BEST6

Effect of Air Intrusion on Reflective Insulations Performance with Heat Flow UP and Down

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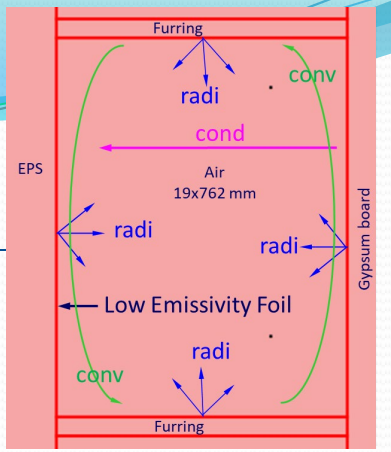
OVERVIEW

- Introduction
- 2D and 3D Numerical Model
- Sample Results of Air Intrusion in RIs with Heat Flow Horizontal
- Objectives
- Air Intrusion in Reflective Insulations (RIs) with Heat Flow Down
- Air Intrusion in RIs with Heat Flow Up
- Summary

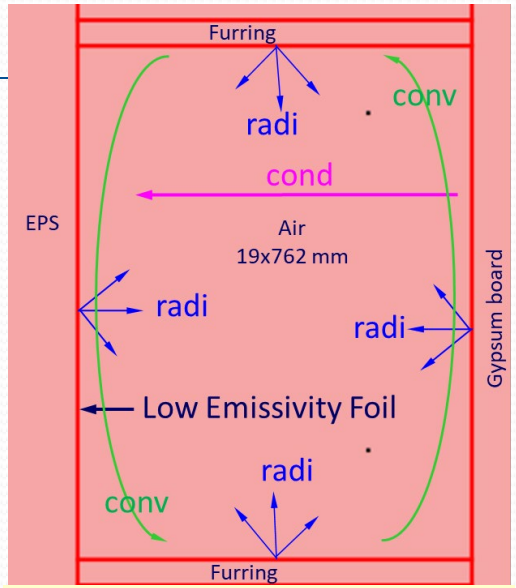
Introduction



- Enclosed airspaces exist in many building components:
  - Windows
  - Curtain walls
  - Skylight devices
  - Reflective insulations in wall systems (e.g. furred –airspace assemblies)
  - Reflective insulations in roofing systems
- Enclosed airspaces use coatings/surfaces/foils of different emittances
- R-value of enclosed airspaces depends on:
  - Thickness
  - Height/length (aspect ratio)
  - Temperature of all surfaces of the enclosed airspace
  - Emittances of all surfaces of the enclosed airspace
  - Inclination angle
  - Direction of heat flow through the enclosed airspace
- Determining accurately the R-value of the enclosed airspaces results in accurate predictions for the energy performance of building components having enclosed airspaces. This will lead to accurate predictions for energy performance of whole buildings

2D and 3D Numerical Model

- 2D and 3D numerical model was developed and used to assess the energy performance and moisture performance (risk of condensation and mold growth) of building components subjected to various climatic conditions
- The numerical model solves simultaneously:
  - Moisture transport equations in airspace and porous media
  - Momentum equation of compressible fluid for airspace and Brinkman/Darcy equation for porous media
  - Energy equations of porous and non-porous media
  - Surface-to-surface radiation equation



Modes of Heat Transfer in Reflective Enclosed Airspace are by Conduction, Convection and Radiation

- The model was extensively validated against test data obtained from:
  - Guarded hot box (ASTM-C1363)
  - Guarded hot plate and heat flow meter (ASTM-C518)
  - Field measurements

Introduction (cont.)

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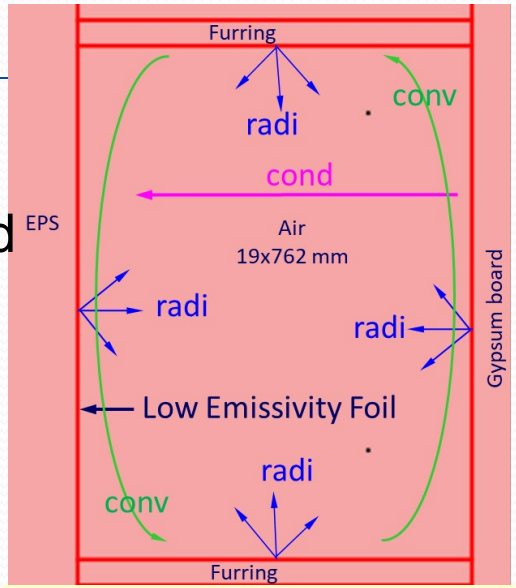

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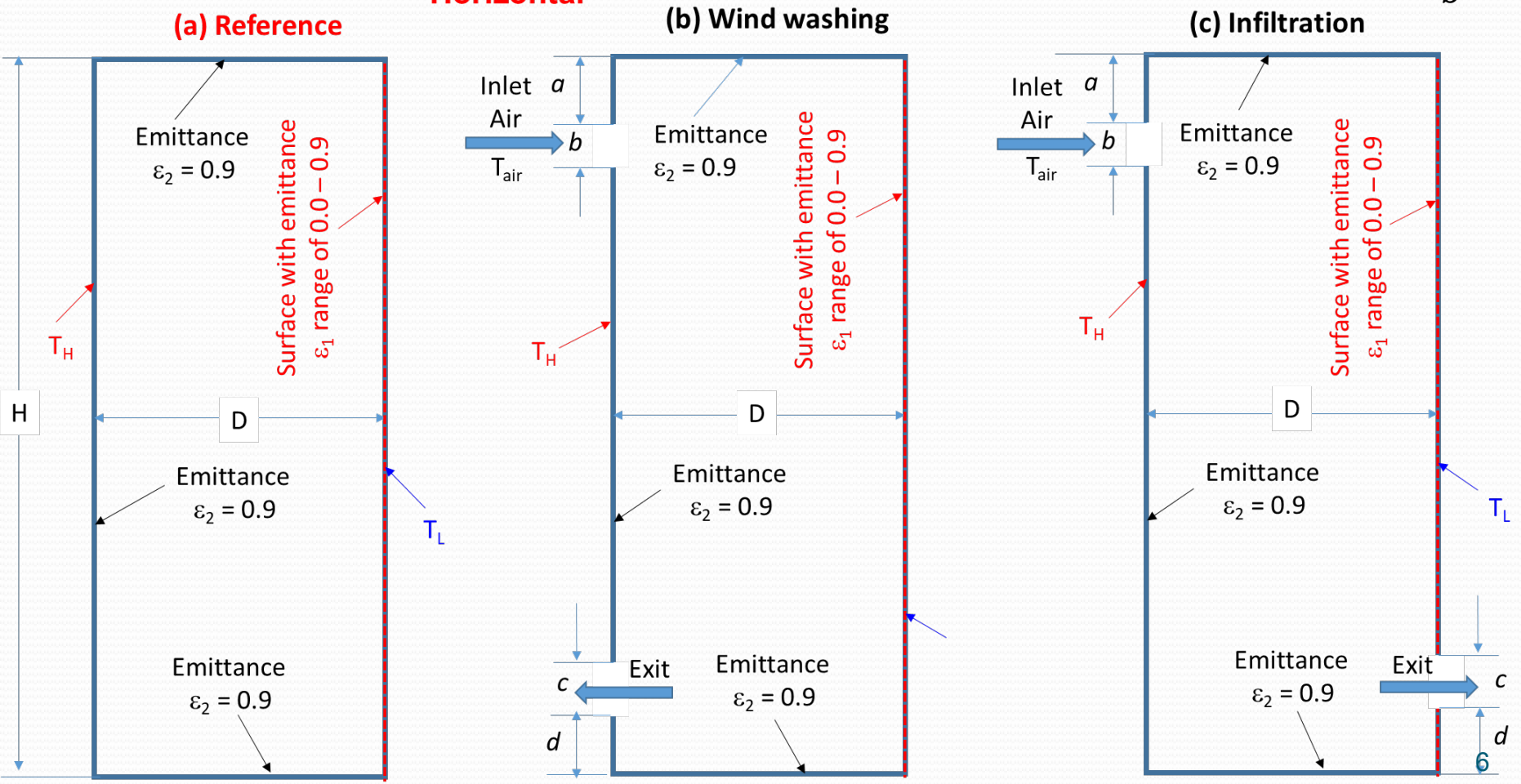
Sample Results of Air Intrusion in RIs with Heat Flow Horizontal

Saber, H.H., and Yarbrough, D.W., "Assessing the Effect of Air Intrusion on Reflective Insulations Performance with Horizontal Heat Flow", *Buildings*, 13 (10), 2461, 2023

Wall applications

Heat Flow Horizontal

$$ACH = \frac{\dot{Q}}{V}, \quad \bar{v} = ACH \times D \times \frac{H}{b}$$



Sample Results of Air Intrusion in RIs with Heat Flow Horizontal (cont.)

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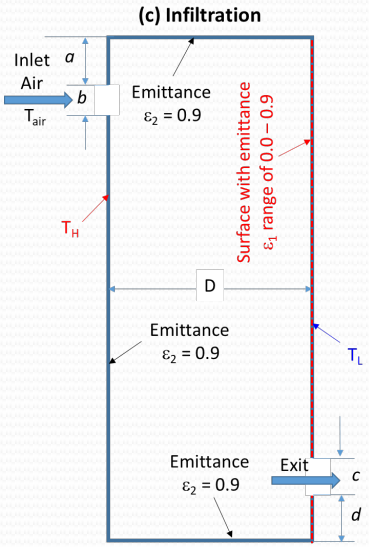
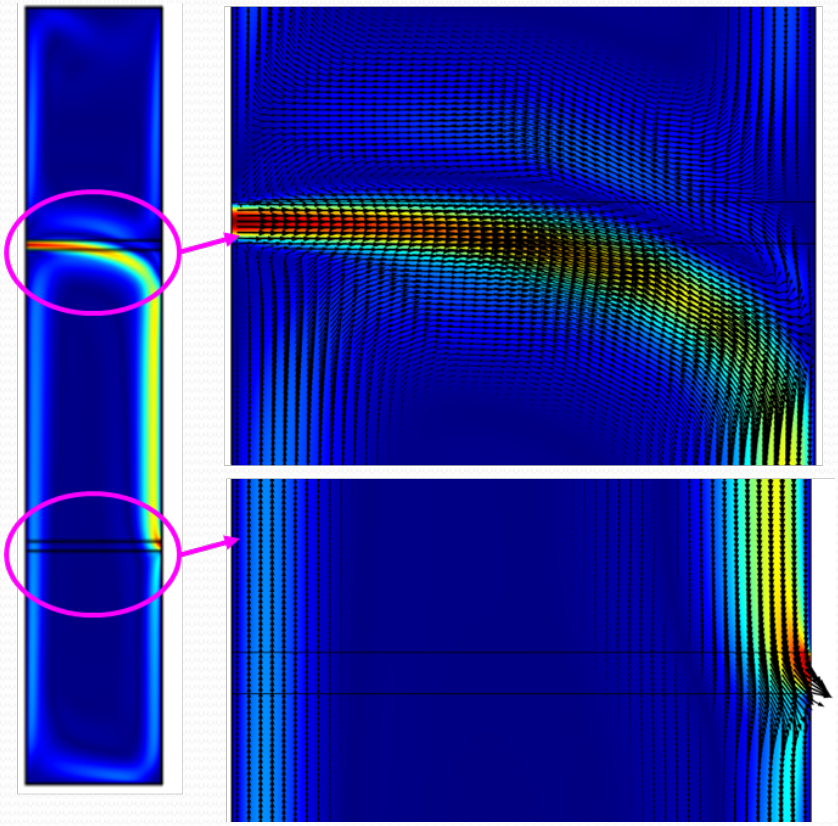
Wall applications

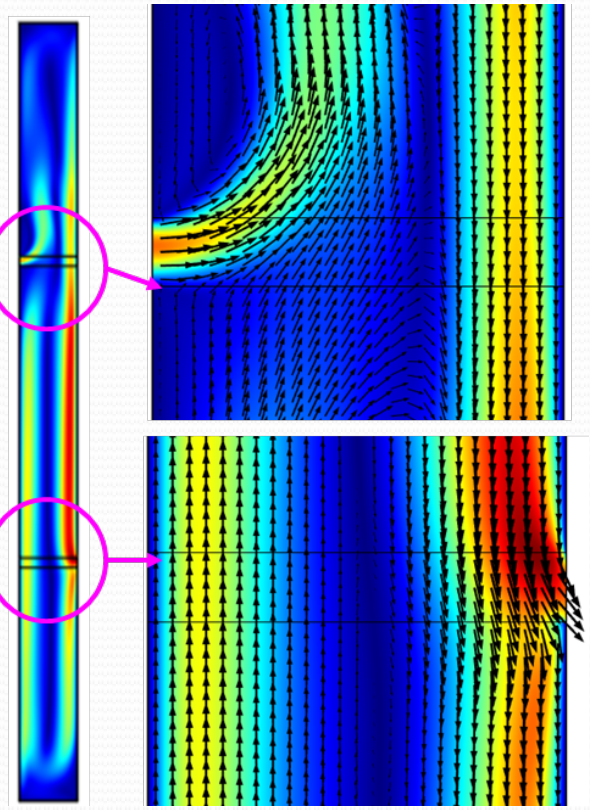
T_{air} = 80°F, ε_F = 0.05, H = 20 inch

Resultant velocity

Heat Flow Horizontal







D = 3.5 in.

D = 1.5 in.

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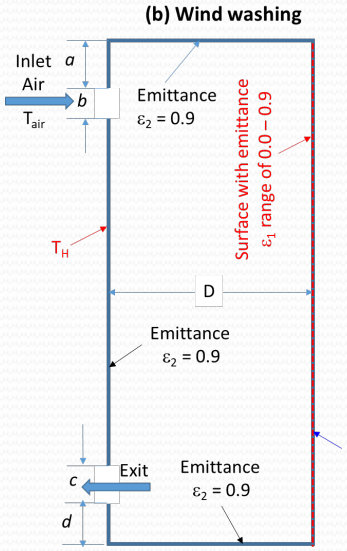
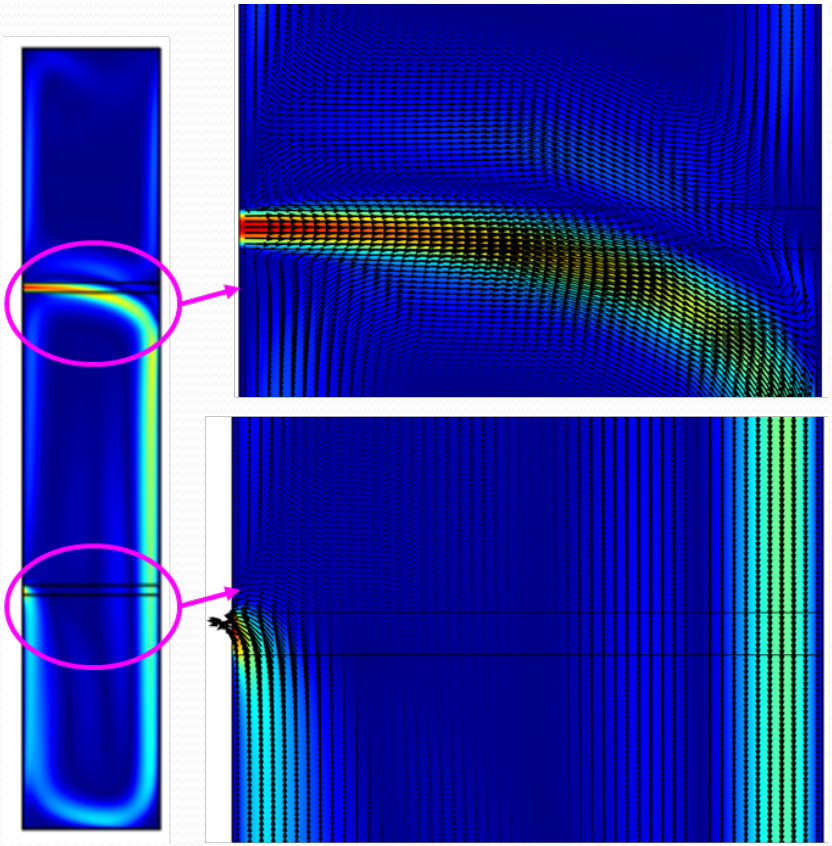
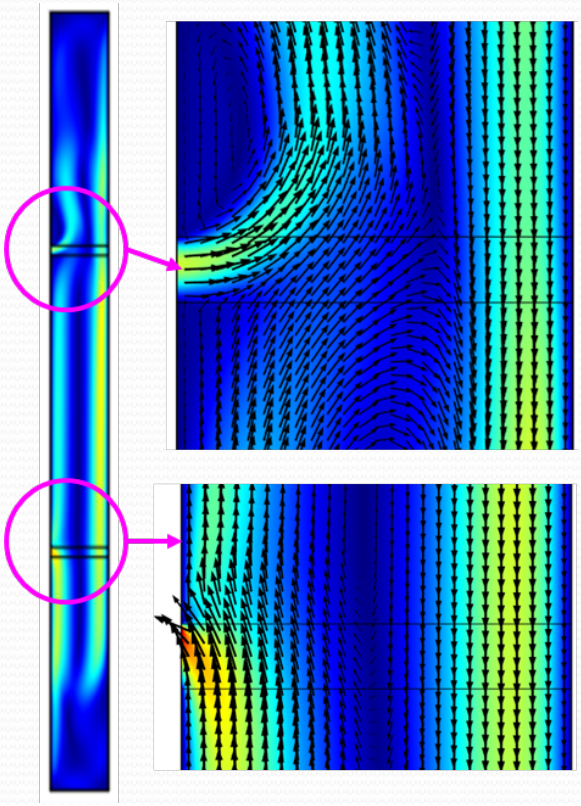
Heat Flow Horizontal







