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Computer simulations of enclosed reflective airspaces

Saber, Hamed H.

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Welcome to the 2014

International Reflective Insulation Manufacturers Conference

Computer Simulations of Enclosed Reflective Airspaces

Dr. Hamed H. Saber
March 7th, 2014

Construction Portfolio
National Research Council of Canada
Ottawa, Canada

I-RIM Conference 2014

OVERVIEW

- hygIRC-C Model
- Reflective Insulations
- Objectives
- Model Benchmarking
- Results
- R-value Correlations for Enclosed Airspaces
- Test R-value Correlations
- Summary

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hygIRC-C Model

- ✓ Recently developed
- ✓ Solves 2D and 3D time dependent **HAM** transport equations.
- ✓ Benchmarked against existing hygIRC-2D and experiments
- ✓ Unlike other hygrothermal models, hygIRC-C has the following new features:
  - CFD capability to model drainage cavities, airspaces, cracks, etc… as well as aerodynamics on buildings
  - Heat transfer by radiation through airspace enclosures of building envelope
  - Runoff due to wind driven rain on facades
  - Model Phase Change Materials (PCMs)

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hygIRC-C Model (cont.)

Examples of Numerical Simulations Conducted Using 2D and 3D hygIRC-C:

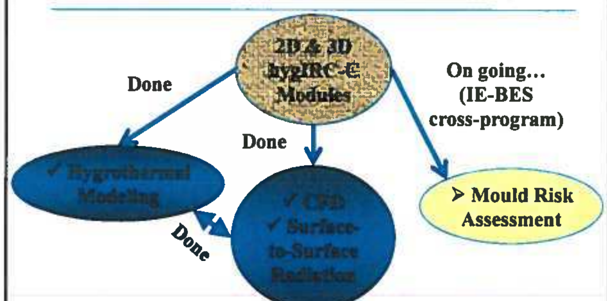
1. hygIRC-C vs hygIRC
2. Wetting and Drying of Cladding Systems
3. Moisture Assessment of Cladding Systems
4. Drying of Ventilated Wall Cavities
5. Evaluating Wall Energy Rating (WER)
6. Thermal Performance of Skylight Devices (ASHRAE –RP1415)
7. Foundation Wall Systems with Furred-Airspace Assembly
8. Insulated Concrete Foam (ICF) Wall systems
9. Wall Systems with Reflective Insulations
10. Performance of Roofing Systems
11. Aerodynamics on Buildings
12. Thermal Performance of EIFS Walls with Drainage Cavities
13. Hygrothermal Performance of Samples Used in Current Mould Experiments
14. Phase Change Materials (PCMs)

hygIRC-C Model (cont.)

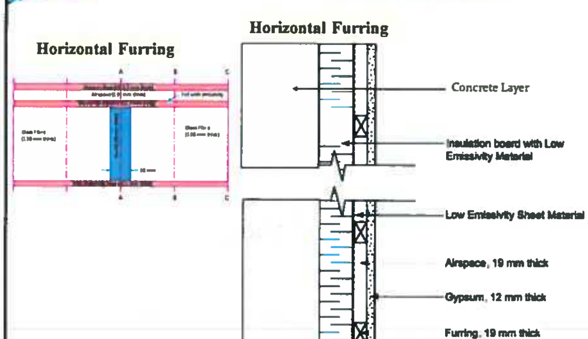
On going…

- A new module for predicting the risk for mould growth will be implemented in hygIRC-C.
- hygIRC-C will be used to predict the performance of the whole building.

hygIRC-C Model (cont.)

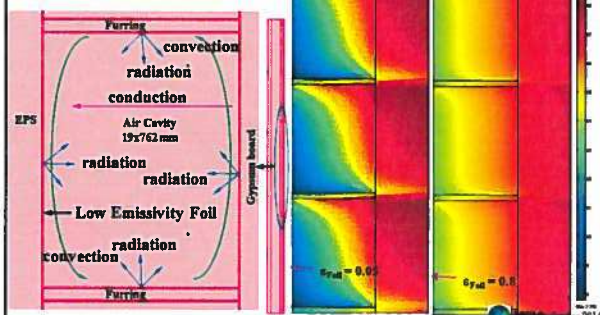


Reflective Insulations

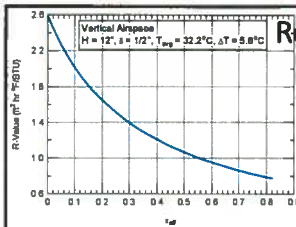


Reflective Insulations (cont.

Modes of heat transfer in the foil bounded to EPS insulation and furred – airspace assembly:
→ **Conduction,**
→ **Convection, and**
→ **Radiation**



Reflective Insulations (cont.



- Foil emissivity can increase due to dust accumulation and/or water vapour condensation
- Foil faced insulations are considered as low vapour permeance products

- To minimize the risk of condensation and moisture accumulation in the building envelope, the NBCC, sec 9.25 addresses the properties and positions of insulation materials serving as vapour barrier and having water vapour permeance (WVP) lower than 80 ng/(Pa.s.m^2)
- Thermal insulation industries submitted CCR-802 to revisit the current requirements in sec 9.25 and include other thermal insulations with different WVP and R-values
- The CCR-802 project started in January 2014 and the new requirements will be included in the 2015 NBCC

Reflective Insulations (cont.

- CCR-802 project (Clients: 4 industries + Canadian Building Code Centre)
- Project Title: Properties and Position of Materials in the Building Envelope for Housing and Small Buildings

For more information:
ftp://s00275.cisti.nrc.ca/outgoing/SCHSB-2010-11/Separate_Files/11.07.2.f%20Low%20Permeance%20Materials.pdf

Reflective Insulations (cont.

