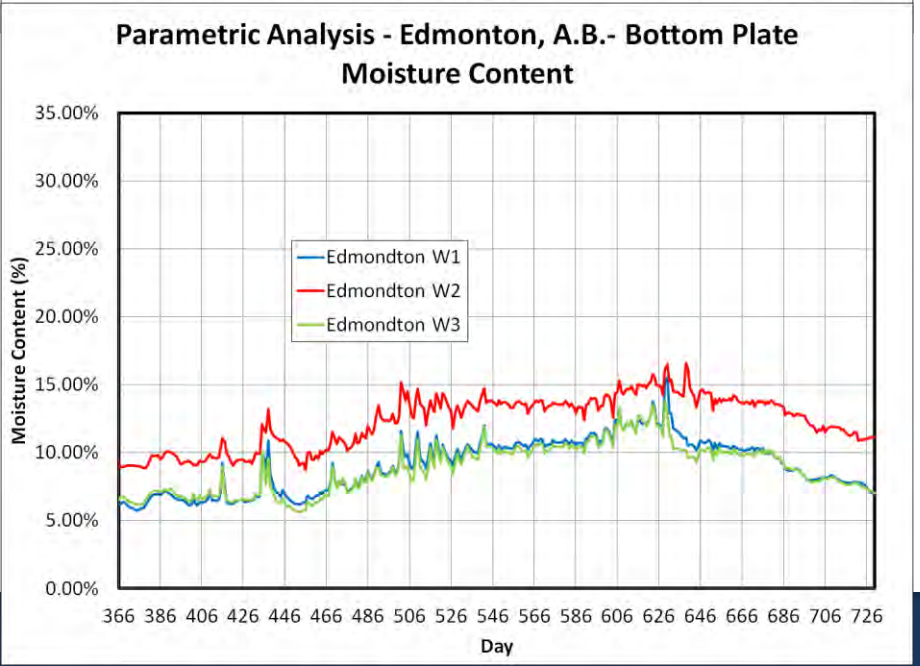


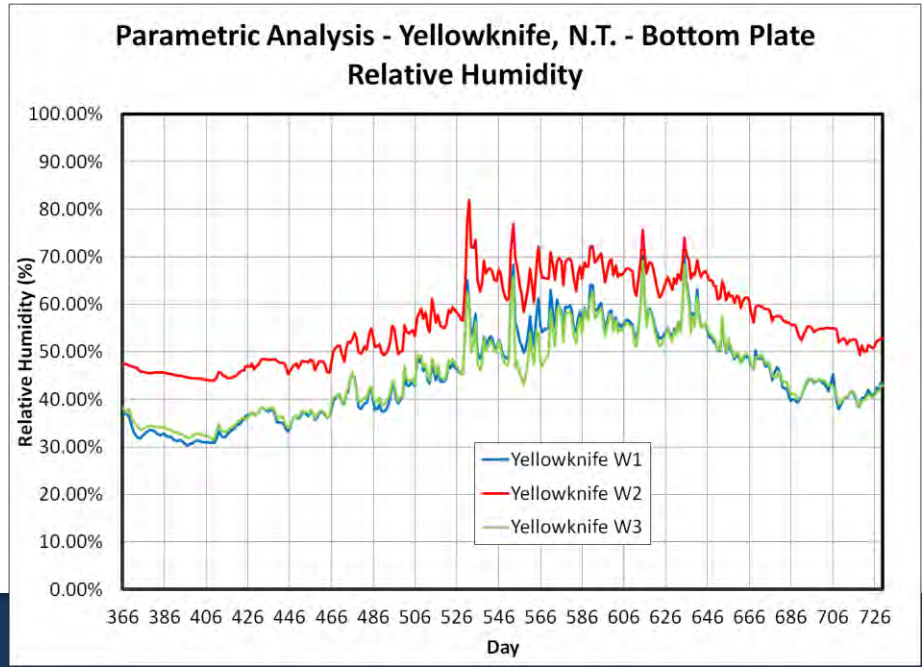


Moisture content





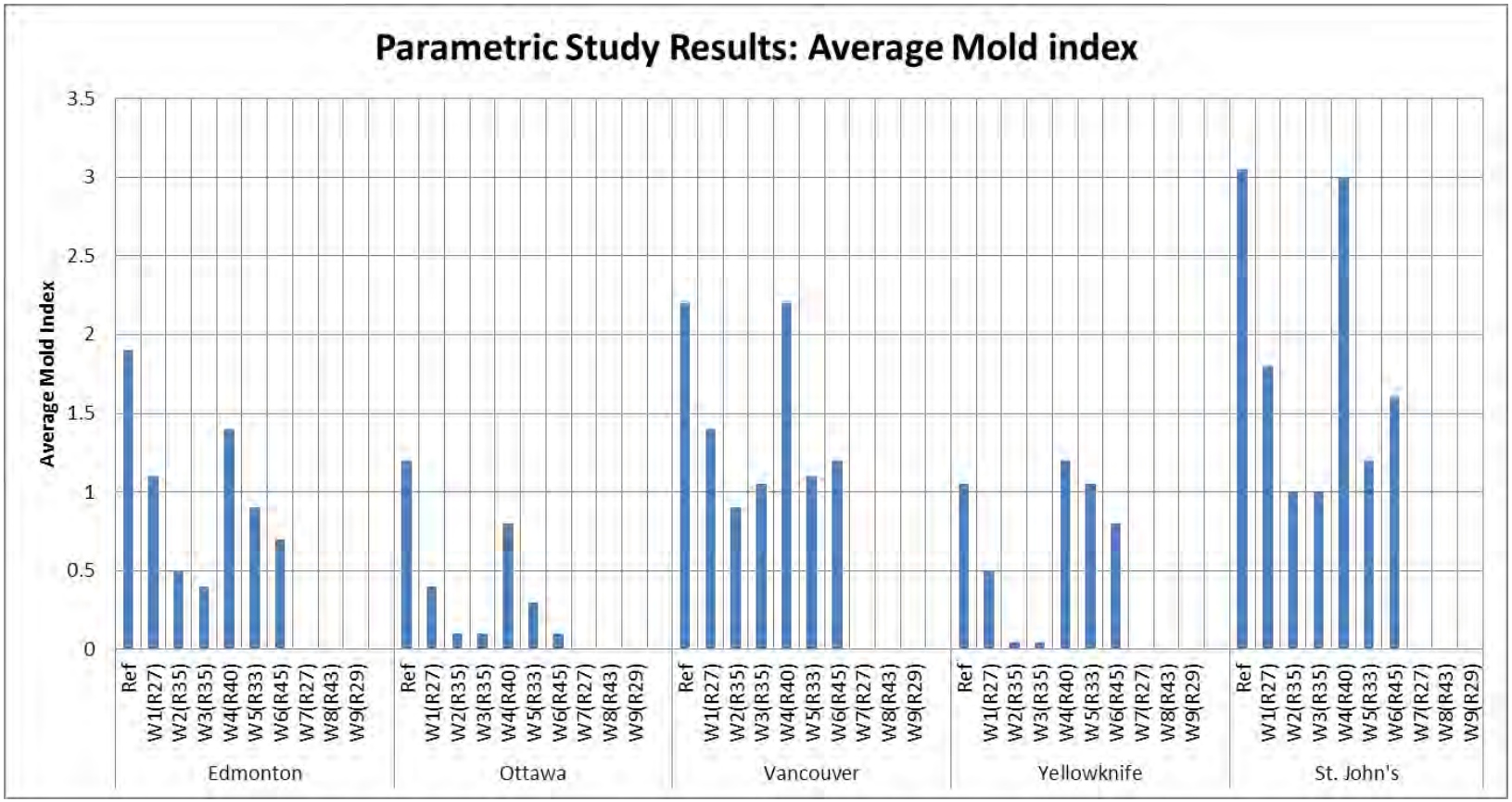




Field Test and Simulation Results

$$RH_{crit} = -0.00267T^3 + 0.160T^2 - 3.13T + 100.0 \text{ when } T \leq 20$$

$$RH_{crit} = 80\% \text{ when } T > 20$$



Conclusions

- Both, experimental and simulation results **confirmed** that highly insulated assemblies are capable of adequate thermal and hygrothermal performance ensuring buildings' expected longevity.
- **Foam** insulations (XPS, EPS) perform better in **humid** climates, and **fibre** insulations (mineral, wood, cellulose, glass) in **dry** climates.
- Acceptable building performance is heavily dependent on the quality of workmanship
- Net zero energy status can be achieved with R40 and higher values, in certain locations in Canada (higher temperatures, higher solar irradiation levels)

Thank you for your attention!