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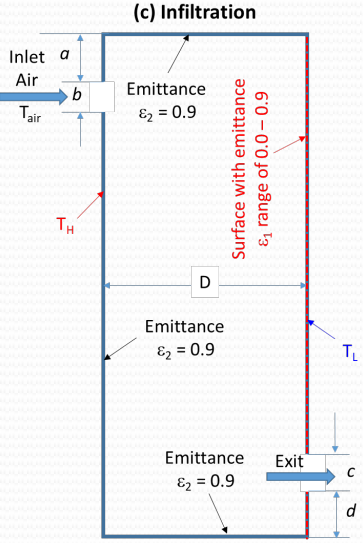
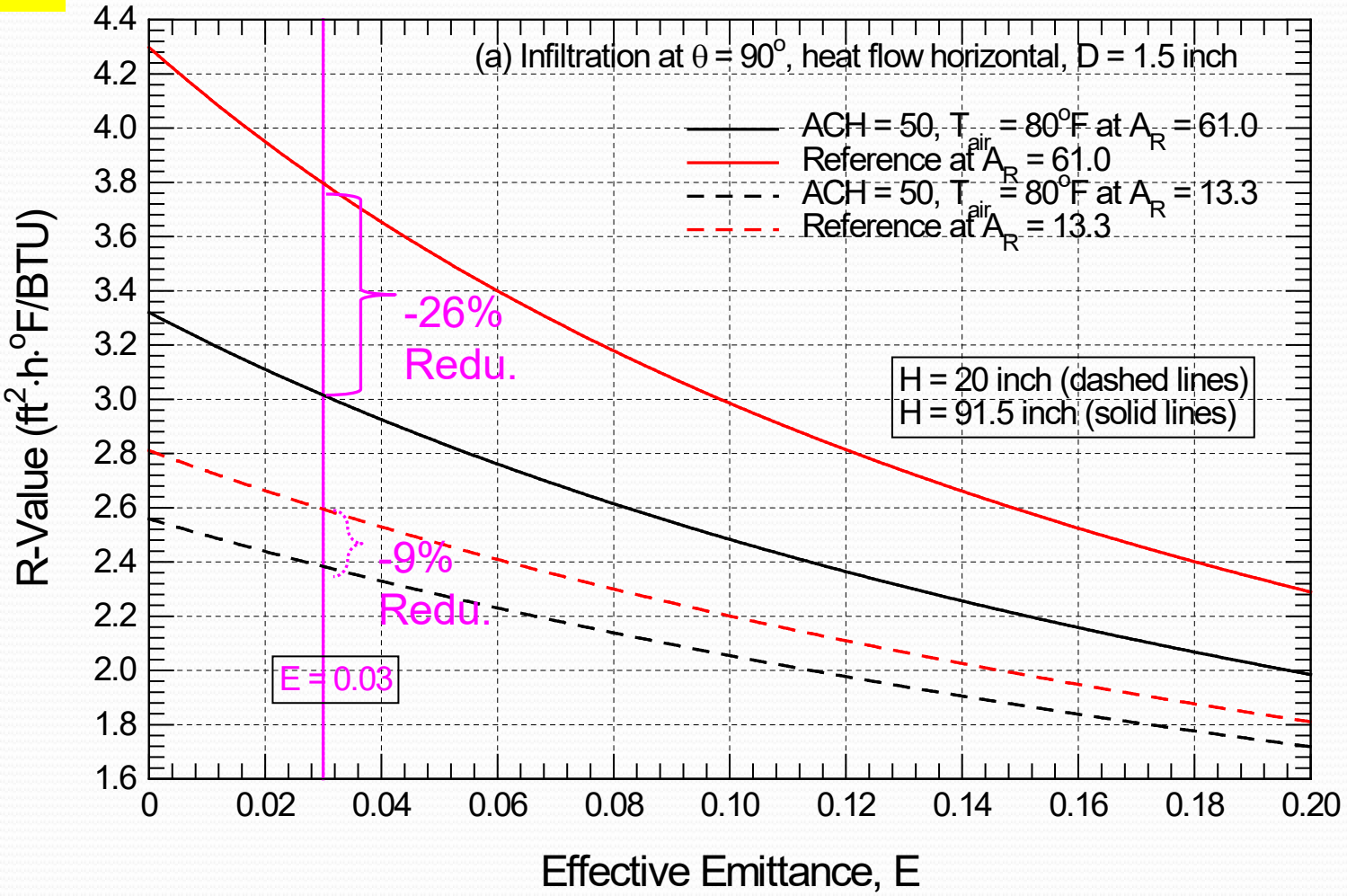
Wall applications

Heat Flow Horizontal



Thin Assembly

Effect of aspect ratio at the same ACH of 50



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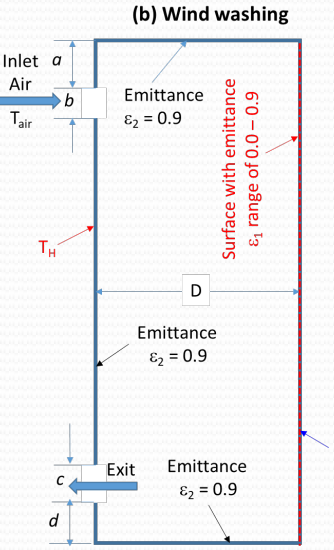

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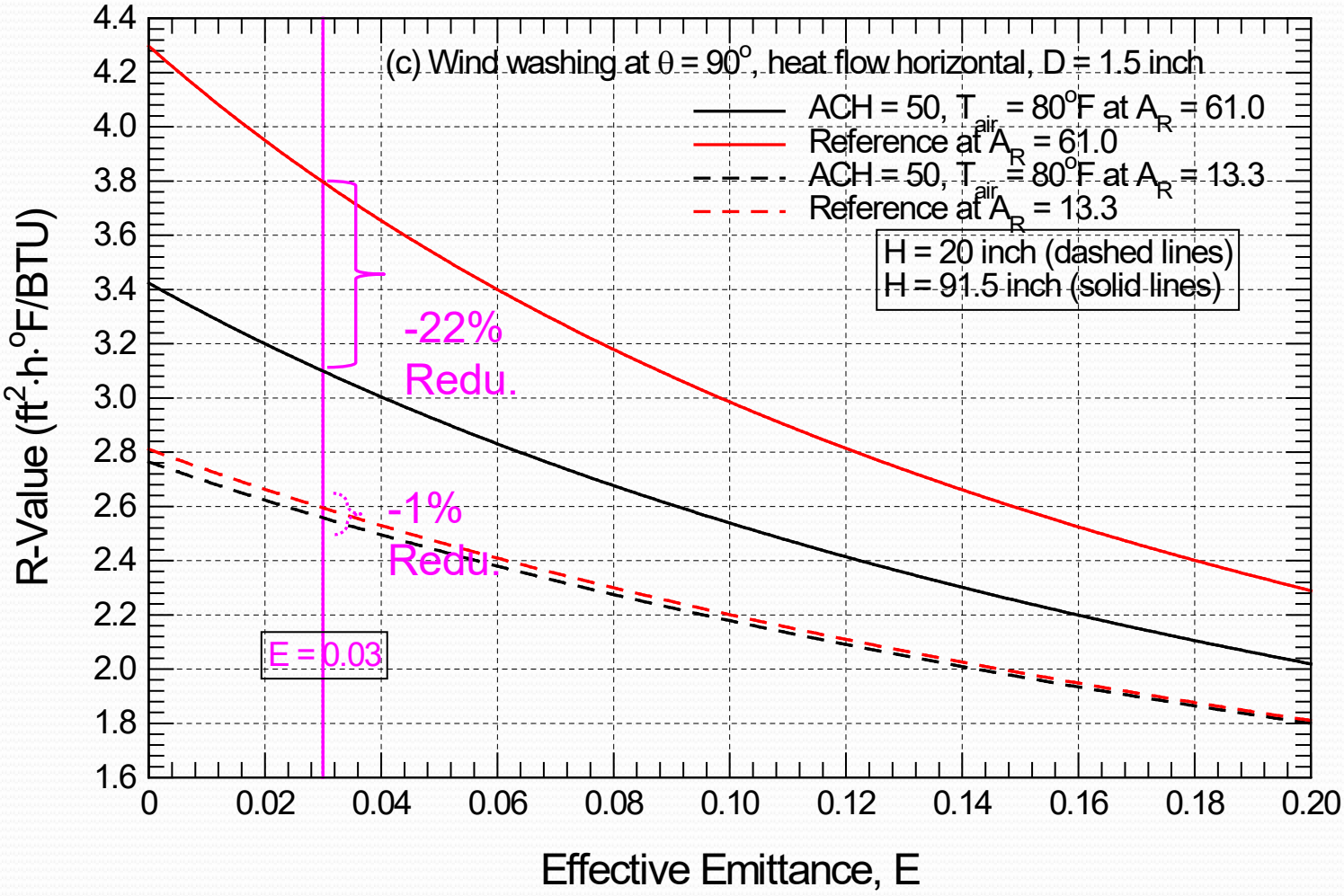
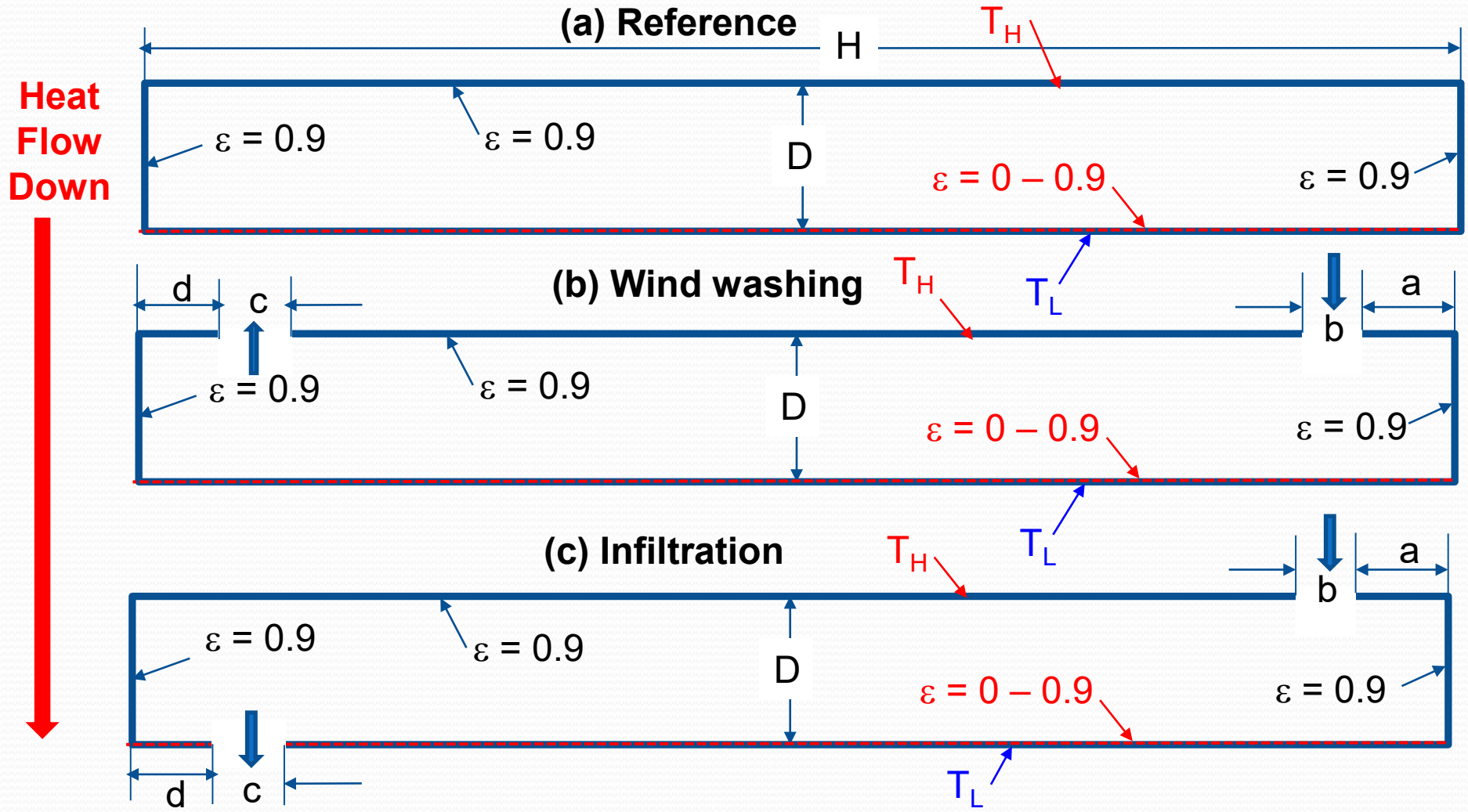


Objectives

For horizontal reflective insulation assemblies, use the numerical model to investigate the effect of air intrusion on the thermal performance for the cases of:

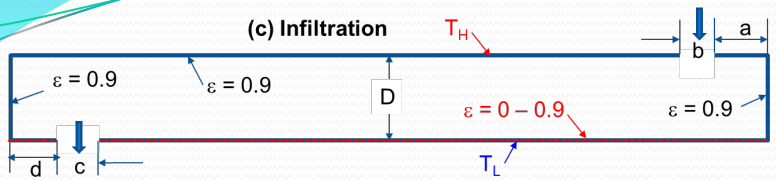
- Heat flow down (summer conditions)
- Heat flow up (winter conditions)

Air Intrusion in RIs with Heat Flow Down



a = b= 6 inch, b = c = 0.25 inch, d = 6 inch, H = 20.0 & 91.5 inch,
D = 1.5 & 3.5 inch, T_H = 90°F, T_L = 60°F, T_{air} = 80°F, 90°F, 100°F

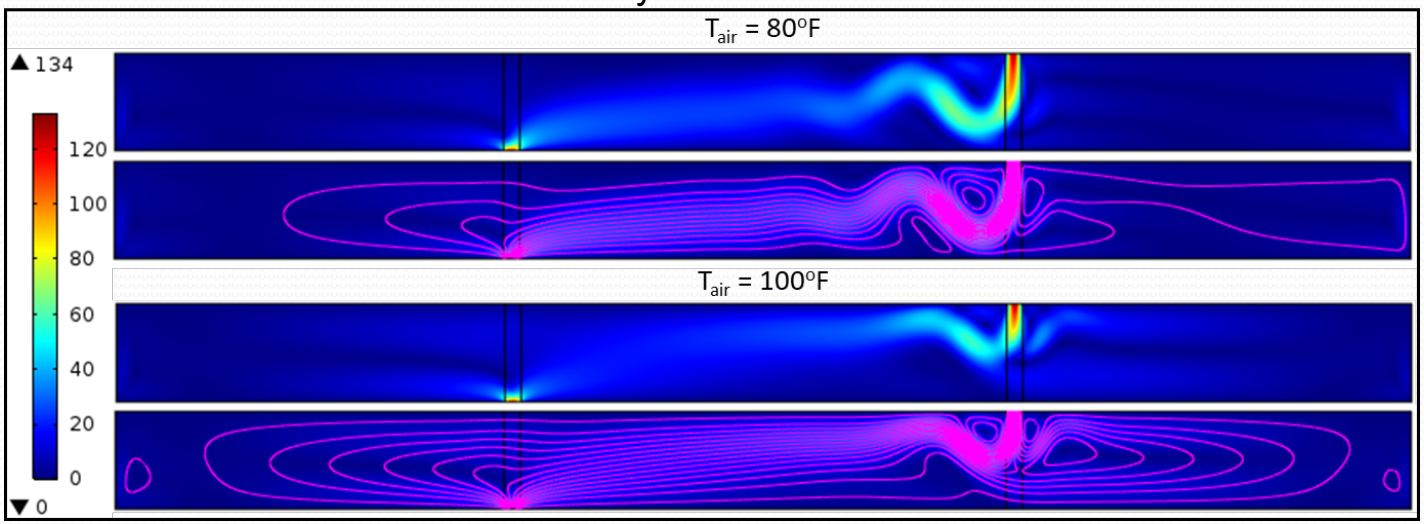
Air Intrusion in RIs with Heat Flow Down (cont.)



