



# Thermal Bridging Modeling with Benchmarking

October 2018

Mehdi Ghobadi, PhD, MBA

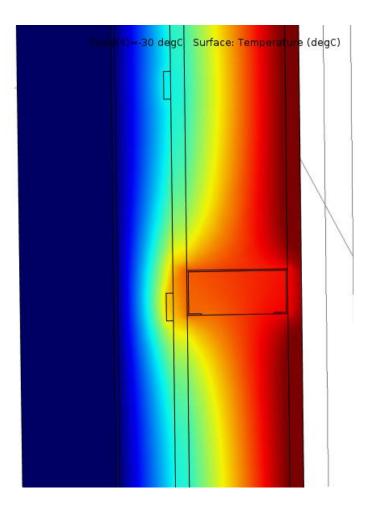
### Outline

- Project description
- > Wall assemblies
- > Experiments
- > Numerical simulations
- > Results
- > Benchmarking
- > Conclusion



### **Project Description**

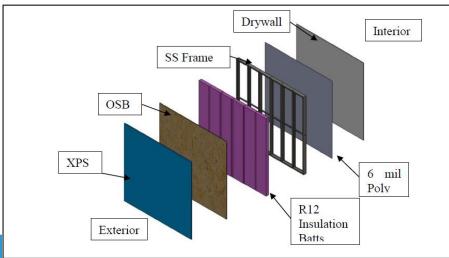
- Pan-Canadian climate plan, which is adopted in 2016, requires Canada to meet its 2030 emissions target
- 17% of Canada's GHG emissions are due to buildings
- Thermal bridging can greatly affect the thermal performance of assemblies specially in high performance buildings
- This project includes guarded hot box testing of seven wall assemblies and COMSOL simulation of 27 wall assemblies in one year
- Numerical results for three WAs are benchmarked against Guarded Hot Box (GHB) test results.

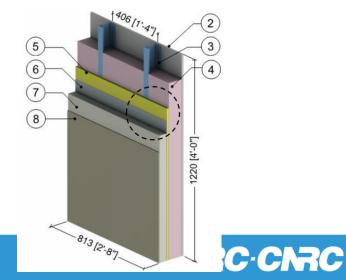




### Summary of the walls that were tested

ID	ASHRAE	Interior	Fiberglass	Cavity	Steel Stud	Steel Stud	Steel	Steel	Steel	Exterior	Exterior	Cladding
	ID	Sheathing	Cavity	Depth	Thickness	Spacing	Stud	Track	Track	Sheathing	Insulation	
			Insulation			(o.c.)	Flange	Thickness	Flange			
W1	SS. 19	1/2"	R-12	3 5/8"	20 gauge	16"	1 5/8"	1.03 mm	Not stated	5/8"	none	none
		(13 mm)	(RSI 2.1)	(92 mm)		(406 mm)	(41 mm)			(16 mm)		
		gypsum								OSB		
W2	SS. 20	1/2"	R-12	3 5/8"	20 gauge	16"	1 5/8"	1.03 mm	Not stated	5/8"	1"	none
		(13 mm)	(RSI 2.1)	(92 mm)		(406 mm)	(41 mm)			(16 mm)	(25mm) XPS	
		gypsum								OSB		
W3	SS. 21	1/2"	R-12	3 5/8"	20 gauge	16"	1 5/8"	1.03 mm	Not stated	5/8"	2"	none
		(13 mm)	(RSI 2.1)	(92 mm)		(406 mm)	(41 mm)			(16 mm)	(50mm) XPS	
		gypsum								OSB		





### **Experiments: Guarded Hot Box (GHB)**

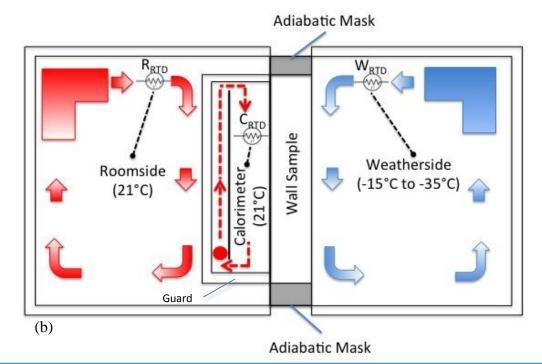
- Q = the heat input to the calorimeter (W)
- A = the specimen area normal to the direction of heat transfer (m<sup>2</sup>)

 $\Delta T$  = the absolute temperature difference between the interior and exterior air (°K)



 $A * \Delta T$ 

 $RSI = \cdot$ 





# **Temperature dependent conductivity**

> The temperature dependent conductivity of the materials used in the wall assemblies tested in the GHB.