ASHRAE R-values for enclosed airspaces

- Requires multi-dimensional interpolations/ extrapolations (ΔT, T_{avg}, ε_{eff})
- Effect of length/height is neglected
- 30° slope is not available

Position of Air Space	Direction of Heat Flow	Mean Temp., °C	Temp. Diff., K	13 mm Air Space: 0.03	0.05	0.2	0.5	0.82
Horiz.	Up ↑	32.2	5.6	0.37	0.36	0.27	0.17	0.13
		10.0	16.7	0.29	0.28	0.23	0.17	0.13
		10.0	5.6	0.37	0.36	0.28	0.20	0.15
		−17.8	11.1	0.30	0.30	0.26	0.20	0.16
		−17.8	5.6	0.37	0.36	0.30	0.22	0.18
		−45.6	11.1	0.30	0.29	0.26	0.22	0.18
		−45.6	5.6	0.36	0.35	0.31	0.25	0.20
45° Slope	Up ↗	32.2	5.6	0.43	0.41	0.29	0.19	0.13
		10.0	16.7	0.36	0.35	0.27	0.19	0.15
		10.0	5.6	0.43	0.43	0.32	0.21	0.16
		−17.8	11.1	0.39	0.38	0.31	0.23	0.18
		−17.8	5.6	0.46	0.45	0.36	0.25	0.19
		−45.6	11.1	0.37	0.36	0.31	0.25	0.21
		−45.6	5.6	0.46	0.45	0.38	0.29	0.23
Vertical	Horiz. →	32.2	5.6	0.43	0.41	0.29	0.19	0.14
		10.0	16.7	0.43	0.43	0.32	0.22	0.16
		10.0	5.6	0.47	0.45	0.33	0.22	0.16
		−17.8	11.1	0.50	0.48	0.38	0.26	0.20
		−17.8	5.6	0.52	0.50	0.39	0.27	0.20
		−45.6	11.1	0.51	0.50	0.41	0.31	0.24
		−45.6	5.6	0.56	0.53	0.43	0.31	0.26
45° Slope	Down ↘	32.2	5.6	0.44	0.41	0.29	0.19	0.14
		10.0	16.7	0.46	0.44	0.33	0.22	0.16
		10.0	5.6	0.47	0.45	0.33	0.22	0.16
		−17.8	11.1	0.51	0.49	0.39	0.27	0.20
		−17.8	5.6	0.52	0.50	0.39	0.27	0.20
		−45.6	11.1	0.56	0.54	0.44	0.33	0.25
		−45.6	5.6	0.57	0.54	0.45	0.33	0.26
Horiz.	Down ↓	32.2	5.6	0.44	0.41	0.30	0.19	0.14
		10.0	16.7	0.47	0.45	0.33	0.22	0.16
		10.0	5.6	0.47	0.45	0.33	0.22	0.16
		−17.8	11.1	0.52	0.50	0.39	0.27	0.20
		−17.8	5.6	0.52	0.50	0.39	0.27	0.20
		−45.6	11.1	0.57	0.55	0.45	0.33	0.26
		−45.6	5.6	0.58	0.56	0.46	0.33	0.26

OBJECTIVES

- Benchmark hygIRC-C model
- Conduct parametric study in order to develop practical correlations for determining the effective R-values of enclosed airspaces with different:
  - Dimensions (aspect ratios),
  - Average temperatures,
  - Temperature differentials,
  - Direction of heat transfer, and
  - Wide Range of emissivity
- Test R-value correlations

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Model Benchmarking

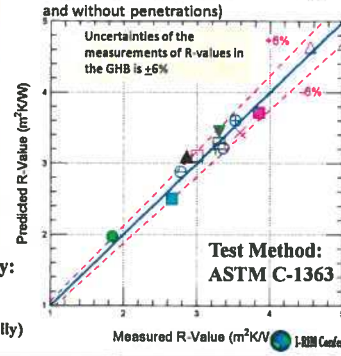
Wall without penetration

Wall with penetration

Wall Cavity was filled by:

- Glass Fibre
- Open cell SPF
- Closed cell SPF (partially)

Comparison of predicted R-values with the measurements at ΔP = 0 Pa for 2x6 Walls (with and without penetrations)



14

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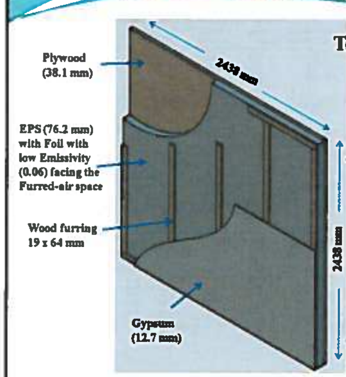
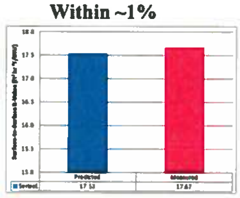
Model Benchmarking (cont.)



Test Method: ASTM C-1363

Within ~1%



15

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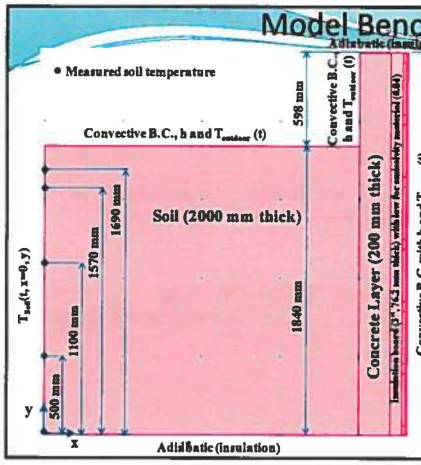
Model Benchmarking (cont.)