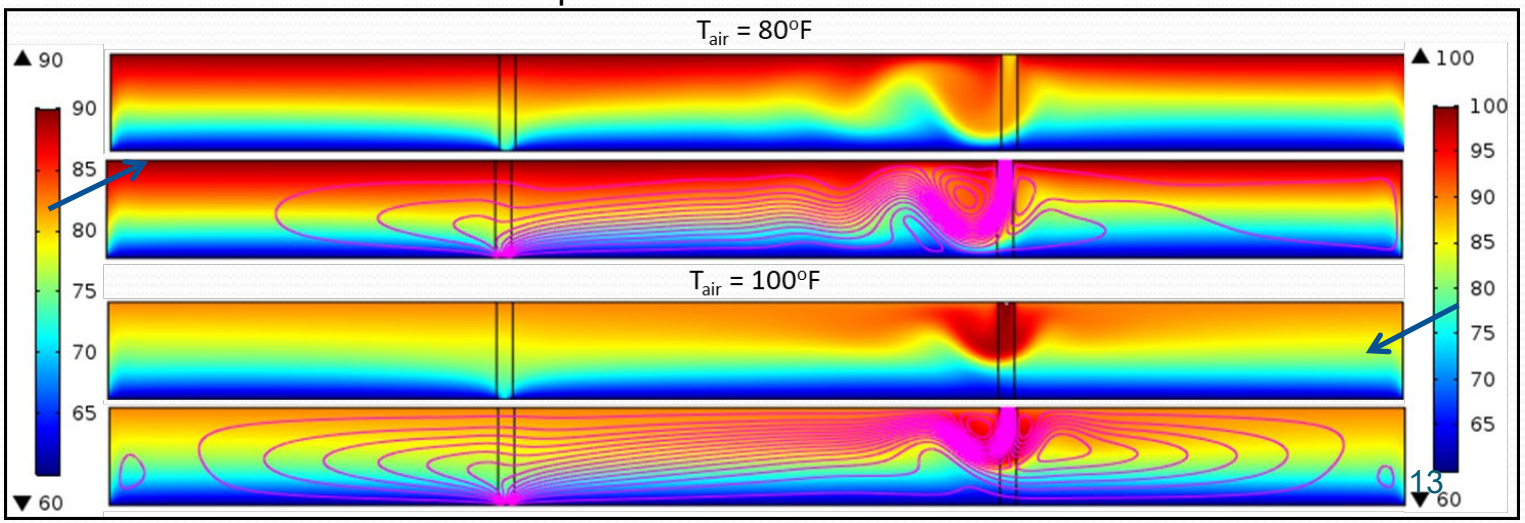
Infiltration, ACH = 100, E = 0.05, H = 20 in, D = 1.5 in

Heat Flow Down

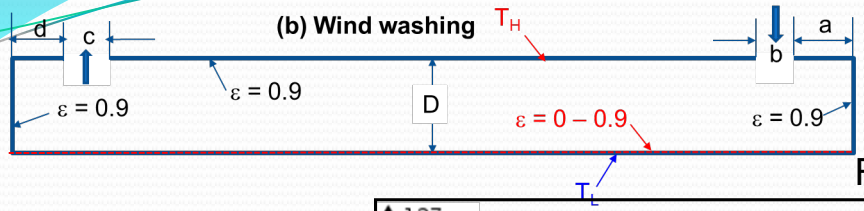
Resultant velocity distribution in mm/s



Temperature distribution in °F

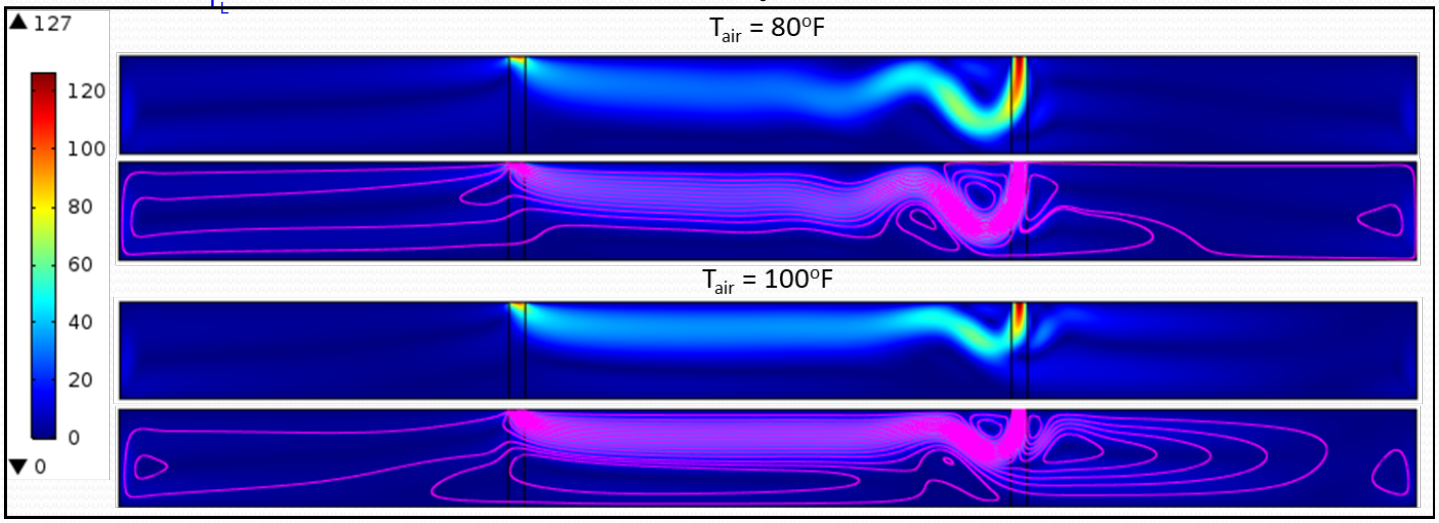


Air Intrusion in RIs with Heat Flow Down (cont.)



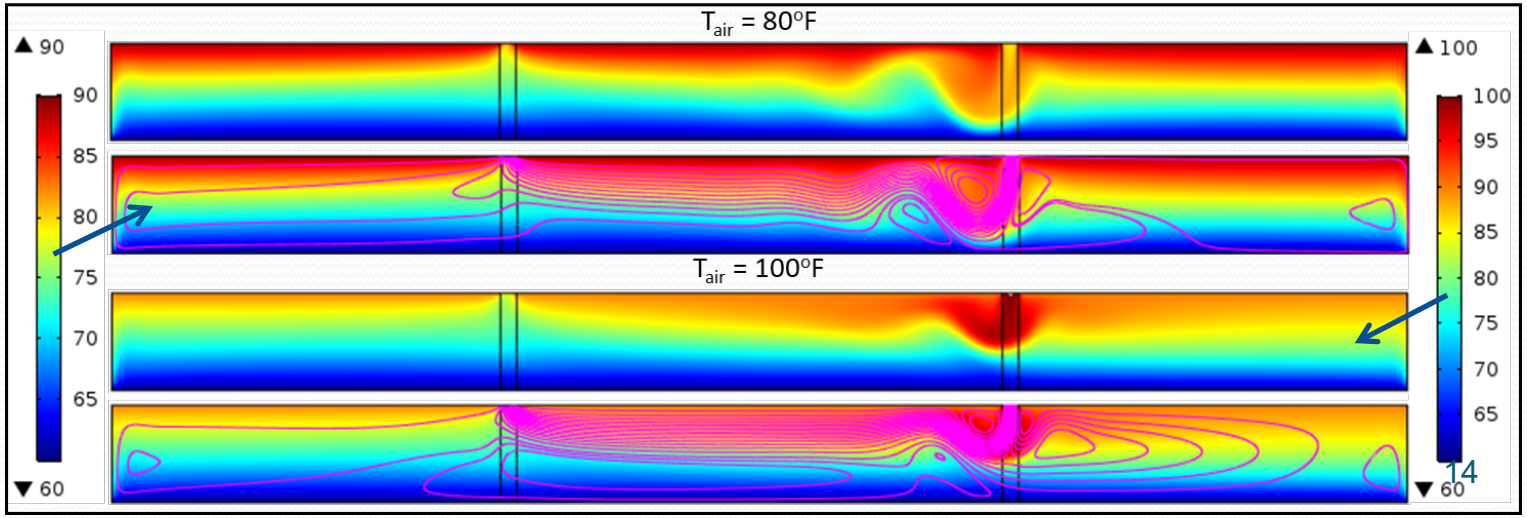
Wind washing, ACH = 100, E = 0.05, H = 20 in, D = 1.5 in

Resultant velocity distribution in mm/s



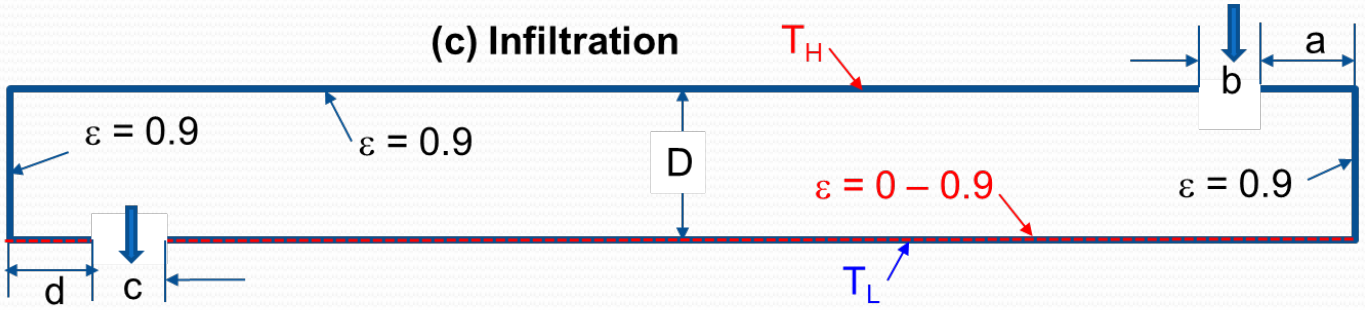
Heat Flow Down

Temperature distribution in °F



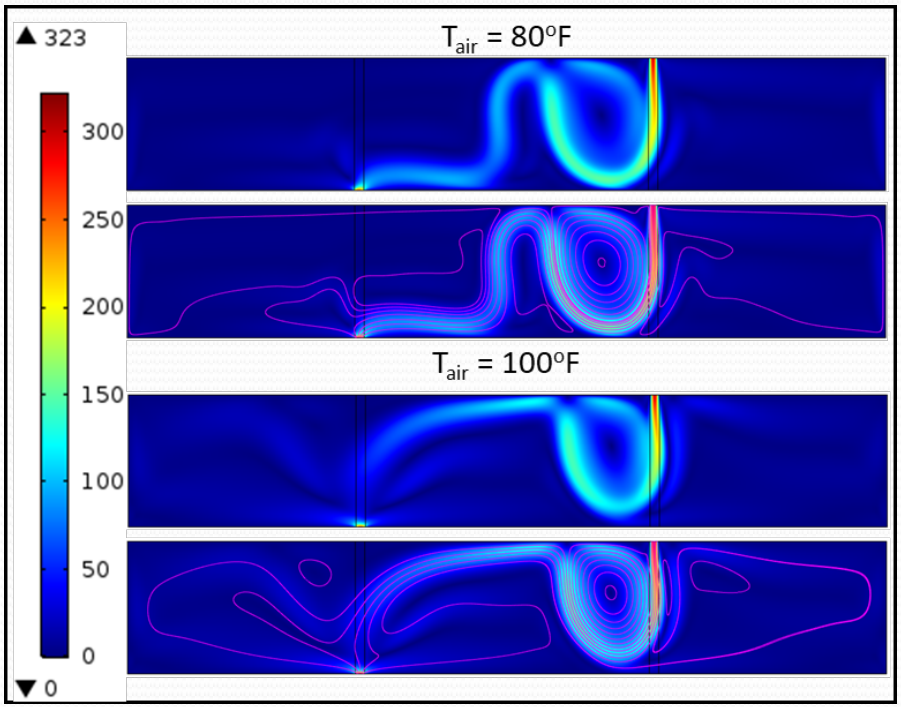
Air Intrusion in RIs with Heat Flow Down (cont.)

Heat Flow Down

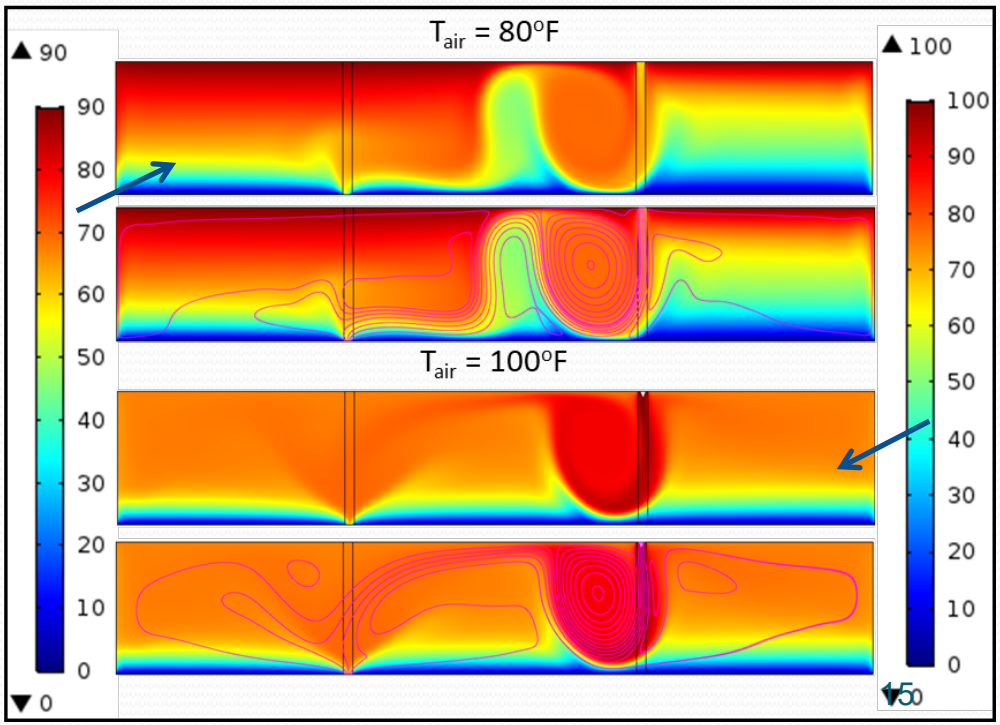


Infiltration, ACH = 100, E = 0.05, H = 20 in, D = 3.5 in

Resultant velocity distribution in mm/s

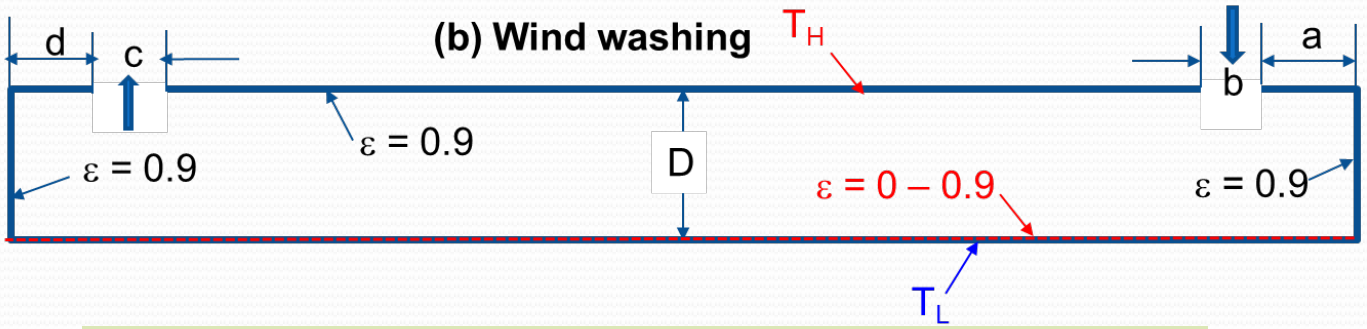


Temperature distribution in °F



Air Intrusion in RIs with Heat Flow Down (cont.)