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Michael A. Lacasse , PhD., P.Eng., Senior Research Officer, NRC

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Mould Index

Description of Mould Index (M) levels

M	Mould Index (M) Description of Growth Rate
0	No growth
1	Small amounts of mould on surface (microscope), initial stages of local growth
2	Several local mould growth colonies on surface (microscope)
3	Visual findings of mould on surface, < 10% coverage, or < 50% coverage of mould (microscope)
4	Visual findings of mould on surface, 10%–50% coverage, or > 50% coverage of mould (microscope)
5	Plenty of growth on surface, > 50% coverage (visual)
6	Heavy and tight growth, coverage about 100%

Mould growth sensitivity classes and some corresponding materials

Sensitivity Class	Materials	RH_{min} (%)*
Very Sensitive	Pine sapwood	80
Sensitive	Glued wooden boards, spruce	80
Medium Resistant	Concrete, aerated and cellular concrete, glass wool, polyester wool	85
Resistant	PUR with polished surface	85

Mould index (M) criteria developed by Hukka and Viitanen, Viitanen and Ojanen, and Ojanen et al.

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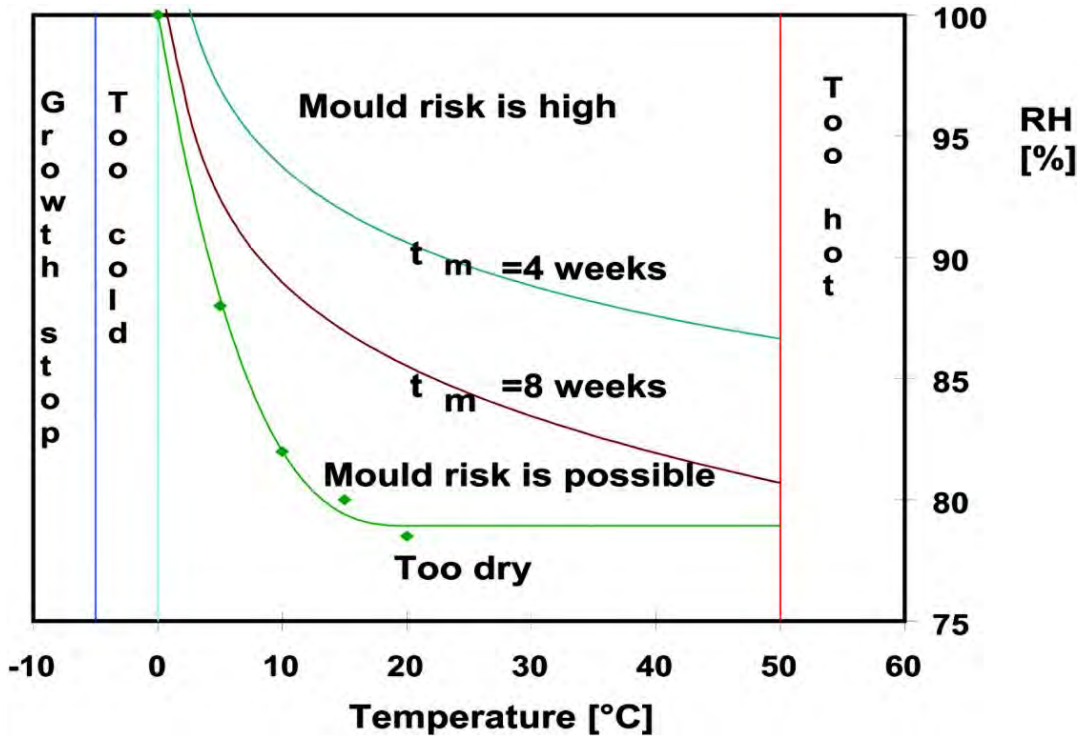
Hukka, A., and Viitanen, H.A., "A mathematical model of mould growth on wooden material, Wood Science and Technology", vol. 33 (6), pp 475-485, 1999.

Viitanen, H.A., and Ojanen, T., "Improved model to predict mould growth in building materials" Proc. Thermal Performance of Ext. Envelopes of Whole Buildings X, 8 p., 2007.

Ojanen, T., Viitanen, H.A., Peuhkuri, R, Lähdesmäki, K., Vinha, J., and Salminen, K., "Mould Growth Modeling of Building Structures Using Sensitivity Classes of Materials", 11th Intl. Conf. on Thermal Performance of the Exterior Envelopes of Whole Buildings XI (Clearwater, USA), 10 p., 2010.

Mould Index

$$RH_{crit} = -0.00267T^3 + 0.160T^2 - 3.13T + 100.0 \text{ when } T \leq 20$$

$$RH_{crit} = 80\% \text{ when } T > 20$$