What is the contribution of furred-airspace assembly with low foil emissivity on the R-value and energy saving?

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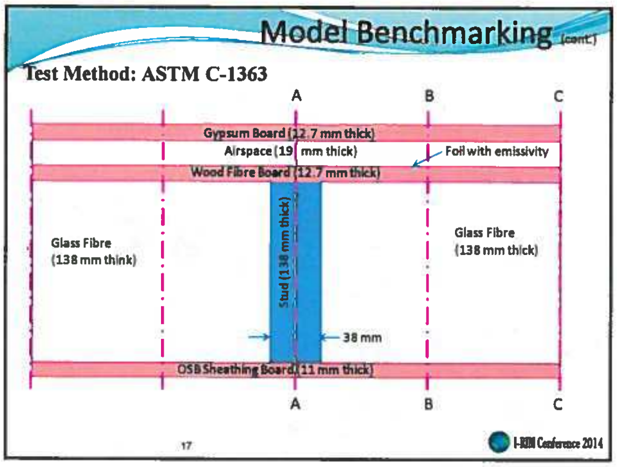
Model Benchmarking (cont.)
Test Method: ASTM C-1363
A
B
C
Gypsum Board (12.7 mm thick)
Airspace (19 mm thick)
Foil with emissivity
Wood Fibre Board (12.7 mm thick)
Glass Fibre (138 mm think)
Stud (138 mm thick)
Glass Fibre (138 mm thick)
38 mm
OSB Sheathing Board (11 mm thick)
17
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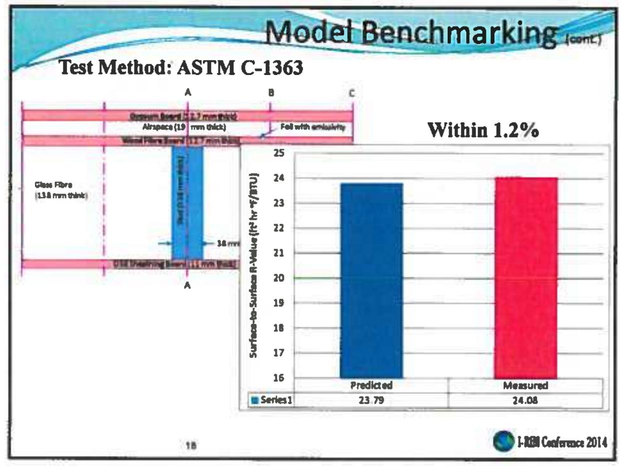
Model Benchmarking (cont.)
Test Method: ASTM C-1363
Within 1.2%
Surface-to-Surface R-Value (ft² hr °F/BTU)
Predicted
Measured
Series1
23.79
24.08
18
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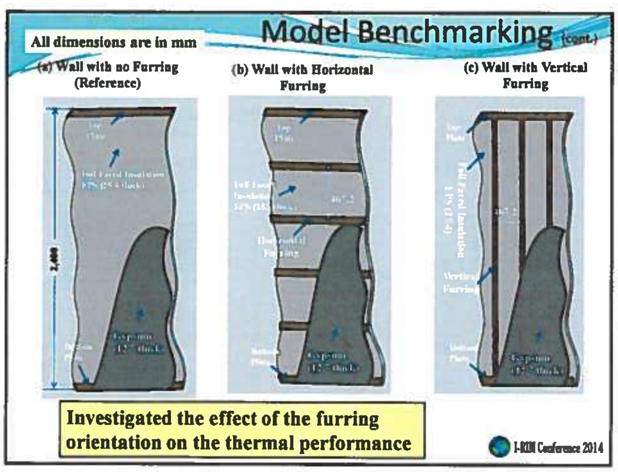
All dimensions are in mm
Model Benchmarking (cont.)
(a) Wall with no Furring (Reference)
(b) Wall with Horizontal Furring
(c) Wall with Vertical Furring
Investigated the effect of the furring orientation on the thermal performance
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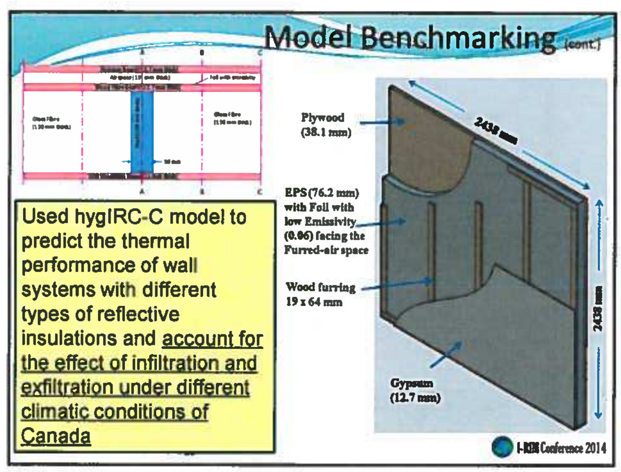
Model Benchmarking (cont.)
Used hygIRC-C model to predict the thermal performance of wall systems with different types of reflective insulations and account for the effect of infiltration and exfiltration under different climatic conditions of Canada
Plywood (38.1 mm)
2438 mm
EPS (76.2 mm) with Foil with low Emissivity (0.06) facing the Furred-air space
Wood furring 19 x 64 mm
2438 mm
Gypsum (12.7 mm)
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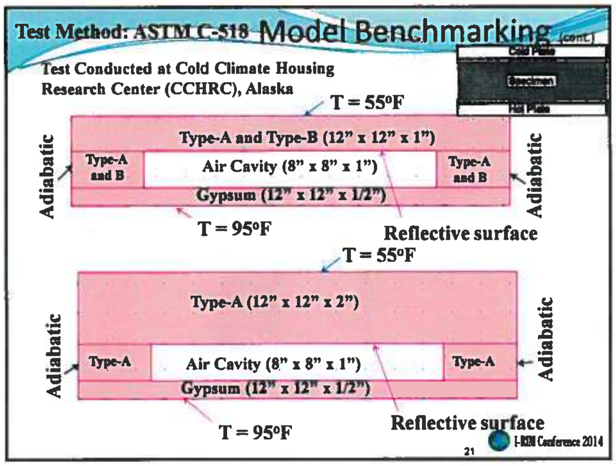