Heat Flow Down



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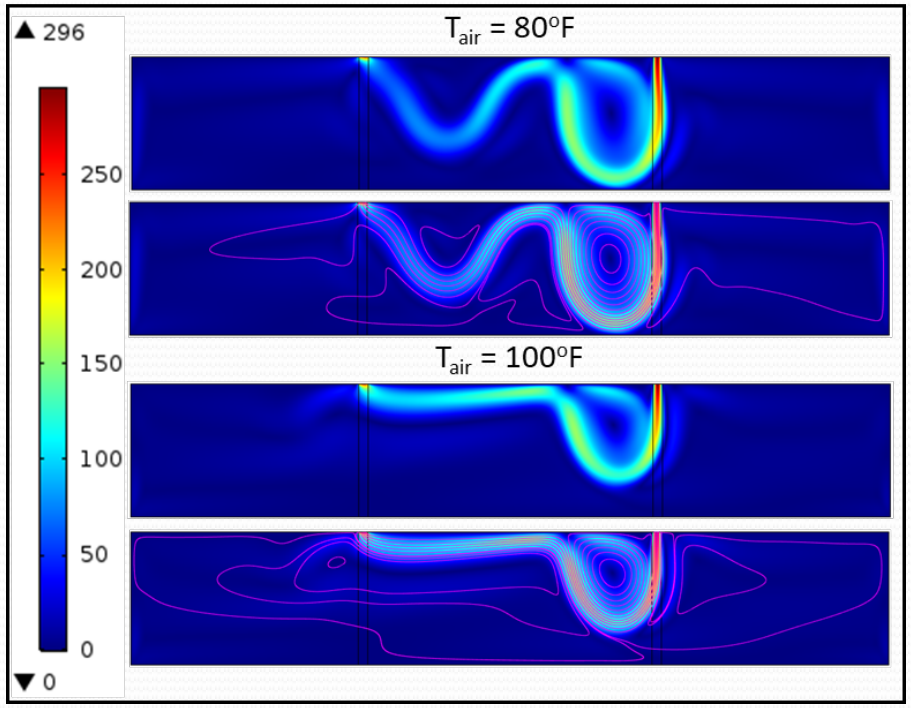
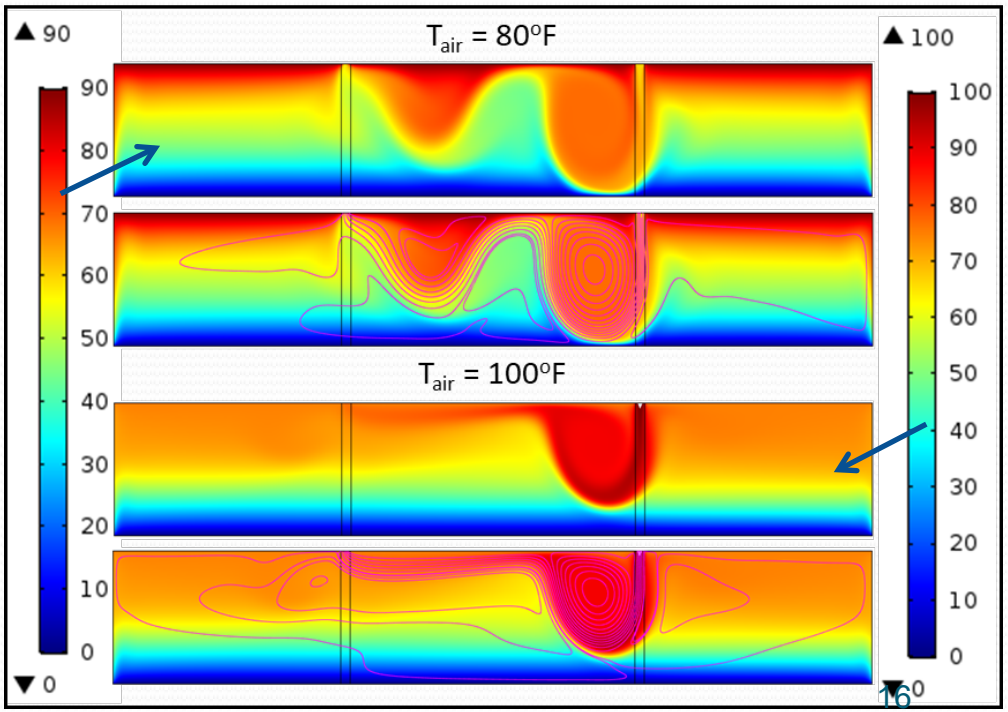
Resultant velocity distribution in mm/s



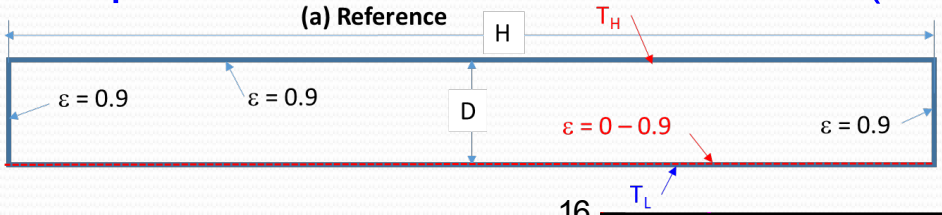
Temperature distribution in °F

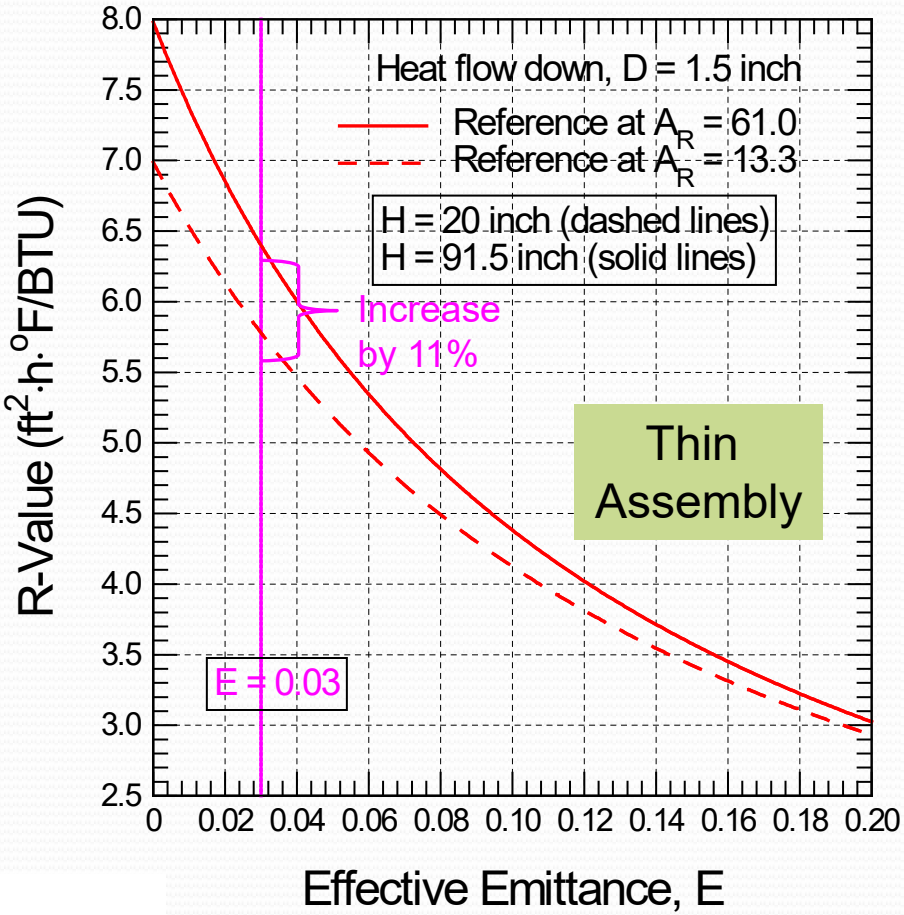


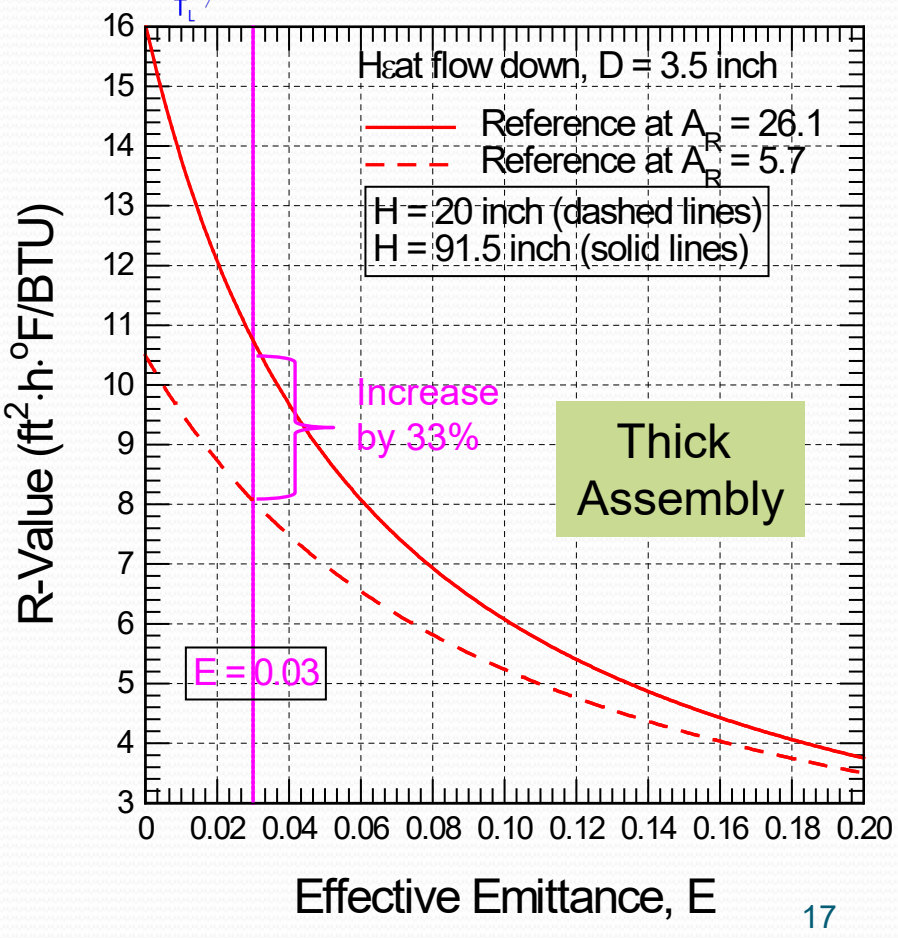
Air Intrusion in RIs with Heat Flow Down (cont.)

Heat Flow Down

Effect of aspect ratio at the same ACH of 0 (Reference)





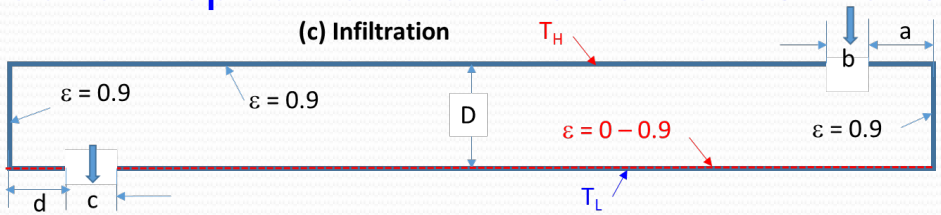


Air Intrusion in RIs with Heat Flow Down (cont.)

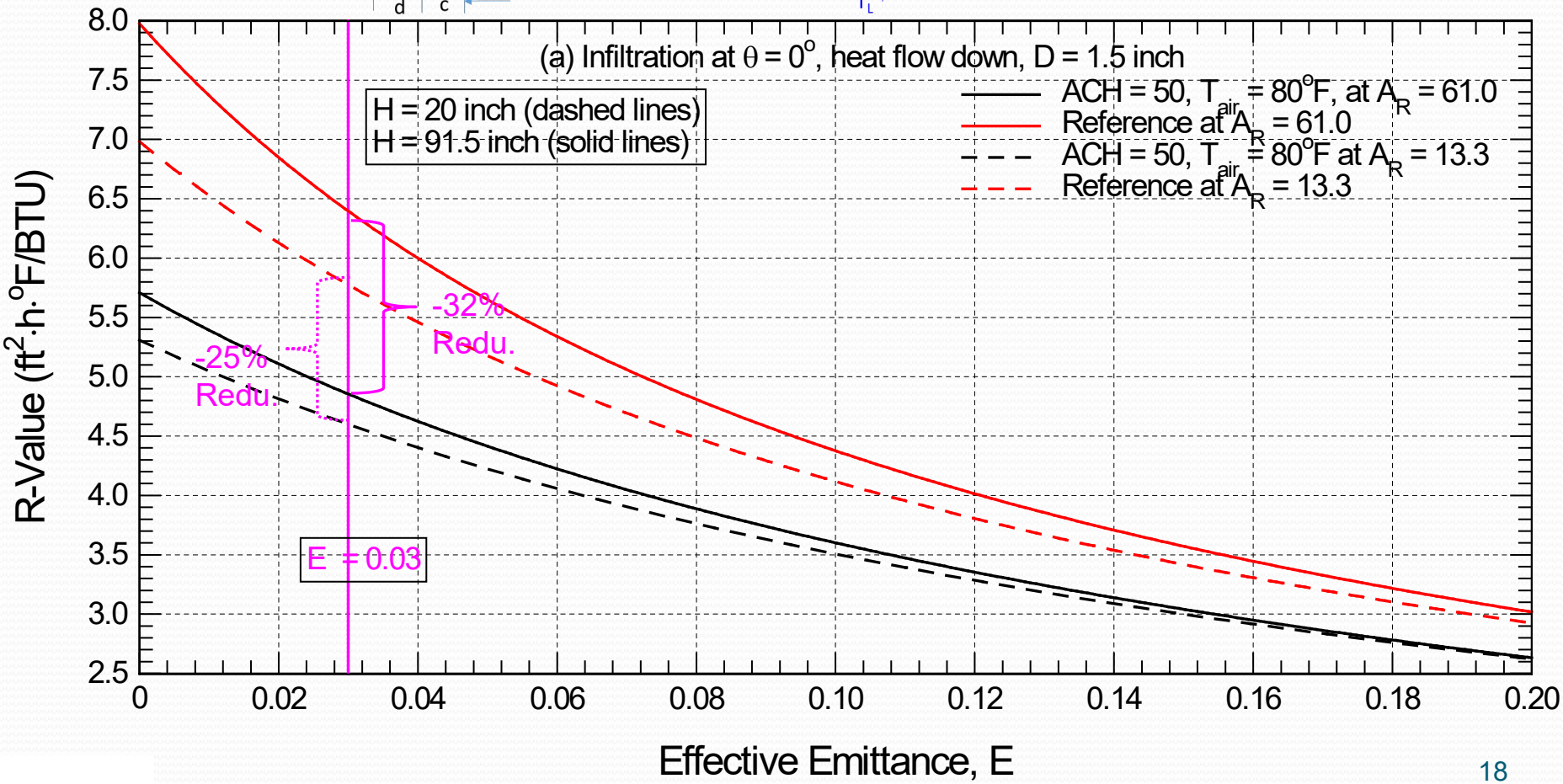
Effect of aspect ratio at the same ACH of 50

Heat Flow Down

Thin Assembly



$$\frac{\dot{V}_{Large\ A_R}}{\dot{V}_{Samall\ A_R}} = 4.58$$

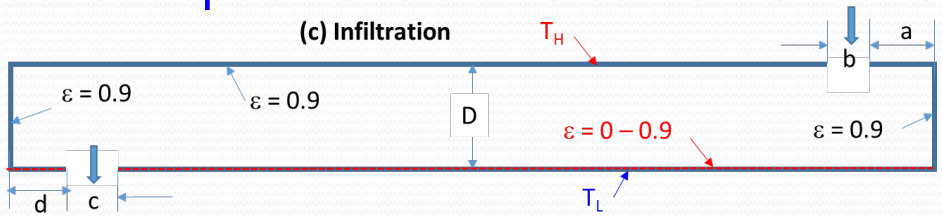


Air Intrusion in RIs with Heat Flow Down (cont.)

Heat Flow Down

Effect of aspect ratio at the same ACH of 50

Thick Assembly



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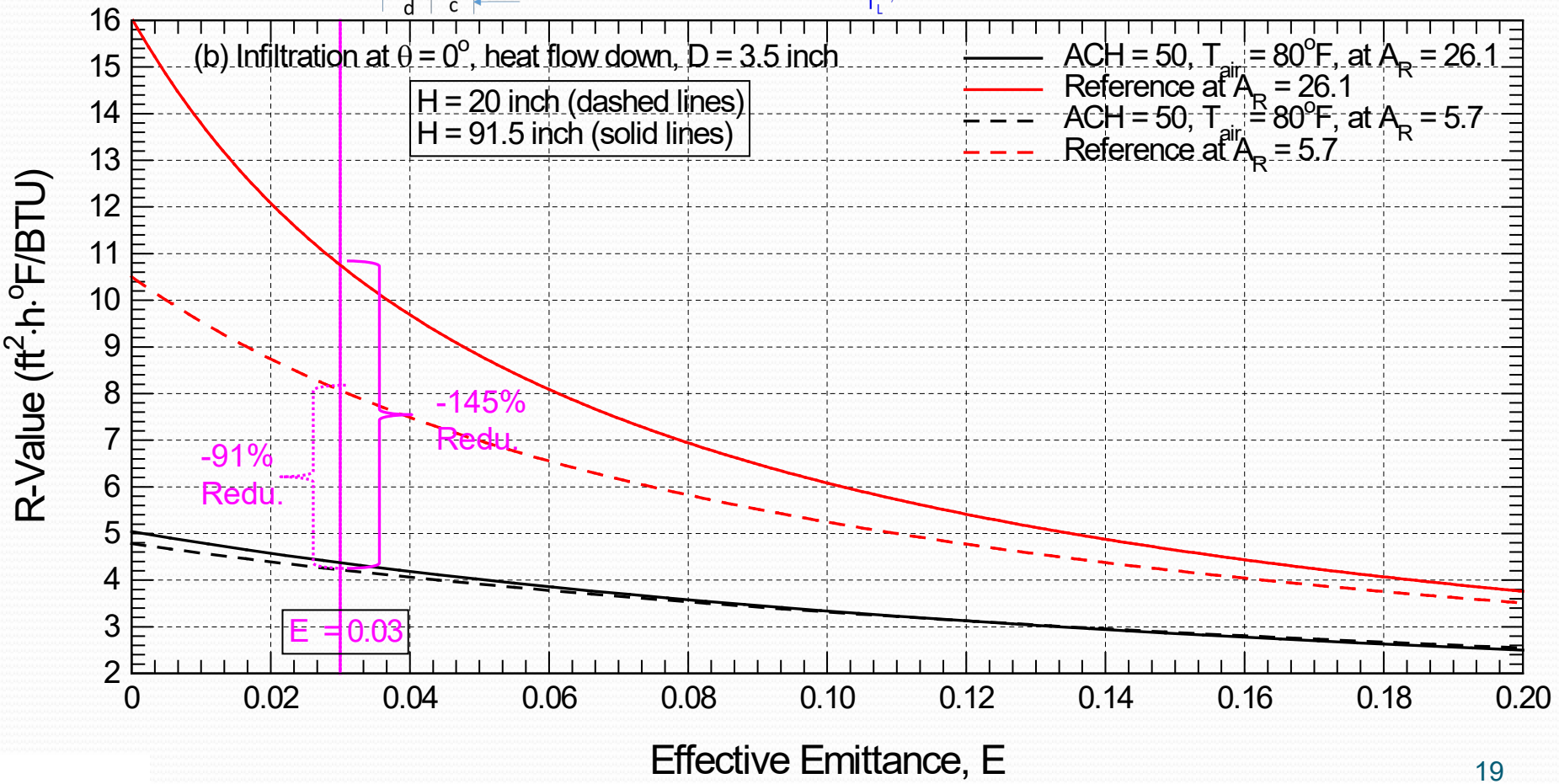
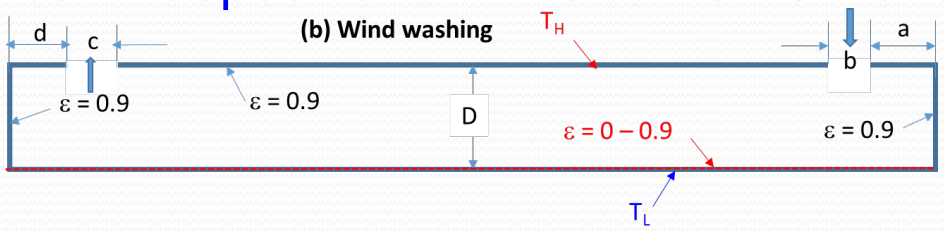


Air Intrusion in RIs with Heat Flow Down (cont.)