Material	Thickness (mm)	T <sub>mean</sub>	RSI (m²K/W)	Fitted Equation for R	K (W/(m.K))	Fitted Equation for K	
		24.68	0.123		0.0487		
OSB	6	12.95	0.126	0.13(1-0.0019T <sub>mean</sub> )	0.047	K=0.0464+0.00009T <sub>mean</sub>	
		0.58	0.129		0.0465		
		24.08	2.248		0.0395		
Glass-fiber	89	11.99	2.421	2.603(1-0.0057T <sub>mean</sub> )	0.0367	K=0.0342+0.0002T <sub>mean</sub>	
		-0.6	2.606		0.034		
		23.95	0.88		0.0284		
XPS	25	11.93	0.928	0.97(1-0.0042T <sub>mean</sub> )	0.0269	K=0.0255+0.0001T <sub>mean</sub>	
		0	0.978		0.0255		
		24.02	1.73		0.0289		
XPS	50	12.04	1.832	1.939(1-0.0045T <sub>mean</sub> )	0.0272	K=0.0258+0.0001T <sub>mean</sub>	
		0.02	1.939		0.0257		





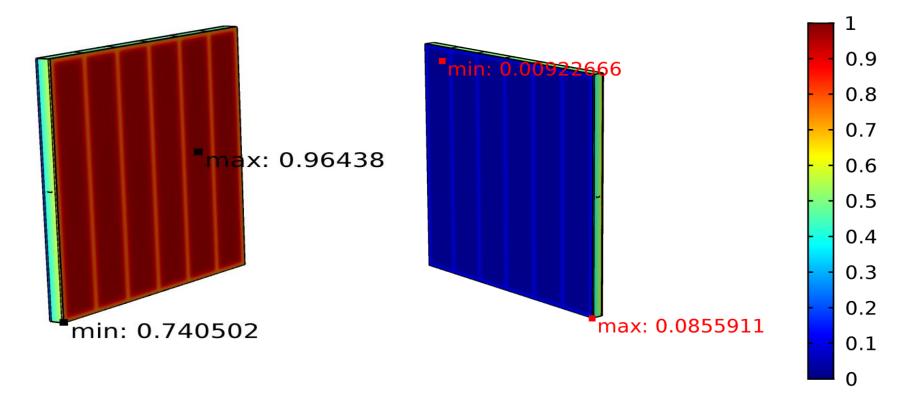
# **Temperature dependent conductivity**