Test Method: ASTM C-518
Model Benchmarking (cont.)
Test Conducted at Cold Climate Housing Research Center (CCHRC), Alaska
Cold Plate
Specimen
Hot Plate
T = 55°F
Type-A and Type-B (12" x 12" x 1")
Type-A and B
Air Cavity (8" x 8" x 1")
Type-A and B
Gypsum (12" x 12" x 1/2")
Adiabatic
Adiabatic
T = 95°F
Reflective surface
T = 55°F
Type-A (12" x 12" x 2")
Type-A
Air Cavity (8" x 8" x 1")
Type-A
Gypsum (12" x 12" x 1/2")
Adiabatic
Adiabatic
T = 95°F
Reflective surface
21
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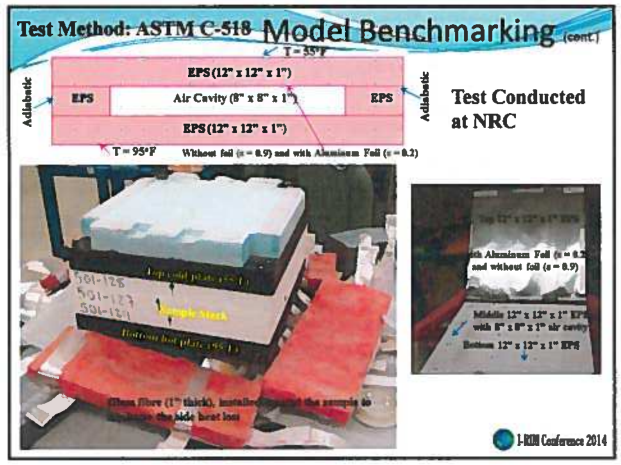
Test Method: ASTM C-518
Model Benchmarking (cont.)
T = 55°F
EPS (12" x 12" x 1")
EPS
Air Cavity (8" x 8" x 1")
EPS
EPS (12" x 12" x 1")
Adiabatic
Adiabatic
T = 95°F
Test Conducted at NRC
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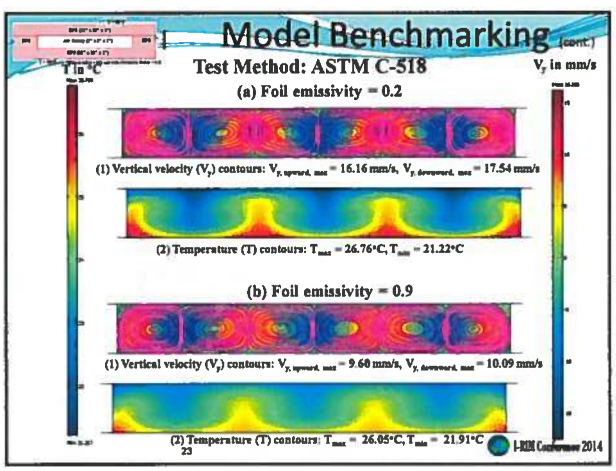
Model Benchmarking (cont.)
Test Method: ASTM C-518
T in °C
V_y in mm/s
(a) Foil emissivity = 0.2
(1) Vertical velocity (V_y) contours: V_y, upward, max = 16.16 mm/s, V_y, downward, max = 17.54 mm/s
(2) Temperature (T) contours: T_max = 26.76°C, T_min = 21.22°C
(b) Foil emissivity = 0.9
(1) Vertical velocity (V_y) contours: V_y, upward, max = 9.60 mm/s, V_y, downward, max = 10.09 mm/s
(2) Temperature (T) contours: T_max = 26.05°C, T_min = 21.91°C
23
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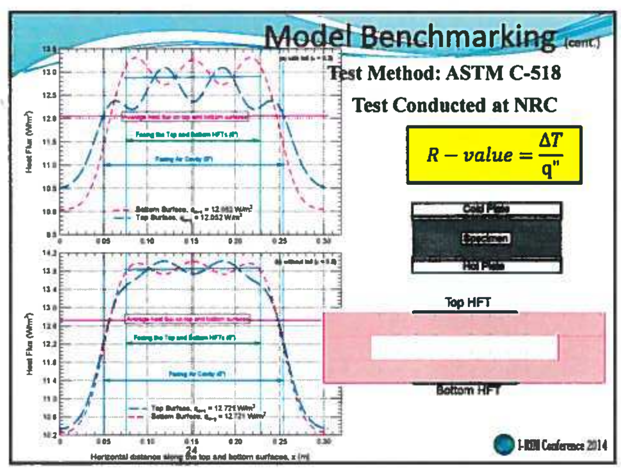
Model Benchmarking (cont.)
Test Method: ASTM C-518
Test Conducted at NRC
R − value = ΔT / q"
Cold Plate
Specimen
Hot Plate
Top HFT
Bottom HFT
Heat Flux (W/m²)