Heat Flow Down

Thin Assembly

Effect of aspect ratio at the same ACH of 50



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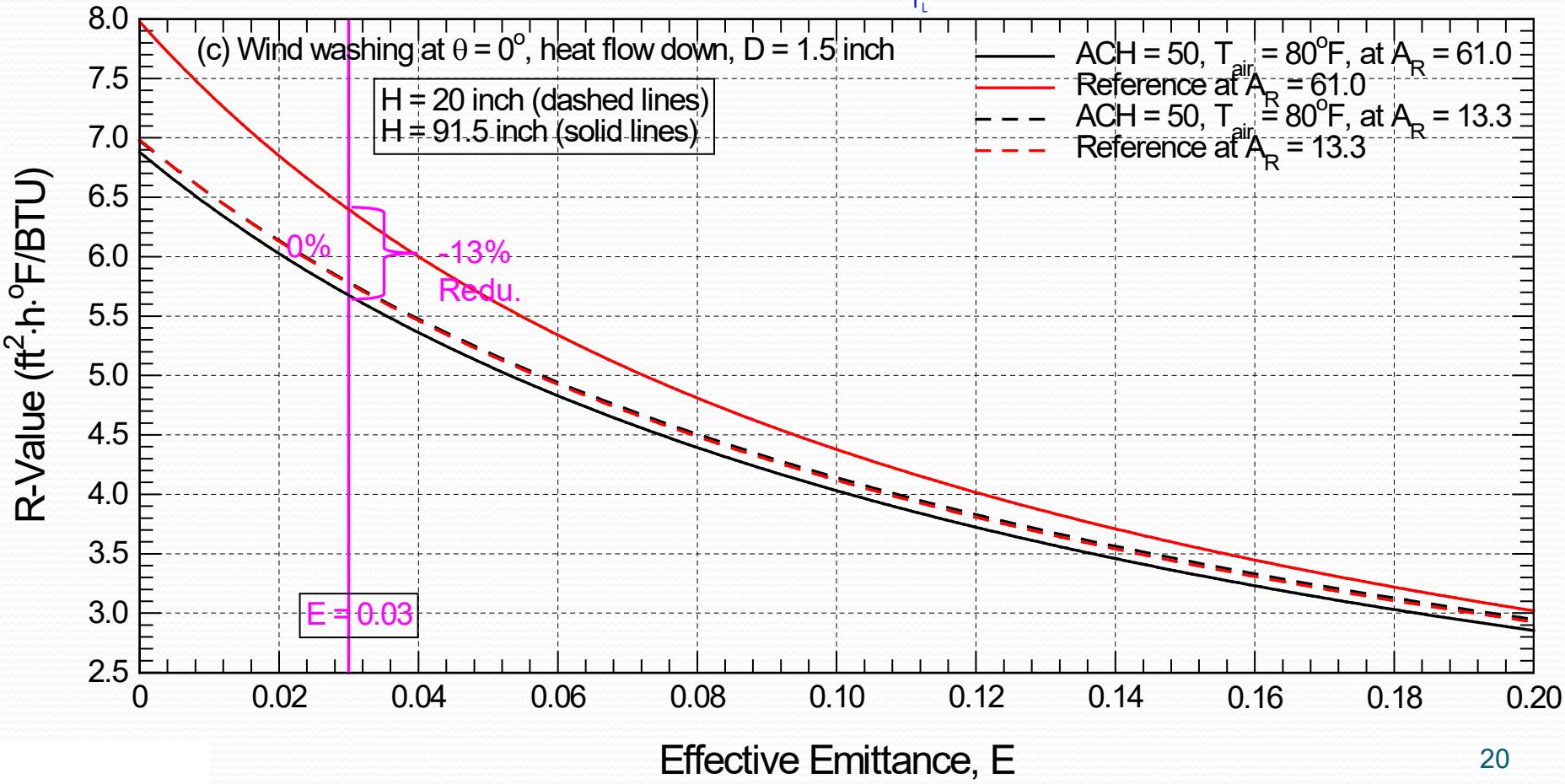
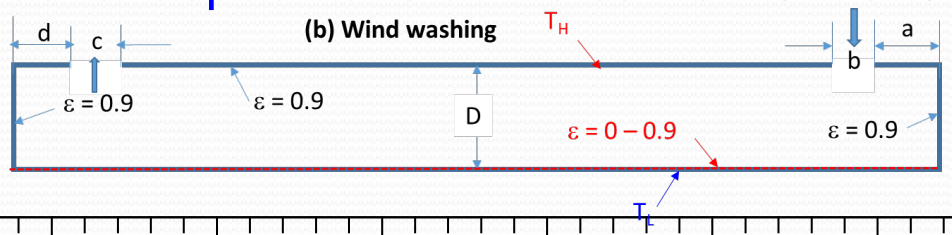


Air Intrusion in RIs with Heat Flow Down (cont.)

Heat Flow Down

Effect of aspect ratio at the same ACH of 50

Thick Assembly



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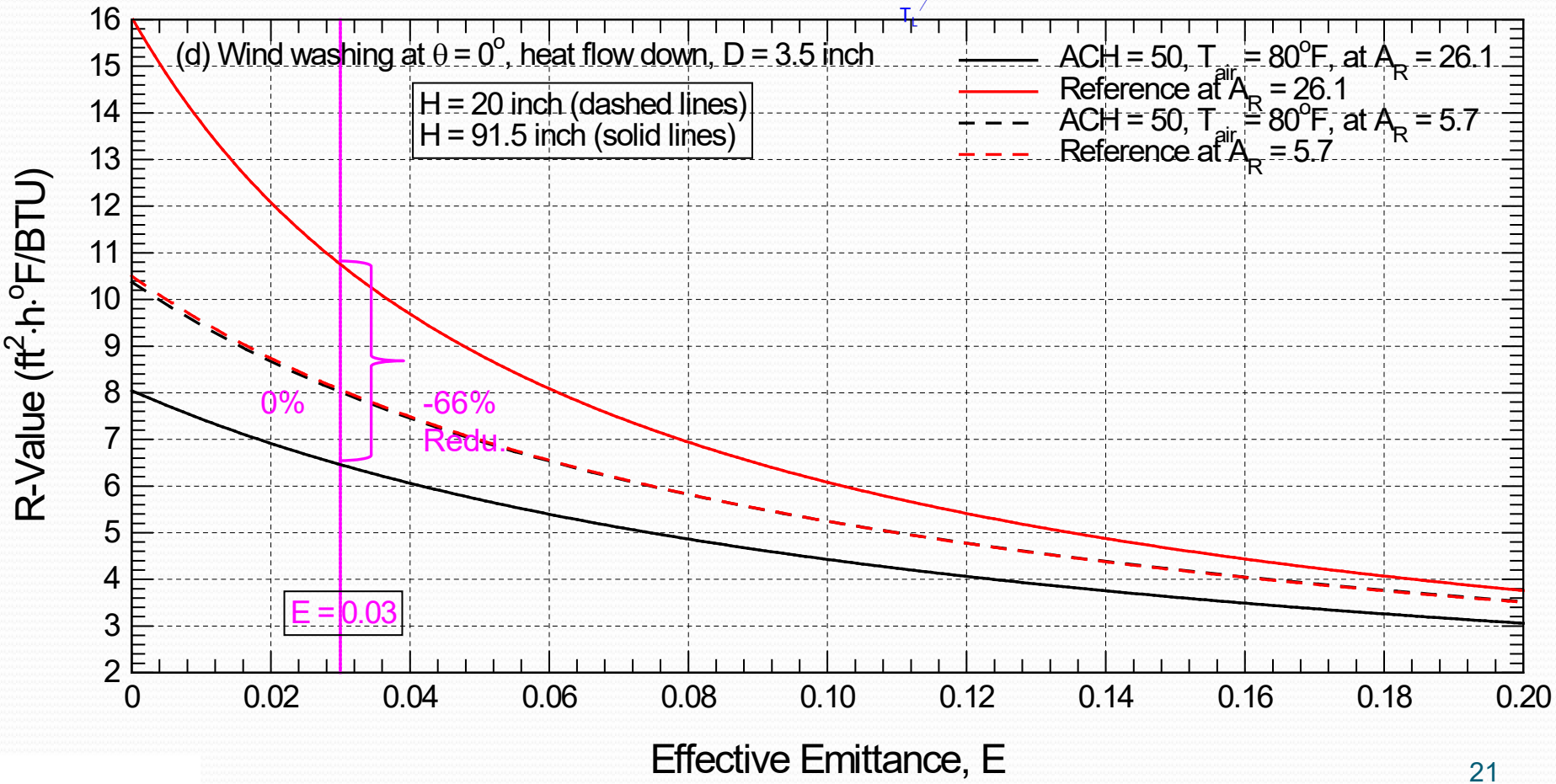
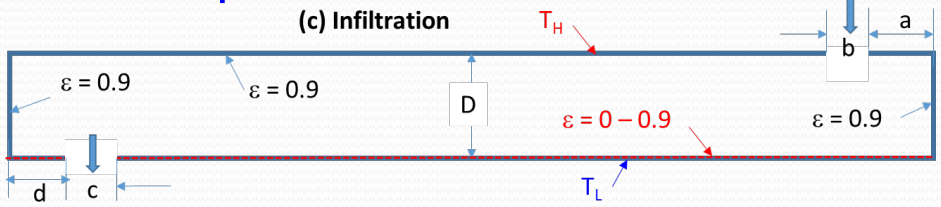


Air Intrusion in RIs with Heat Flow Down (cont.)

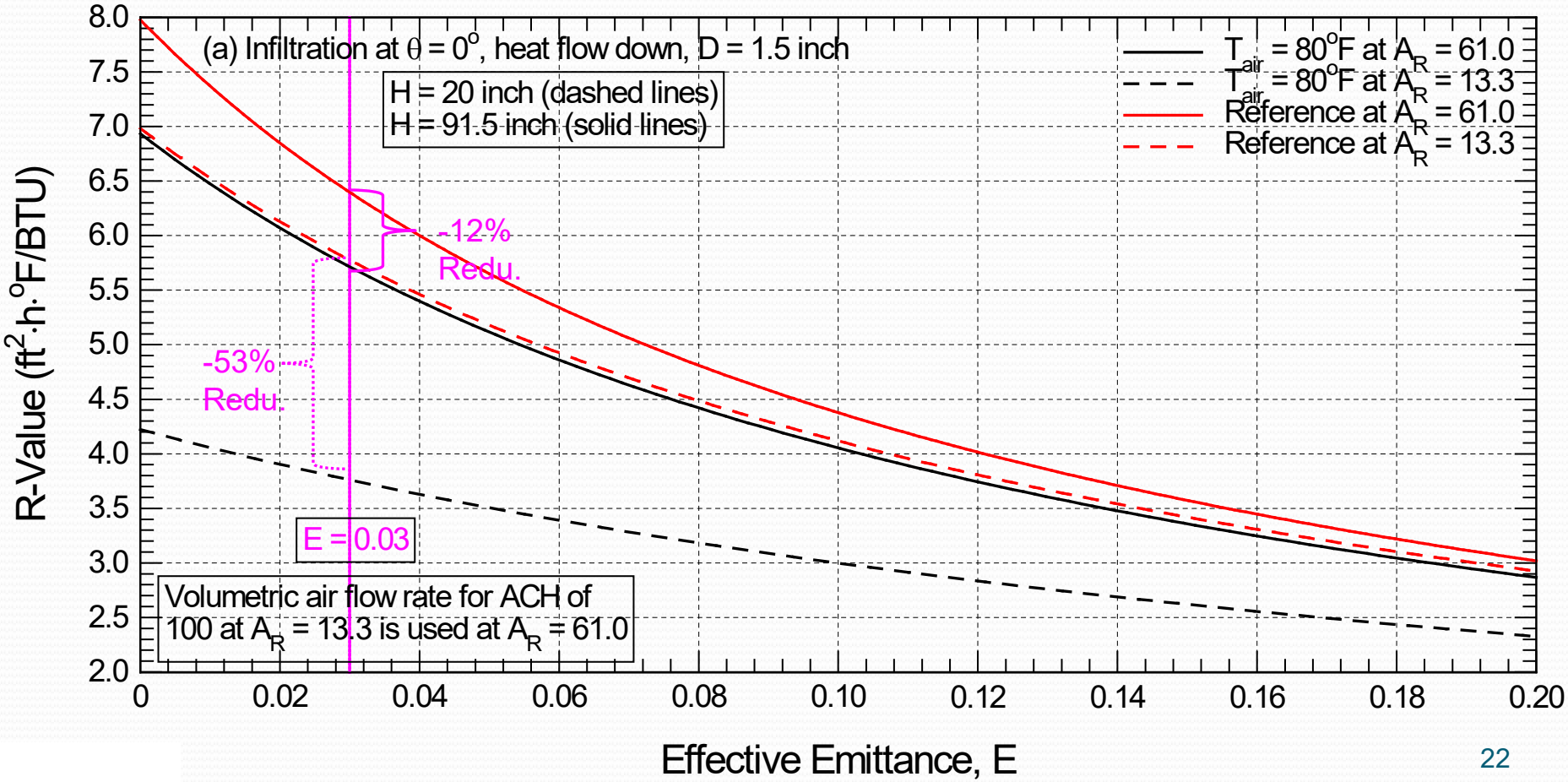
Effect of aspect ratio at the same air leakage rate

Heat Flow Down

Thin Assembly



$$\frac{\dot{V}_{Large\ A_R}}{\dot{V}_{Samall\ A_R}} = 1.0$$

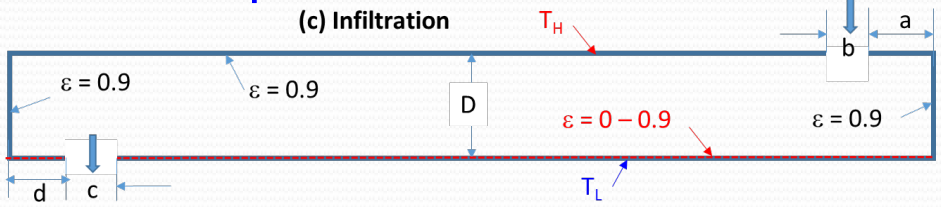


Air Intrusion in RIs with Heat Flow Down (cont.)