			the second se
	Materials Physics Mesh Study Results Developer		
A Component Component States A C	Binnport         Binnport           alid         Add           Material         Heat Transfer Add           in Solids > Physics         Build Meth           Geometry         Materials	Compute Study Add 1 D Plot Add Plot Study Study Study Results Study Study Add Plot	
del Builder 🔷 🗸 🖡	Settings - I Grap		
→ ↑ ↓ ☜ ▾ ▥ャ ▦▸ ▦ ▾		g, ‡ 🗄   C = 🖸   C = 🖉 🖉 🖓 🗑 🕮 🖉 🖉 🖶 🔚 🖕 🖗 📾 🖉 🖗 🖗 🖗	
SS19 NRC.mph (root) Global Definitions	💽 Plot 📷 Create Plot		
Pi Parameters	Label: Analytic 1		
Materials Component 1 (comp1)	Function name: Kfib1		
<ul> <li>Definitions</li> <li>A Geometry 1</li> </ul>	<ul> <li>Definition</li> </ul>		
A 📑 Materials	Expression: 0.03438+0.000212*(T-273.15)		
Gypsum Board (mat1) Steel Stud (mat2)	Arguments: T		
<ul> <li>Fiberglass Ins (mat3)</li> <li>Basic</li> </ul>	Derivatives: Automatic 🔹		
<ul> <li>Analytic 1 (Kfib1)</li> <li>Exterior Sheating (mat4)</li> </ul>	Periodic Extension		
🔺 间 Heat Transfer in Solids (ht)	▼ Units		
🔚 Solid 1 🔚 Initial Values 1	Arguments: K		
🔚 Thermal Insulation 1	Function: W/(m*K)		
📟 Warm side heat 🔚 Cold side heat			
🔚 Symmetry 1	Advanced		
🚍 Flanking Loss 🚍 Thermal Contact 1	<ul> <li>Plot Parameters</li> </ul>		
🛦 Mesh 1	** Argument Lower limit Upper limit		
∿∞ Study 1 Parametric Sweep	T 230 300		
🔁 Step 1: Stationary			
Image: Solver Configurations Results			
Data Sets	↑ ↓ 辰		
<ul> <li>Environment Values</li> <li>Tables</li> </ul>			
🕨 🛅 Temperature (ht)			
Isothermal Contours (ht) 1D Plot Group 3		es Progress Log Evaluation 3D	
Sector Se		離 🚾 55 83 0.45 📏 📋 🔳 📾 🖙 🗮 🔻	
🔣 Reports		y z Value	
	-0.3615	0.27163 0.035283 16.771	
		6.78 GB   6.98 GB	
	S19 NRC.mph		▲ 📴 🕪 1:44 F