Horizontal distance along the top and bottom surfaces, x (m)
24
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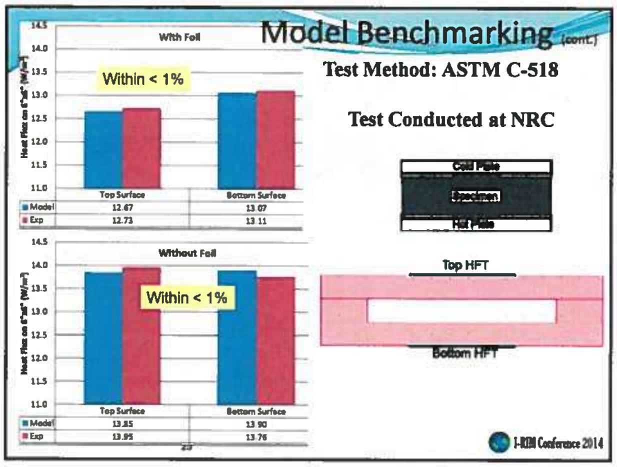
Model Benchmarking (cont.)
Test Method: ASTM C-518
Test Conducted at NRC
With Foil
Within < 1%
Top Surface
Bottom Surface
Model 12.67 13.07
Exp 12.73 13.11
Without Foil
Within < 1%
Model 13.85 13.90
Exp 13.95 13.76
Cold Plate
Specimen
Hot Plate
Top HFT
Bottom HFT
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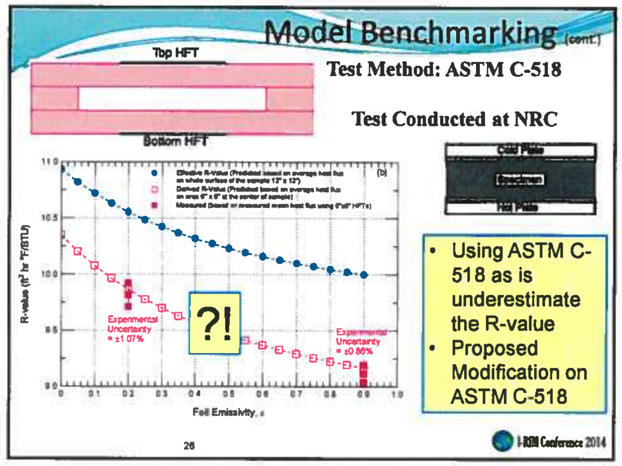
Model Benchmarking (cont.)
Top HFT
Bottom HFT
Test Method: ASTM C-518
Test Conducted at NRC
Cold Plate
Specimen
Hot Plate
R-value (ft² hr °F/BTU)
Foil Emissivity, ε
Experimental Uncertainty = ±1.07%
Experimental Uncertainty = ±0.86%
?!
Using ASTM C-518 as is underestimate the R-value
Proposed Modification on ASTM C-518
26
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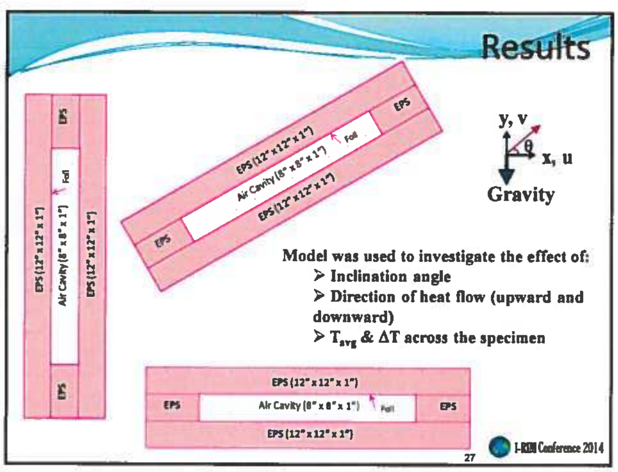
Results
EPS (12" x 12" x 1")
Air Cavity (8" x 8" x 1")
Foil
EPS
y, v
θ
x, u
Gravity
Model was used to investigate the effect of:
Inclination angle
Direction of heat flow (upward and downward)
T avg & ΔT across the specimen
27
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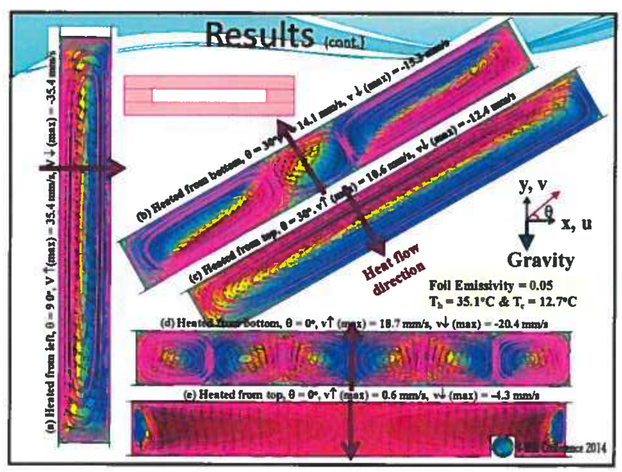
Results (cont.)
(a) Heated from left, θ = 90°, V↑(max) = 35.4 mm/s, V↓(max) = -35.4 mm/s
(b) Heated from bottom, θ = 30°, v↑ = 14.1 mm/s, v↓ (max) = -15.3 mm/s
(c) Heated from top, θ = 30°, v↑ (max) = 10.6 mm/s, v↓ (max) = -12.4 mm/s
Heat flow direction
y, v
θ
x, u
Gravity
Foil Emissivity = 0.05
Th = 35.1°C & Tc = 12.7°C
(d) Heated from bottom, θ = 0°, v↑ (max) = 18.7 mm/s, v↓ (max) = -20.4 mm/s