Effect of aspect ratio at the same air leakage rate

Heat Flow Down

Thick Assembly



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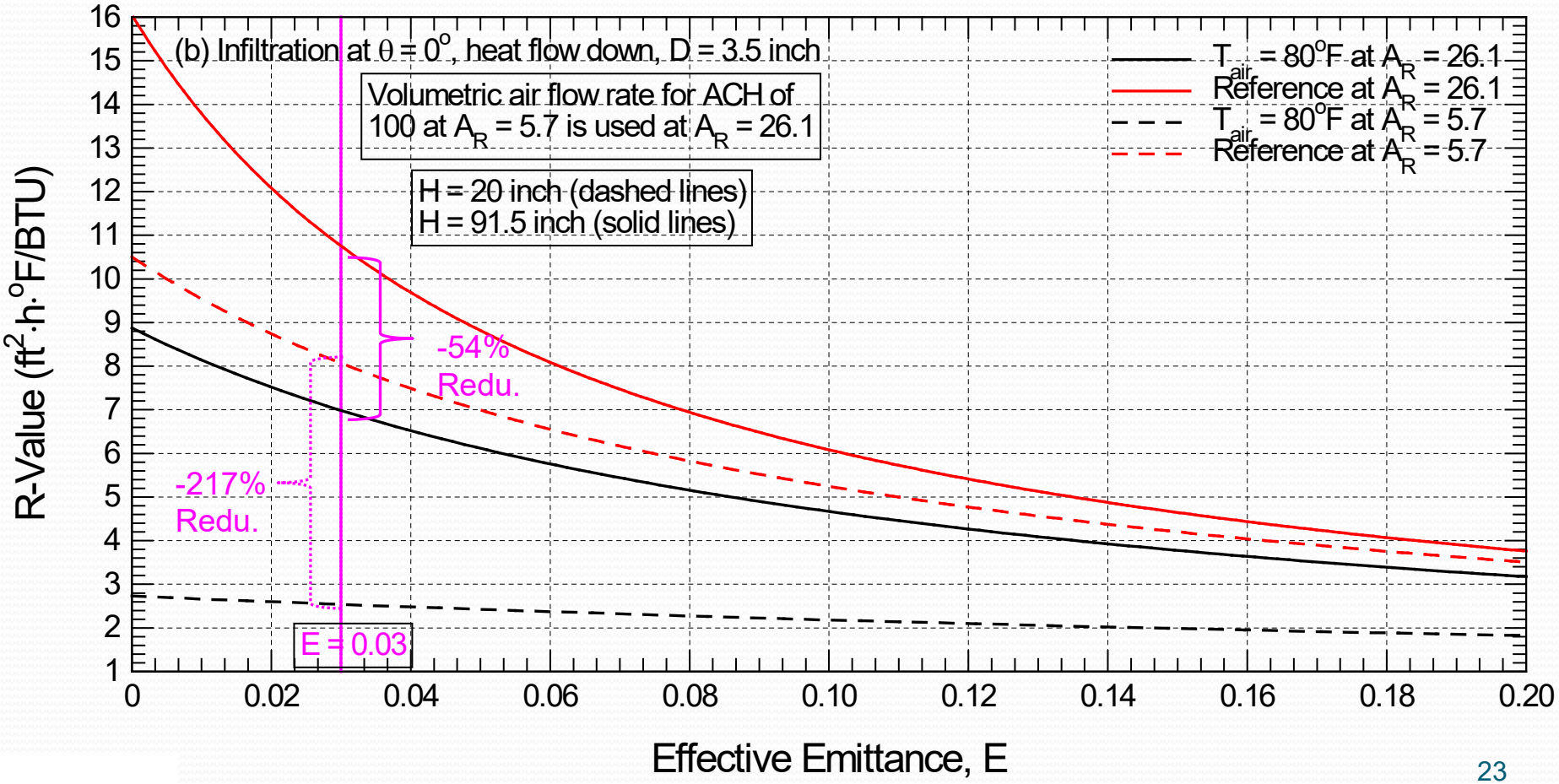
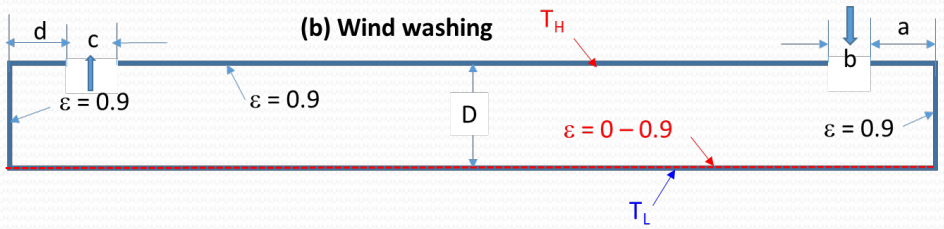


Air Intrusion in RIs with Heat Flow Down (cont.)

Effect of aspect ratio at the same air leakage rate

Heat Flow Down

Thin Assembly



$$\frac{\dot{V}_{Large\ A_R}}{\dot{V}_{Samall\ A_R}} = 1.0$$

(c) Wind washing at θ = 0°, heat flow down, D = 1.5 inch

H = 20 inch (dashed lines)
H = 91.5 inch (solid lines)

T_{air} = 80°F at A_R = 61.0
Reference at A_R = 61.0
T_{air} = 80°F at A_R = 13.3
Reference at A_R = 13.3

-3% Redu.

-6% Redu.

E = 0.03

Volumetric air flow rate for ACH of 100 at A_R = 13.3 is used at A_R = 61.0

R-Value ($ft^2 \cdot h \cdot {}^oF/BTU$)

8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5

0 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18 0.20

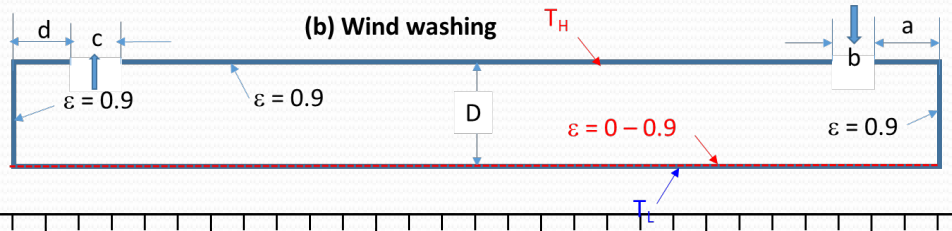
Effective Emittance, E

Air Intrusion in RIs with Heat Flow Down (cont.)

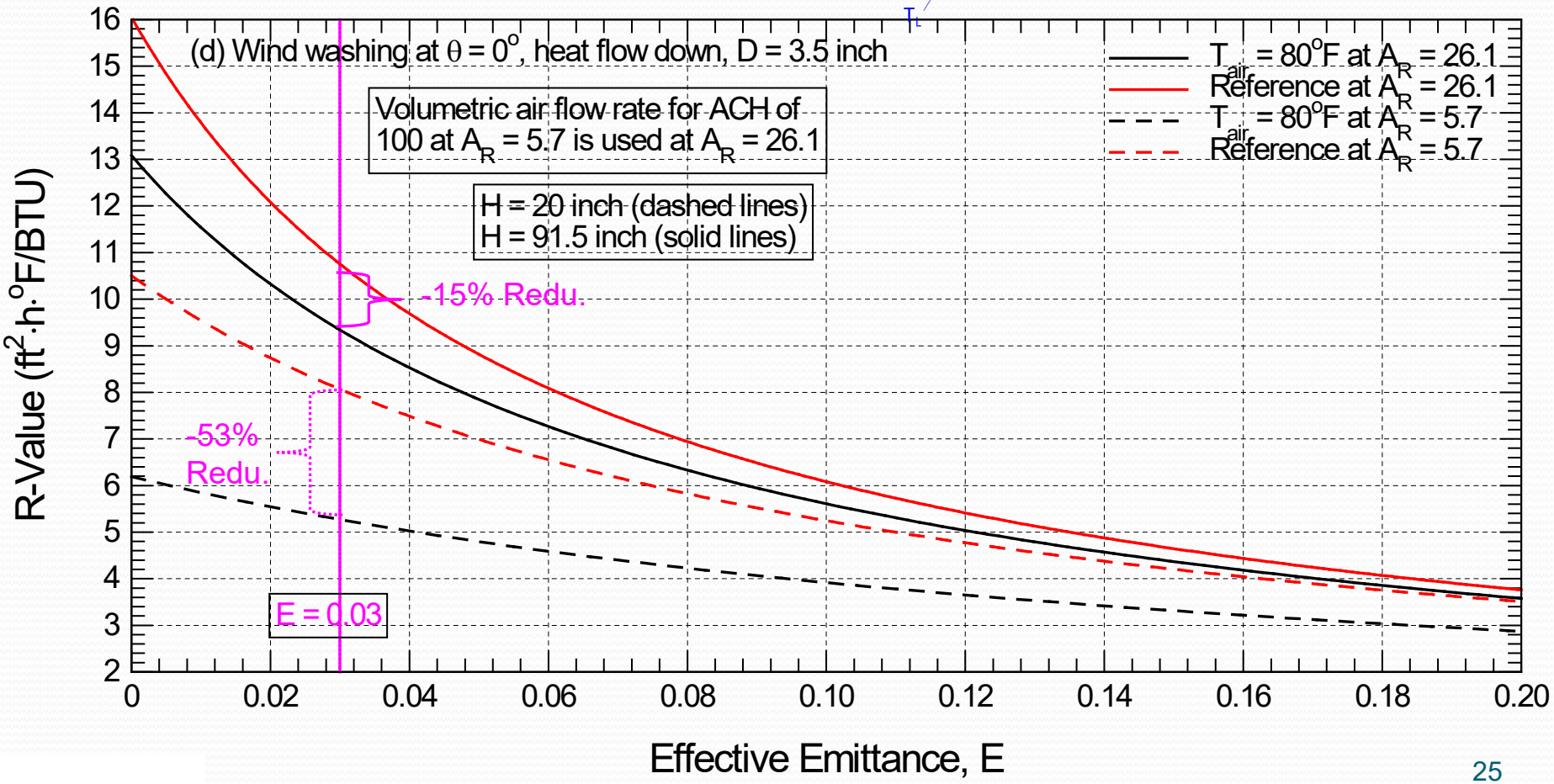
Effect of aspect ratio at the same air leakage rate

Heat Flow Down

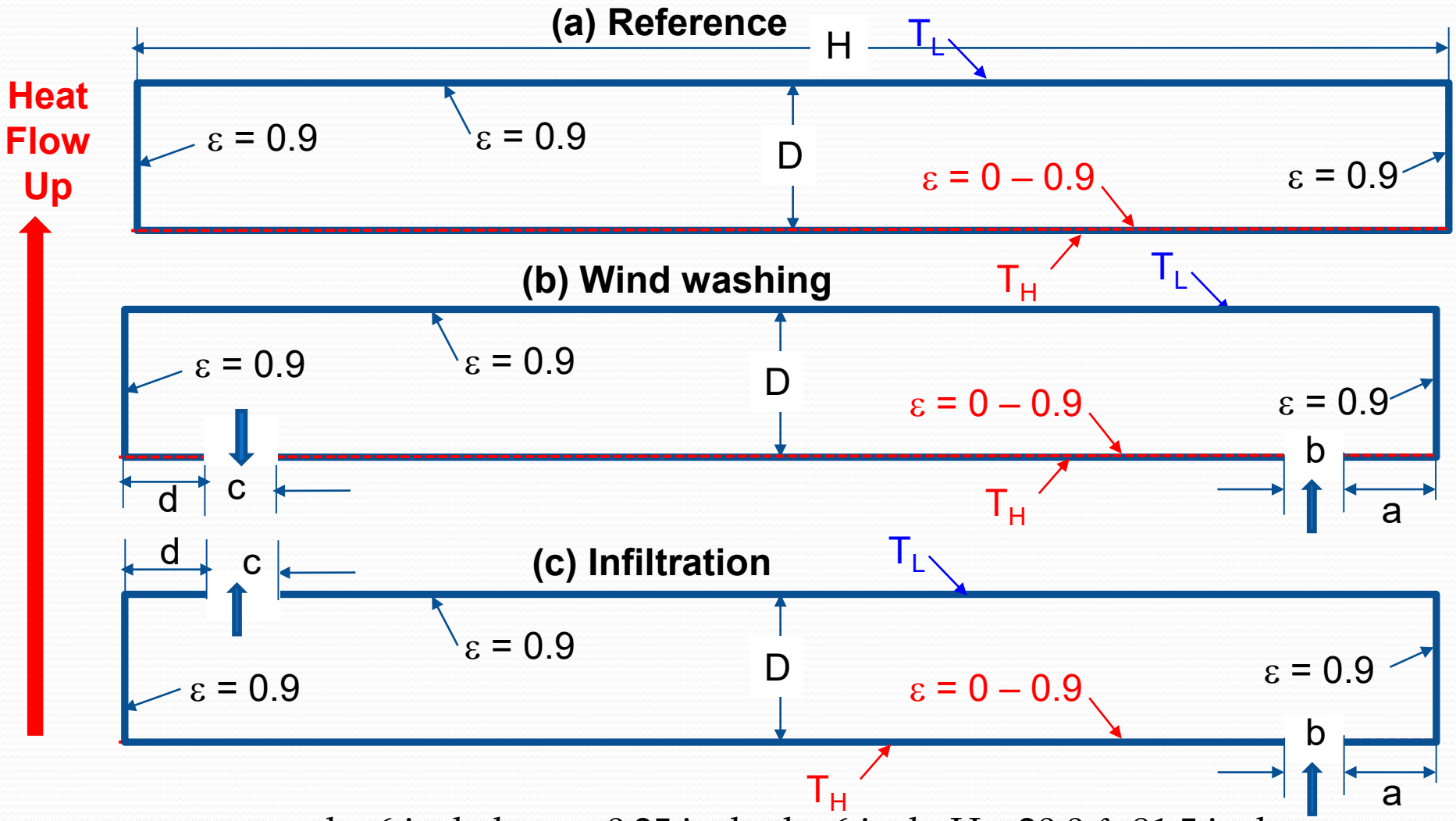
Thick Assembly



$$\frac{\dot{V}_{Large\ A_R}}{\dot{V}_{Samall\ A_R}} = 1.0$$



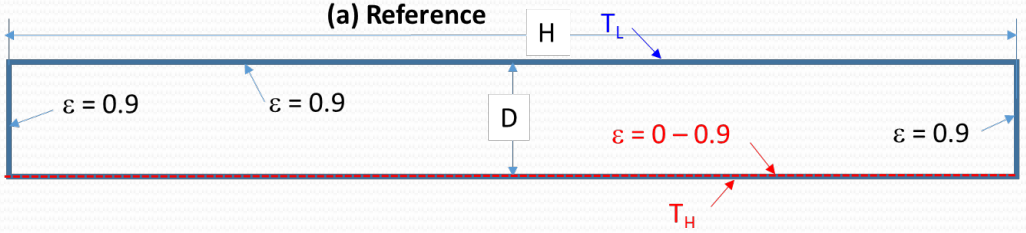
Air Intrusion in RIs with Heat Flow Up



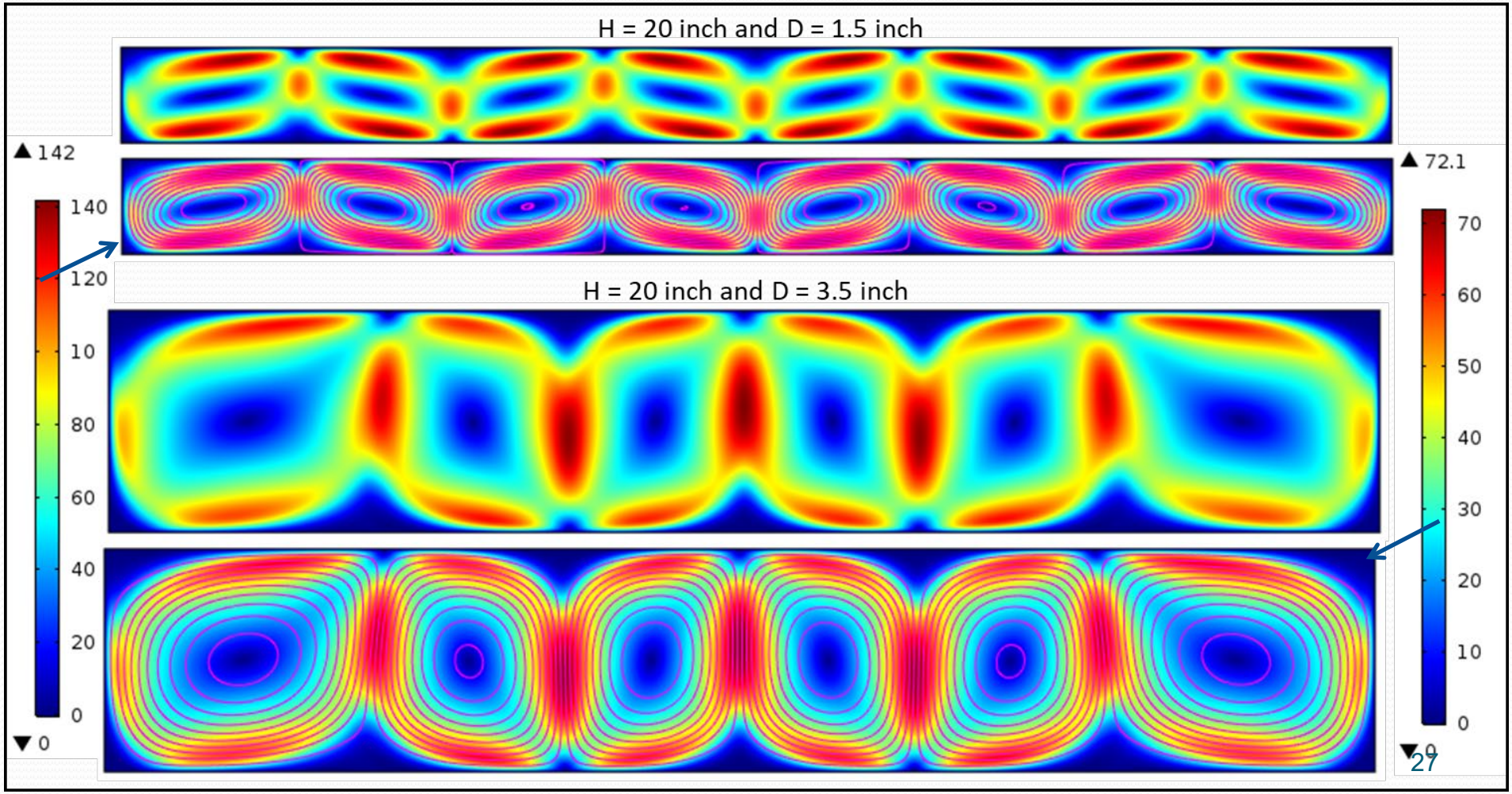
a = b= 6 inch, b = c = 0.25 inch, d = 6 inch, H = 20.0 & 91.5 inch,
D = 1.5 & 3.5 inch, T_H = 90°F, T_L = 60°F, T_{air} = 80°F, 90°F, 100°F

Air Intrusion in RIs with Heat Flow Up (cont.)