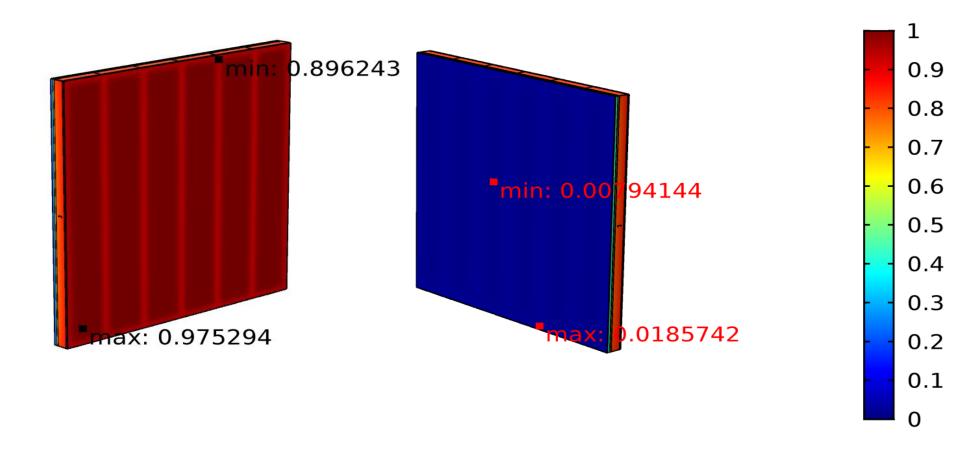
#### **W1 Surface Temperature Index**

$$T_{i} = \frac{T_{surface} - T_{outdoor}}{T_{indoor} - T_{outdoor}}$$



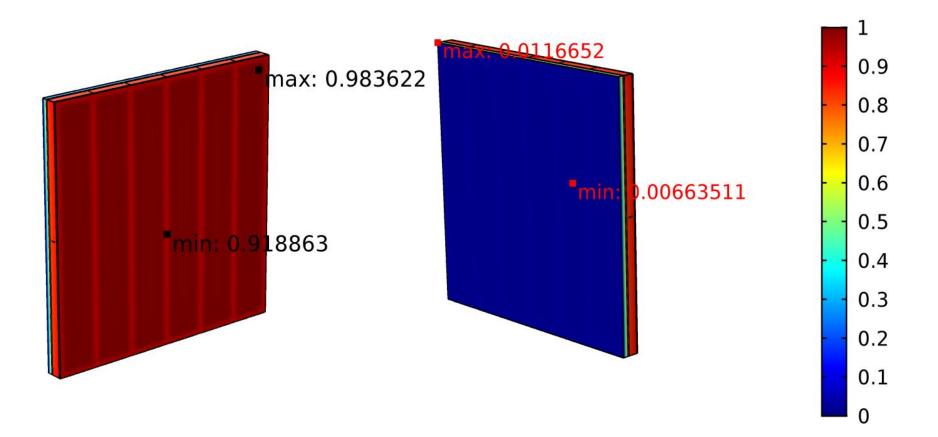


# W2 Surface Temperature Index





#### **W3 Surface Temperature Index**

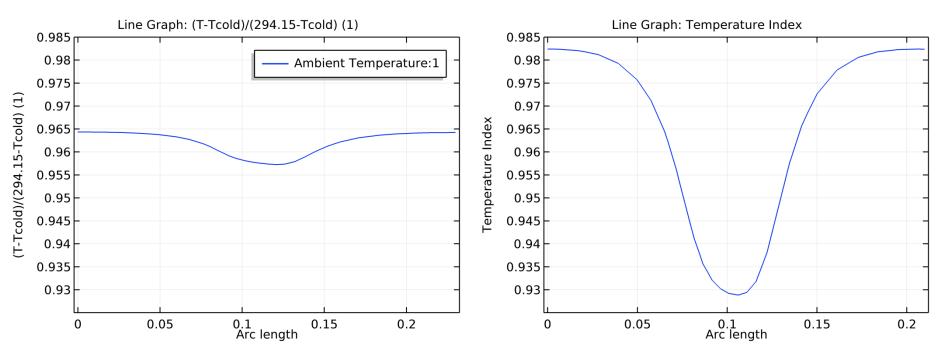




#### **Temperature on the warm surface**

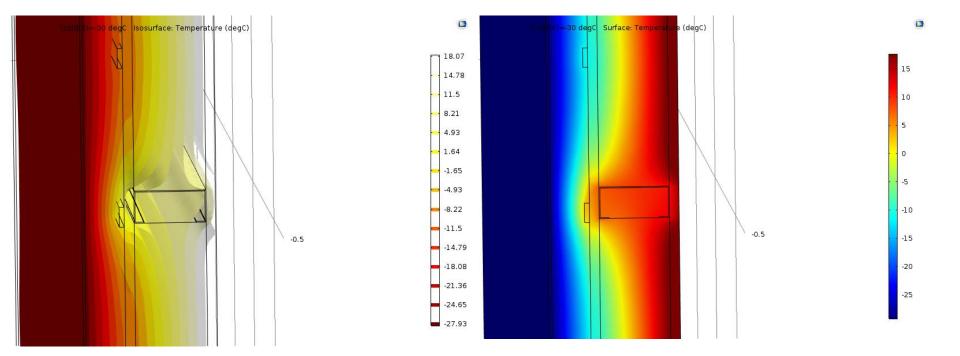
#### With exterior insulation

#### Without exterior insulation





#### W3. Temperature/isothermal surfaces along a stud





### **Benchmarking with the new GHB results**

#### **Benchmarking results for W1**

	COMSO	L results		<b>GHB</b> Results		No Thermal Bridging		
Т <sub>о</sub> (°С)	RSI StS	R StS	RSI StS	R StS	Difference	RSI StS	R StS	Increase
-5	1.36	7.77	1.43	8.17	5.13%	2.82	16.02	106%
-20	1.37	7.73	1.42	8.30	3.55%	3.03	17.20	122%
-35	1.45	8.14				3.14	17.82	119%

#### **Benchmarking results for W2**

	COMSO	L results		GHB Results		No Thermal Bridging		
Т <sub>о</sub> (°С)	RSI StS	R StS	RSI StS	R StS	Difference	RSI StS	R StS	Increase
-5	2.26	12.86	2.35	13.34	3.66%	3.59	20.40	59%
-20	2.39	13.60	2.40	13.63	0.21%	3.87	21.96	61%
-35	2.46	13.97	2.45	13.91	0.39%	3.98	22.59	62%

#### **Benchmarking results for W3**

	COMSO	L results		GHB Results		No Thermal Bridging		
т <sub>о</sub> (°С)	RSI StS	R StS	RSI StS	R StS	Difference	RSI StS	R StS	Increase
-5	3.27	18.57	3.15	17.89	3.84%	4.62	26.22	41%
-20	3.37	19.14	3.23	18.34	4.37%	4.89	27.77	45%
-35	3.43	19.48	3.23	18.34	6.21%	5.02	28.51	46%