(e) Heated from top, θ = 0°, v↑ (max) = 0.6 mm/s, v↓ (max) = -4.3 mm/s
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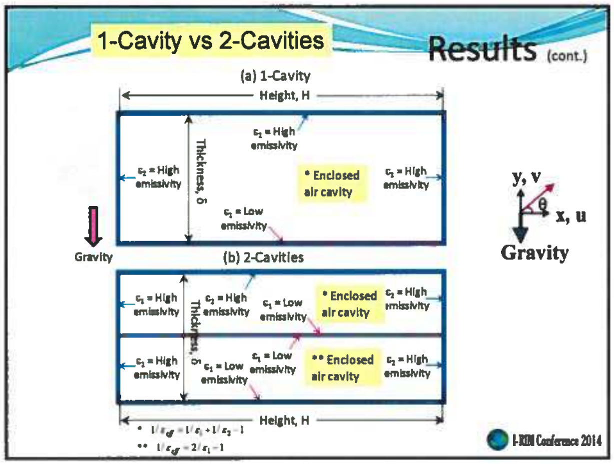
1-Cavity vs 2-Cavities
Results (cont.)
(a) 1-Cavity
Height, H
ε2 = High emissivity
ε2 = High emissivity
Thickness, δ
* Enclosed air cavity
ε2 = High emissivity
ε1 = Low emissivity
Gravity
(b) 2-Cavities
ε2 = High emissivity
ε2 = High emissivity
ε1 = Low emissivity
* Enclosed air cavity
ε2 = High emissivity
ε2 = High emissivity
ε1 = Low emissivity
ε1 = Low emissivity
** Enclosed air cavity
ε2 = High emissivity
Height, H
y, v
θ
x, u
Gravity
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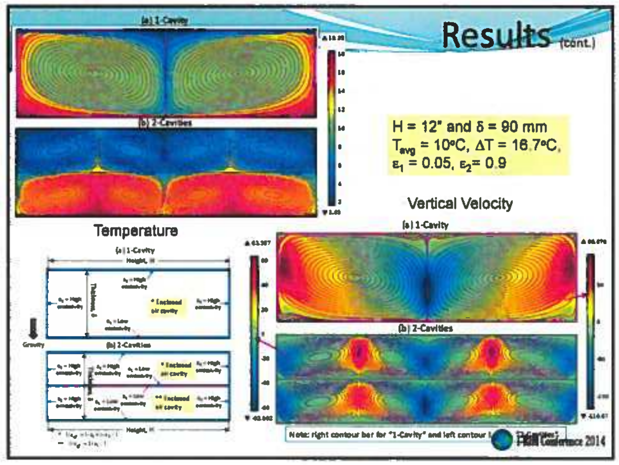
Results (cont.)
(a) 1-Cavity
(b) 2-Cavities
H = 12" and δ = 90 mm
Tavg = 10°C, ΔT = 16.7°C,
ε1 = 0.05, ε2 = 0.9
Vertical Velocity
Temperature
(a) 1-Cavity
(b) 2-Cavities
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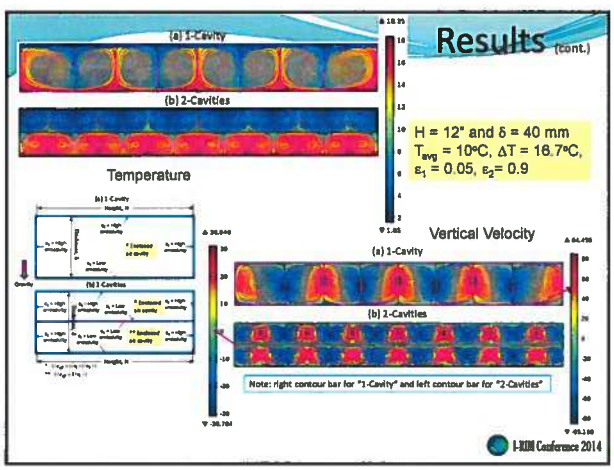
Results (cont.)
(a) 1-Cavity
(b) 2-Cavities
H = 12" and δ = 40 mm
Tavg = 10°C, ΔT = 16.7°C,
ε1 = 0.05, ε2 = 0.9
Temperature
Vertical Velocity
(a) 1-Cavity
(b) 2-Cavities
Note: right contour bar for "1-Cavity" and left contour bar for "2-Cavities"
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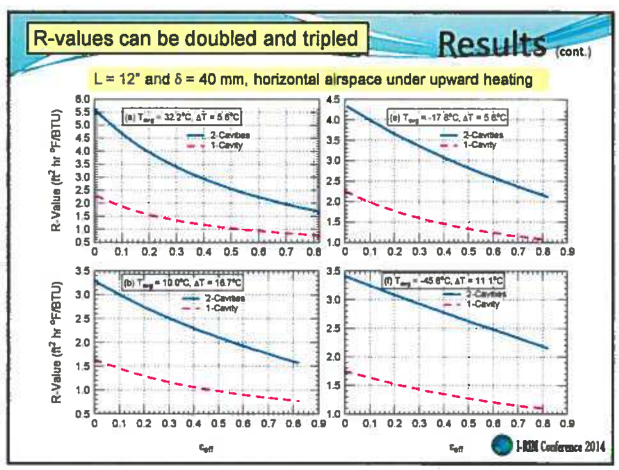
R-values can be doubled and tripled
Results (cont.)
L = 12" and δ = 40 mm, horizontal airspace under upward heating
R-Value (ft² hr °F/BTU)
2-Cavities
1-Cavity
εeff
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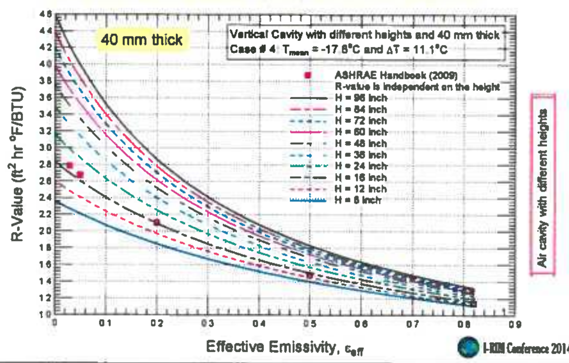
Results (cont.)