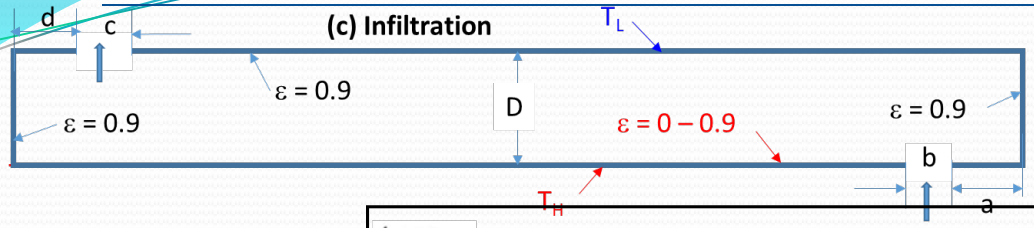
Heat Flow Up



Resultant velocity distribution in mm/s

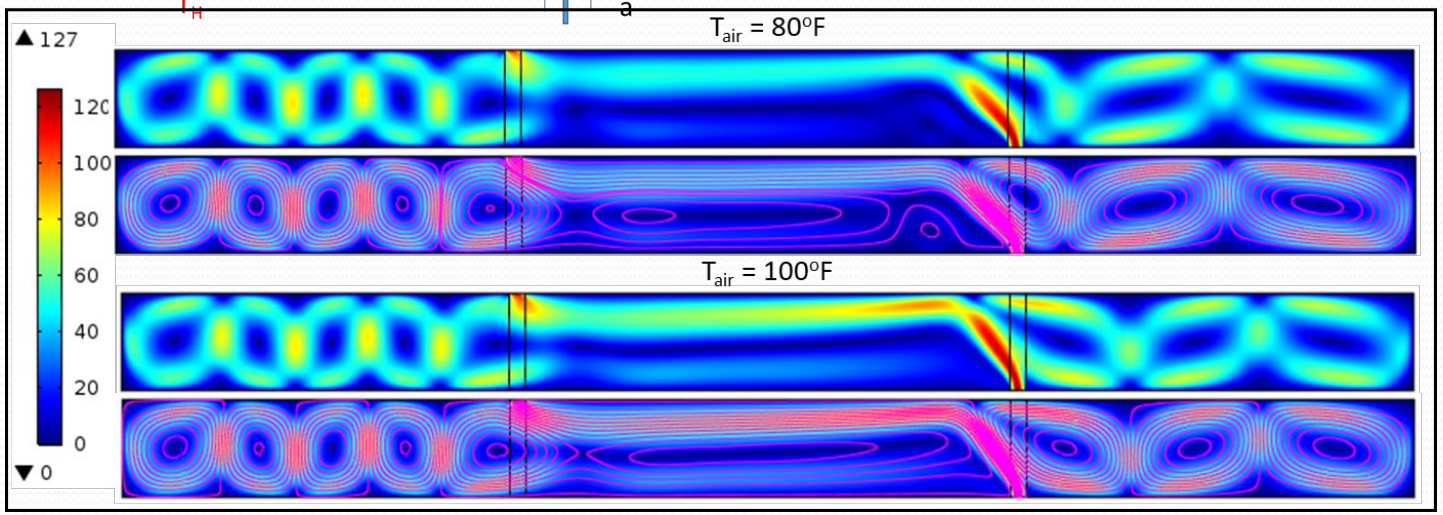


Air Intrusion in RIs with Heat Flow Up (cont.)

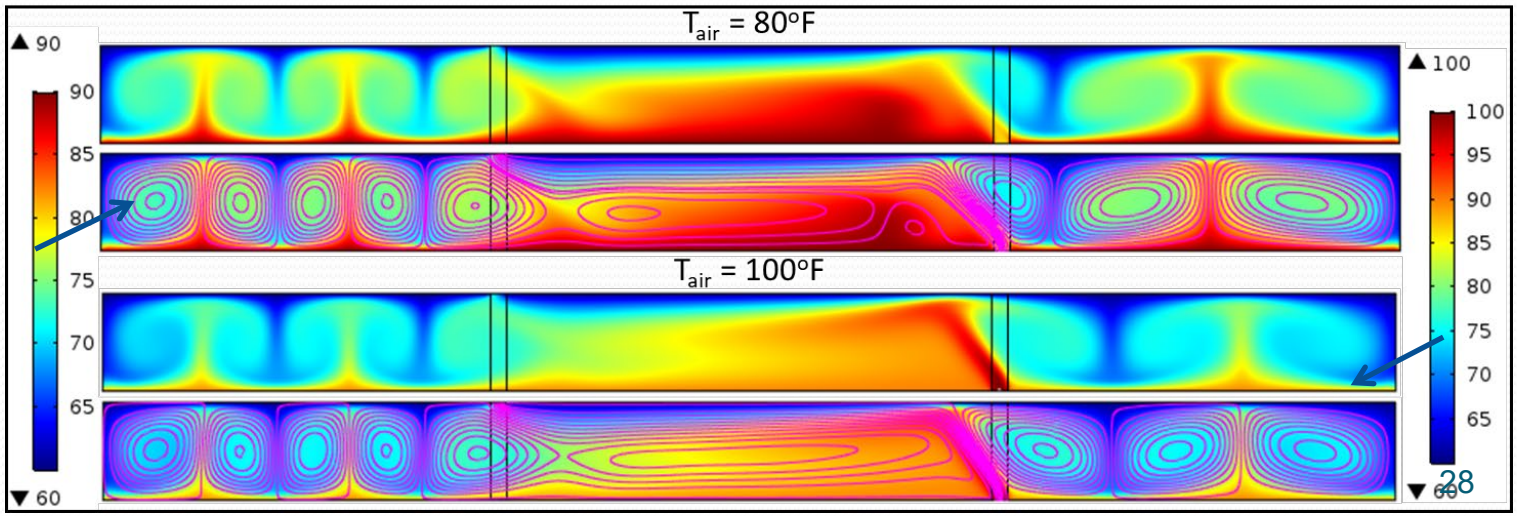


Infiltration, ACH = 100, E = 0.05, H = 20 in, D = 1.5 in

Resultant velocity distribution in mm/s

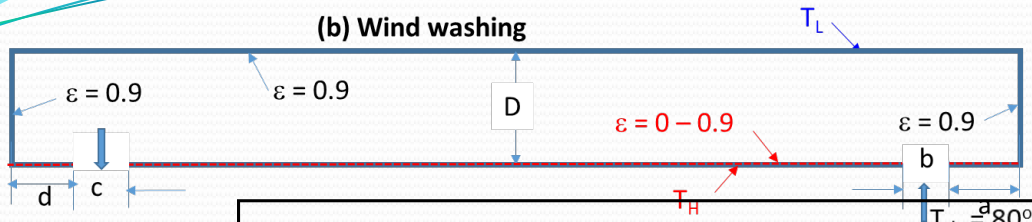


Temperature distribution in °F



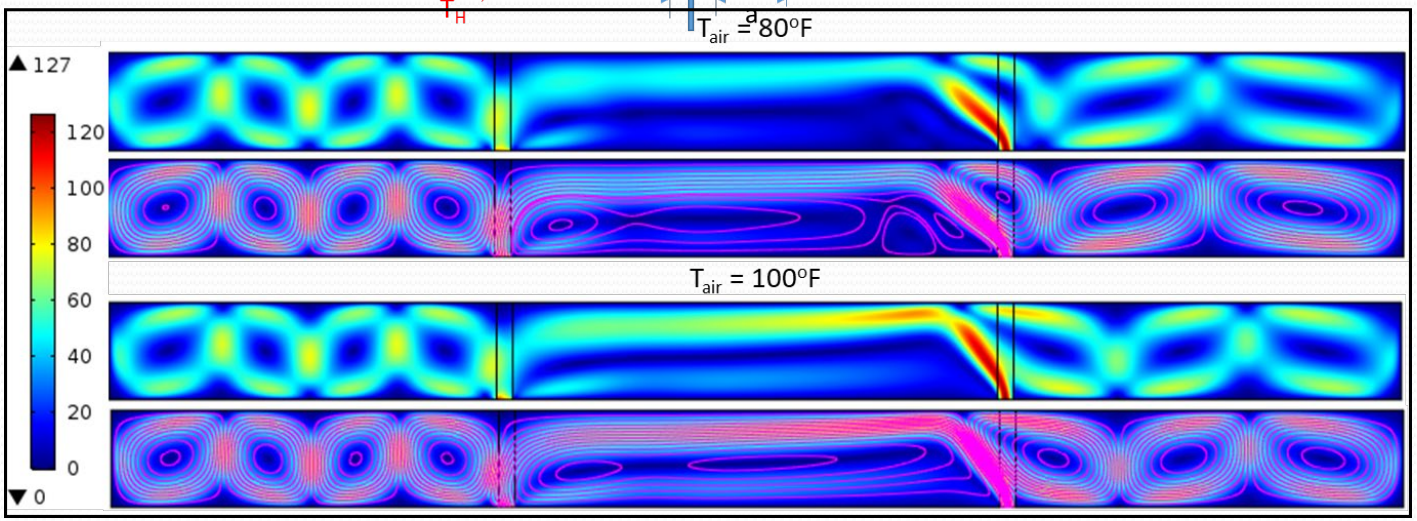
Heat Flow Up

Air Intrusion in RIs with Heat Flow Up (cont.)



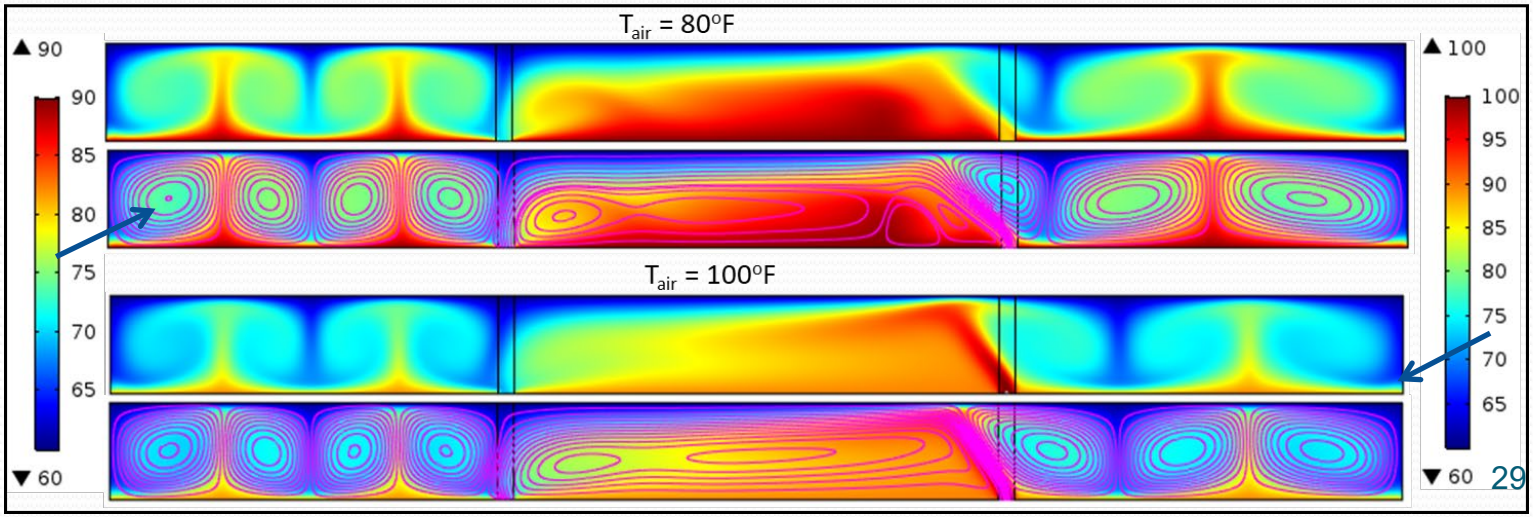
Wind washing, ACH = 100, E = 0.05, H = 20 in, D = 1.5 in

Resultant velocity distribution in mm/s



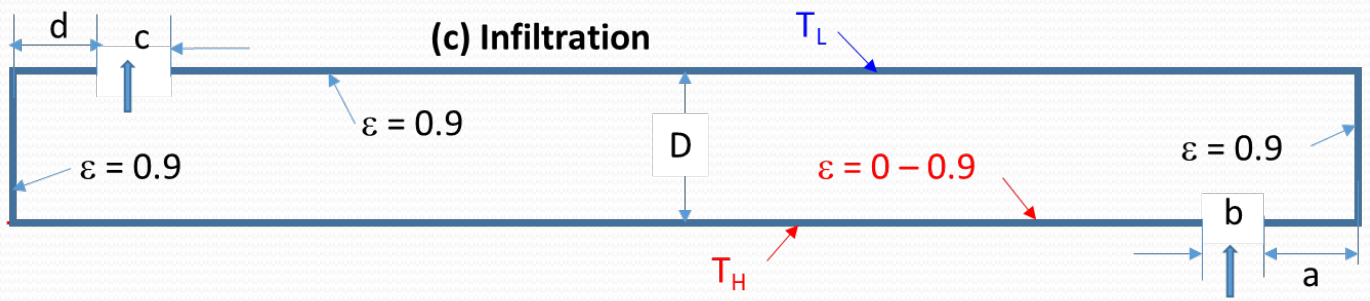
Heat Flow Up

Temperature distribution in °F



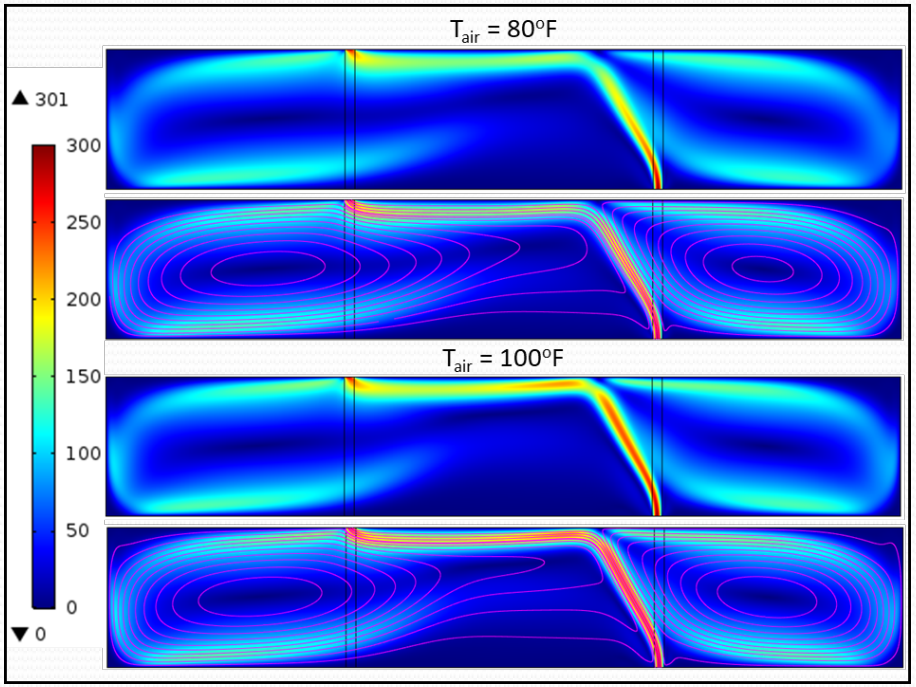
Air Intrusion in RIs with Heat Flow Up (cont.)