# The importance of temperature dependent K

	Experimental results [5]			IH Simulations [	2]	COMSOL results			
Т <sub>о</sub> (°С)	RSI S-t-S	R S-t-S	RSI S-t-S	R S-t-S	Difference	RSI S-t-S	R S-t-S	Difference	
-5	1.35	7.67	1.39	7.90	2.96%	1.33	7.56	1.33%	
-35	1.42	8.07	1.39	7.90	2.11%	1.44	8.17	1.37%	

#### **Benchmarking results for W1**

#### **Benchmarking results for W2**

	Experiment	al results [5]	N	IH Simulations [	2]	COMSOL results		
т <sub>.</sub> (°С)	RSI S-t-S R S-t-S		RSI S-t-S	R S-t-S	Difference	RSI S-t-S	R S-t-S	Difference
-5	2.29	13.00	2.38	13.51	3.93%	2.31	13.10	0.71%
-35	2.41	13.68	2.38	13.51	1.24%	2.44	13.86	1.29%

#### **Benchmarking results for W3**

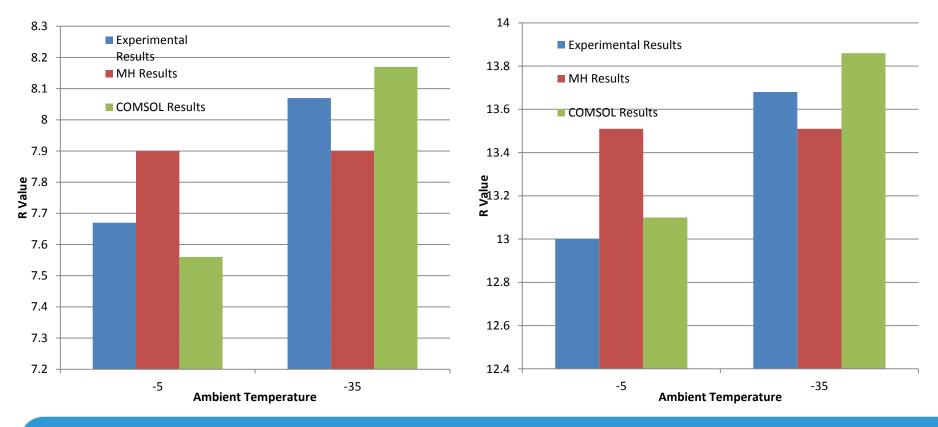
	Experimenta	al results [5]	N	IH Simulations [	2]	COMSOL results			
т <sub>о</sub> (°С)	RSI S-t-S R S-t-S		RSI S-t-S	R S-t-S	Difference	RSI S-t-S	R S-t-S	Difference	
-5	3.09	17.55	3.30	18.74	6.80%	3.20	18.18	3.56%	
-35	3.29	18.68	3.30 18.74		0.30%	3.42	19.45	3.95%	



### The importance of temperature dependent K

#### Wall 1 comparison

#### Wall 1 comparison





### Summary



- Three wall assemblies from previous experimental studies were simulated in COMSOL and average differences of 1.35%, 1.00% and 3.75% were observed between our numerical results and the reported GHB results. All the values are within ±8% which is the uncertainty of GHB tests.
- The wall assemblies were tested again in the NRC GHB facilities and another series of simulations were conducted and benchmarked against the results. Average differences of 4.34%, 1.42% and 4.80% were observed between our numerical results and the GHB results.
- We also conducted another series of simulations replacing the thermal bridging material (steel) with the embedded insulation (glass-fiber) and calculated the R value increase. Average R value increases of 115%, 61% and 41% for the wall assemblies were found. It has been shown that the effect of thermal bridging can become less important by adding exterior insulation.
- It has been shown that using high conductive materials within insulation materials can decrease the thermal performance of the wall more significantly.
- > Using the temperature dependent properties can highly affect the end results when the thermal properties of the used materials change with temperature.



# Thank you for your attention. Questions?