Effect of height of vertical cavity on its R-value



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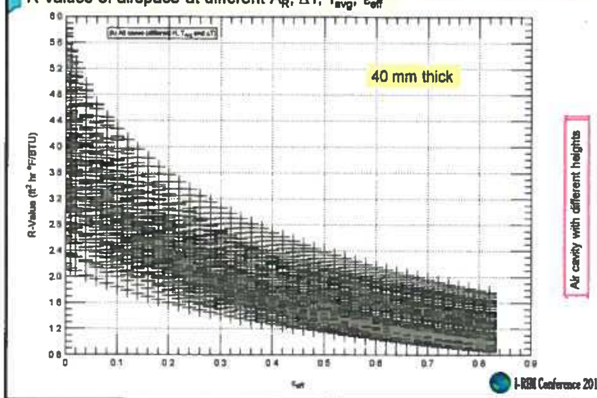
Results (cont.)

R-values of airspace at different A_R, ΔT, T_{avg}, ε_{eff}



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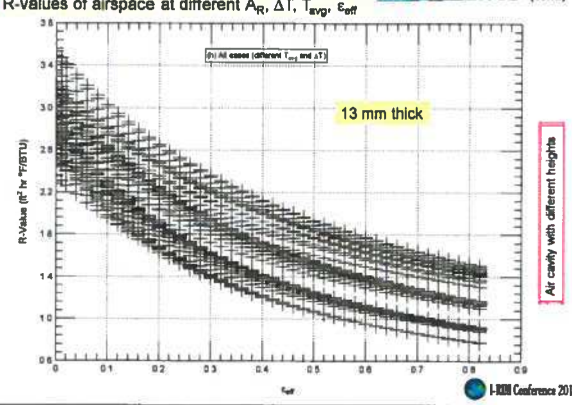
Results (cont.)

R-values of airspace at different A_R, ΔT, T_{avg}, ε_{eff}



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R-value Correlations

$$R-value = R_c(T_{avg}) + a_0 A_R^{\alpha_1} T_{avg}^{\alpha_1} (\Delta T)^{c_1}$$
$$+ a\, \varepsilon_{eff}^{\beta} T_{avg}^{\alpha_2} (\Delta T)^{c_2} \sum_{i=1}^{4} g_i A_R^i + A_R^{\alpha_2} T_{avg}^{\alpha_3} (\Delta T)^{c_3} \sum_{i=1}^{4} b_i \varepsilon_{eff}^i$$

- R-value correlations can be implemented in energy simulation models (Energy+, Esp-r, DOE)
- Proposed to ASHRAE TC4.4 be included in the ASHRAE Handbook of Fundamentals (https://sites.google.com/site/ashraetc44/home/handbook-page)

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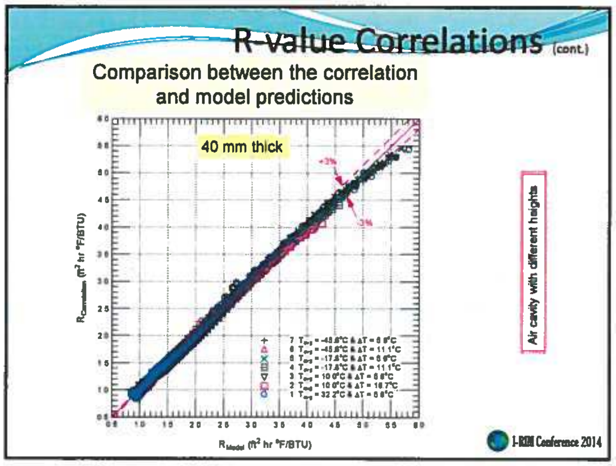

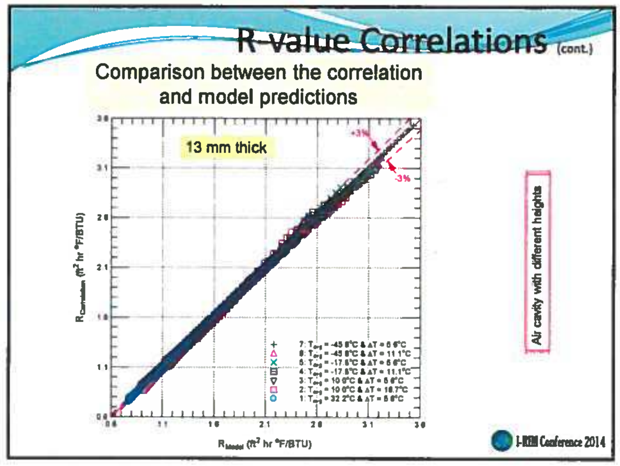

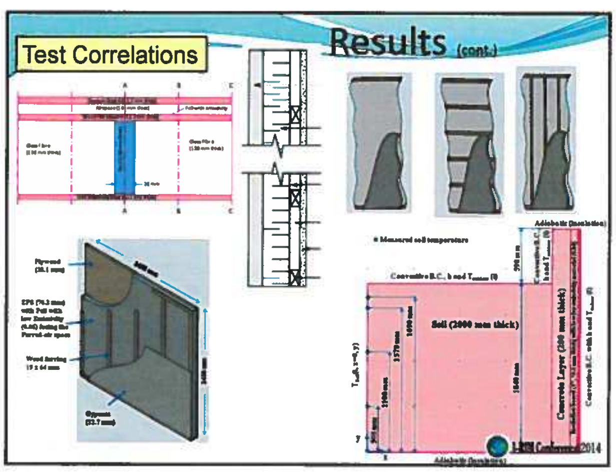

SUMMARY

- hygIRC-C model was benchmarked against experimental data obtained using ASTM C-1363 and ASTM C-518
- Using ASTM C-518 as is resulted in underestimating the R-value of reflective insulations
- Conducted parametric study in order to develop practical correlations for determining the effective R-values of enclosed airspaces with different:
  - Dimensions (aspect ratios),
  - Average temperatures,
  - Temperature differentials,
  - Direction of heat transfer, and
  - Wide Range of emissivity
- R-values obtained using the correlations are in good agreement with that predicted using hygIRC-C model
- R-value correlations are ready to be implemented in energy simulations models (Energy+, Esp-r, DOE)

40

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Publications in area of reflective insulations

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2. Saber, H.H., "Practical Correlation for Thermal Resistance of Horizontal Enclosed Airspaces with Downward Heat Flow for Building Applications", *Journal of Building Physics*, DOI: 10.1177/1744259113498473. The online version of this article can be found at: http://jen.sagepub.com/content/early/2013/08/19/1744259113498473, in press, July 2013.
3. Saber, H.H., "Practical Correlation for Thermal Resistance of 45° Sloped Enclosed Airspaces with Downward Heat Flow for Building Applications", *Journal of Building and Environment*, volume 65, pp. 154-169, 2013, the online version is available at: http://dx.doi.org/10.1016/j.buildenv.2013.04.009.
4. Saber, H.H., "Practical Correlations for Thermal Resistance of Horizontal Enclosed Airspaces with Upward Heat Flow for Building Applications", *Journal of Building and Environment*, (http://dx.doi.org/10.1016/j.buildenv.2012.12.016) vol. 61, pp. 169-187, 2013.
5. Saber, H.H., "Practical Correlations for the Thermal Resistance of Vertical Enclosed Airspaces for Building Applications", *Journal of Building and Environment*, http://dx.doi.org/10.1016/j.buildenv.2012.09.003, vol. 59, pp. 379-396, January 2013.
6. Saber, H.H., Maref, W., Sherrer, G., Swinton, M.C., "Numerical modelling and experimental investigations of thermal performance of reflective insulations," *Journal of Building Physics*, vol. 36, no. 2, pp. 163-177, 2012 (NRCC-54538), DOI: 10.1177/1744259112444021. The online version of this article can be found at: http://jen.sagepub.com/content/early/2012/04/25/1744259112444021.
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41 I-RIM Conference 2014

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9. Saber, H.H., "Thermal Performance of Wall Assemblies with Low Emissivity" *Journal of Building Physics*, vol. 36, no. 3, pp. 308-329, 2013, DOI: 10.1177/1744259112450419. The online version of this article can be found at: http://jen.sagepub.com/content/early/2012/07/02/1744259112450419.
9. Saber, H.H., Maref, W., Swinton, M.C., "Thermal response of basement wall systems with low emissivity material and furred airspace," *Journal of Building Physics*, vol. 35, no. 2, pp. 353-371, 2012, (NRCC-53962), URL: http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc53962.pdf, DOI: http://dx.doi.org/10.1177/1744259111411652.

10. Saber, H.H., Maref, W., Swinton, M.C., St-Onge, C., "Thermal analysis of above-grade wall assembly with low emissivity materials and furred-airspace," *Journal of Building and Environment*, 46, (7), pp. 1403-1414, January-09-11 (NRCC-53584), URL: http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc53584.pdf, DOI: http://dx.doi.org/10.1016/j.buildenv.2011.01.009.
11. Saber, H.H., and Maref, W., "Effect of Furring Orientation on Thermal Response of Wall Systems with Low Emissivity Material and Furred-Airspace", *The Building Enclosure Science & Technology (BEST3) Conference* to be held in April 2-4, 2012 in Atlanta, Georgia, USA, November 2011.
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13. Saber, H.H., and Swinton, M.C., "Determining through Numerical Modeling the Effective Thermal Resistance of a Foundation Wall System with Low Emissivity Materials and Furred – airspace", *ICBEST 2010 - International Conference on Building Envelope Systems and Technologies* (Vancouver, B.C., June 27-30, 2010), pp. 247-257.

42 I-RIM Conference 2014

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Questions?

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Dr. Hamed Saber
Research Officer
Building Envelope Engineering and Materials
1200 Montreal Road, Building M-24
Ottawa, Ontario K1A 0R6
613-993-9772 Docufax 613-998-6802
E-mail: hamed.saber@nrc-cnrc.gc.ca

Canada NRC·CNRC

Conseil national de recherches Canada — National Research Council Canada
Génie — Engineering
Construction — Construction

Dr. Hamed Saber
Agent de recherches
Matériaux et ingénierie de l'enveloppe du bâtiment
1200, chemin Montréal, édifice M-24
Ottawa (Ontario) K1A 0R6
613-993-9772 Docufax 613-998-6802
Courriel : hamed.saber@nrc-cnrc.gc.ca

Canada CNRC·NRC

Thank you!

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800/279-4123
www.rimainternational.org