Heat Flow Up

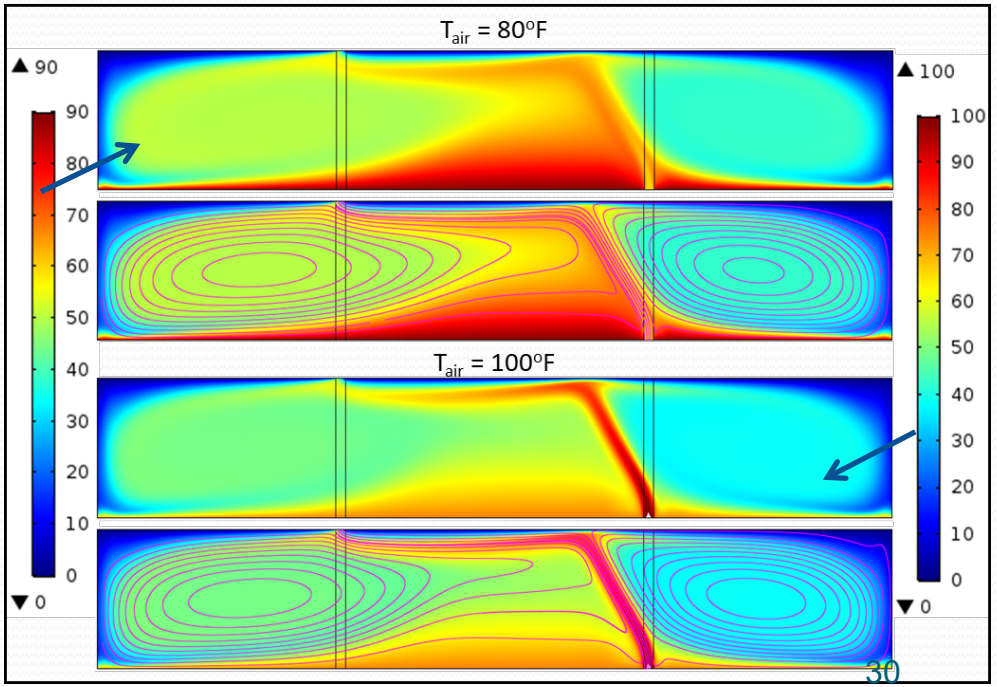


Infiltration, ACH = 100, E = 0.05, H = 20 in, D = 3.5 in

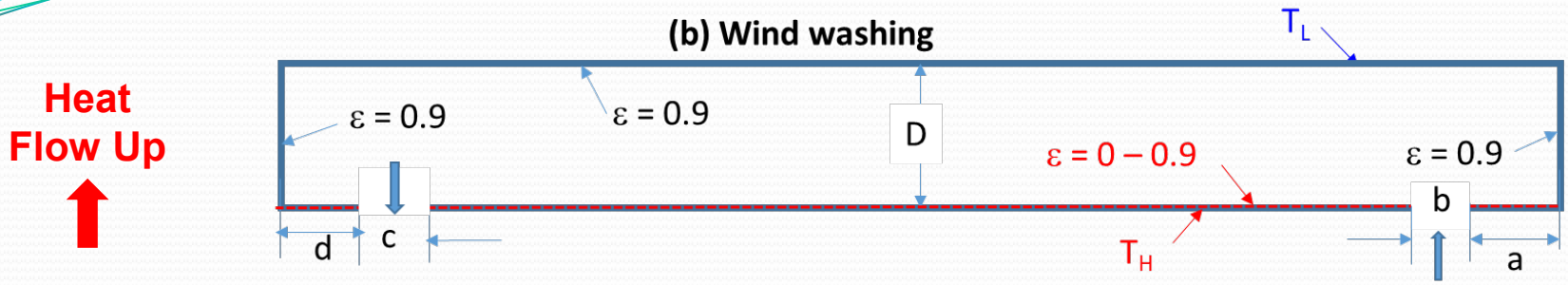
Resultant velocity distribution in mm/s



Temperature distribution in °F

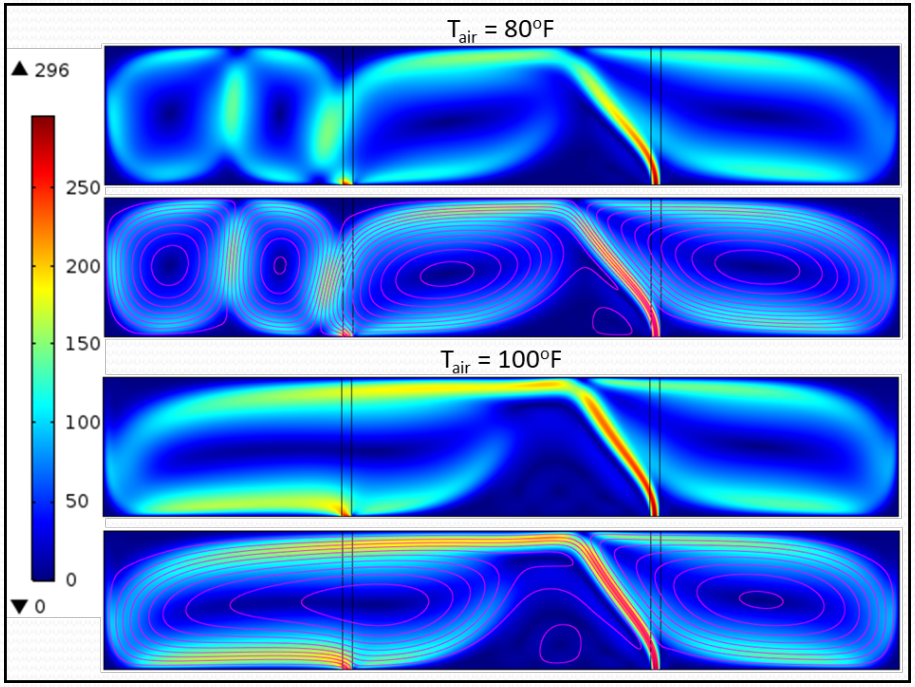


Air Intrusion in RIs with Heat Flow Up (cont.)

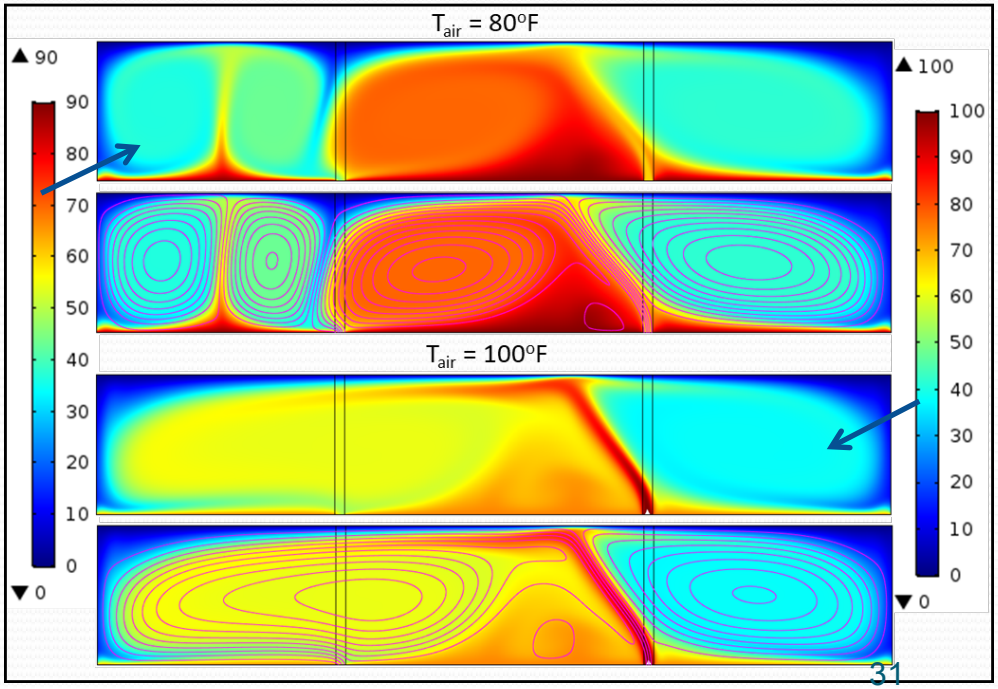


Wind washing, ACH = 100, E = 0.05, H = 20 in, D = 3.5 in

Resultant velocity distribution in mm/s



Temperature distribution in °F

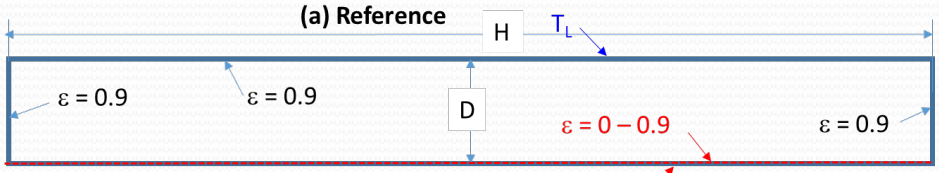


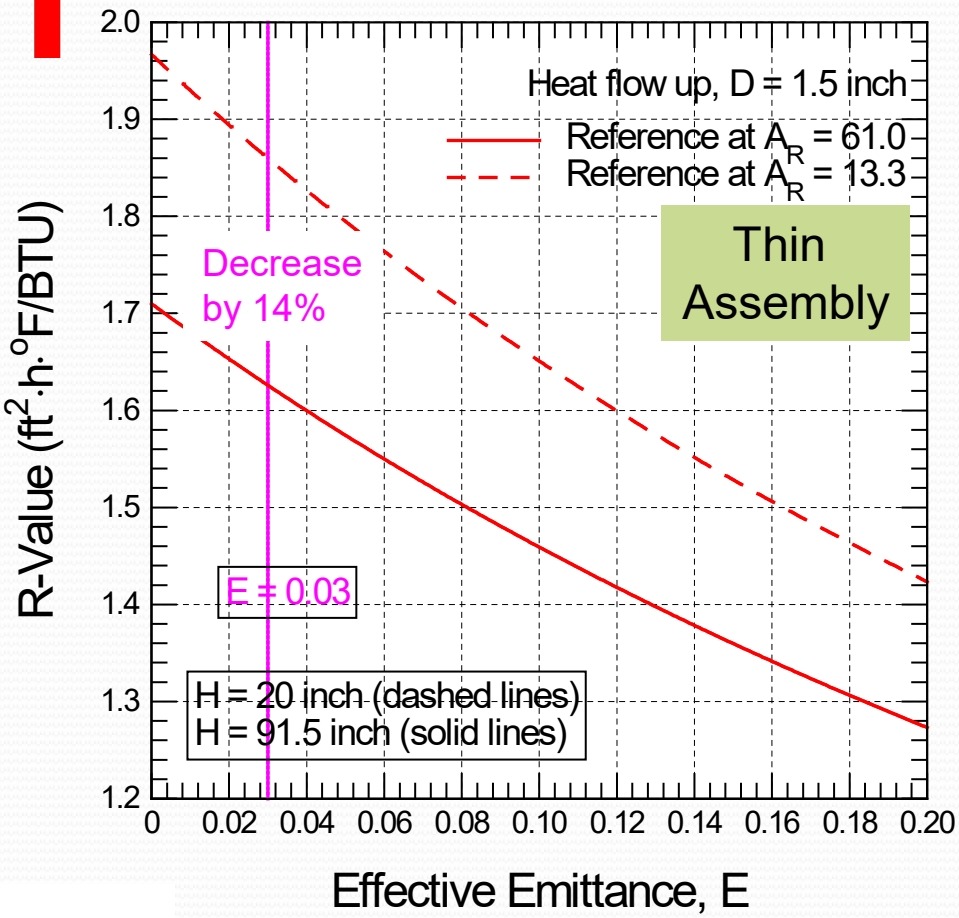
Saber, H.H., and Yarbrough, D.W., "Numerical modelling for evaluation of the thermal resistance of reflective airspaces with and without defects", *Journal of Building Physics, pp. 1-29, 2023.*

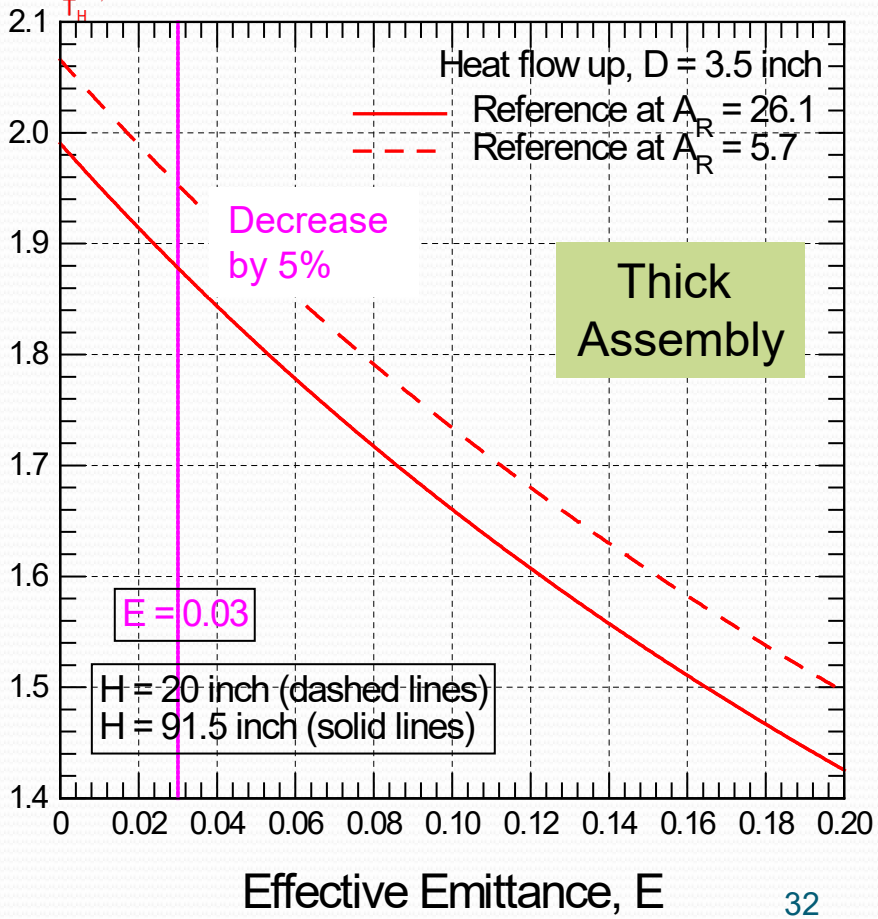
Air Intrusion in RIs with Heat Flow Up (cont.)

Effect of aspect ratio at the same ACH of 0 (Reference)

Heat Flow UP





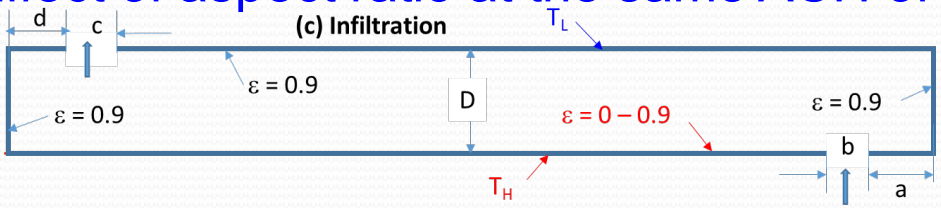


Air Intrusion in RIs with Heat Flow Up (cont.)

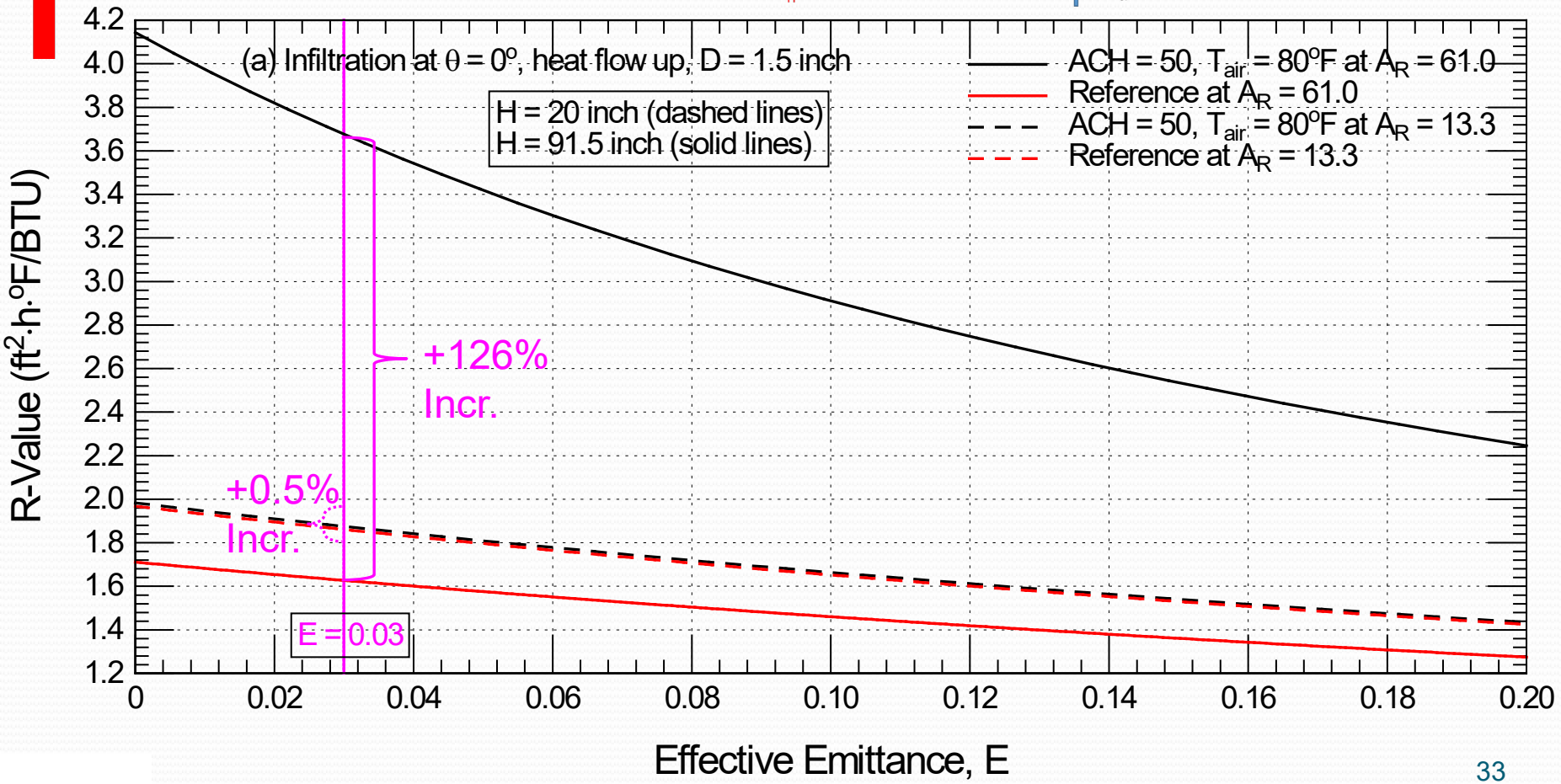
Heat Flow UP

Thin Assembly

Effect of aspect ratio at the same ACH of 50



$$\frac{\dot{V}_{Large\ A_R}}{\dot{V}_{Samall\ A_R}} = 4.58$$

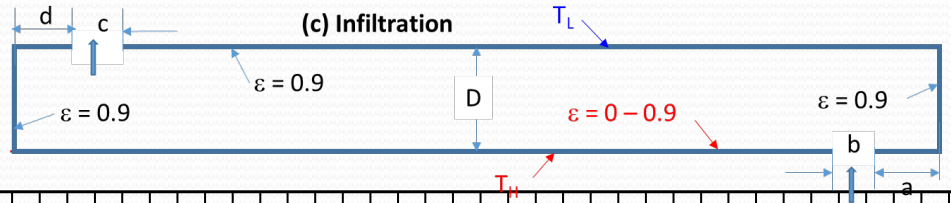


Air Intrusion in RIs with Heat Flow Up (cont.)

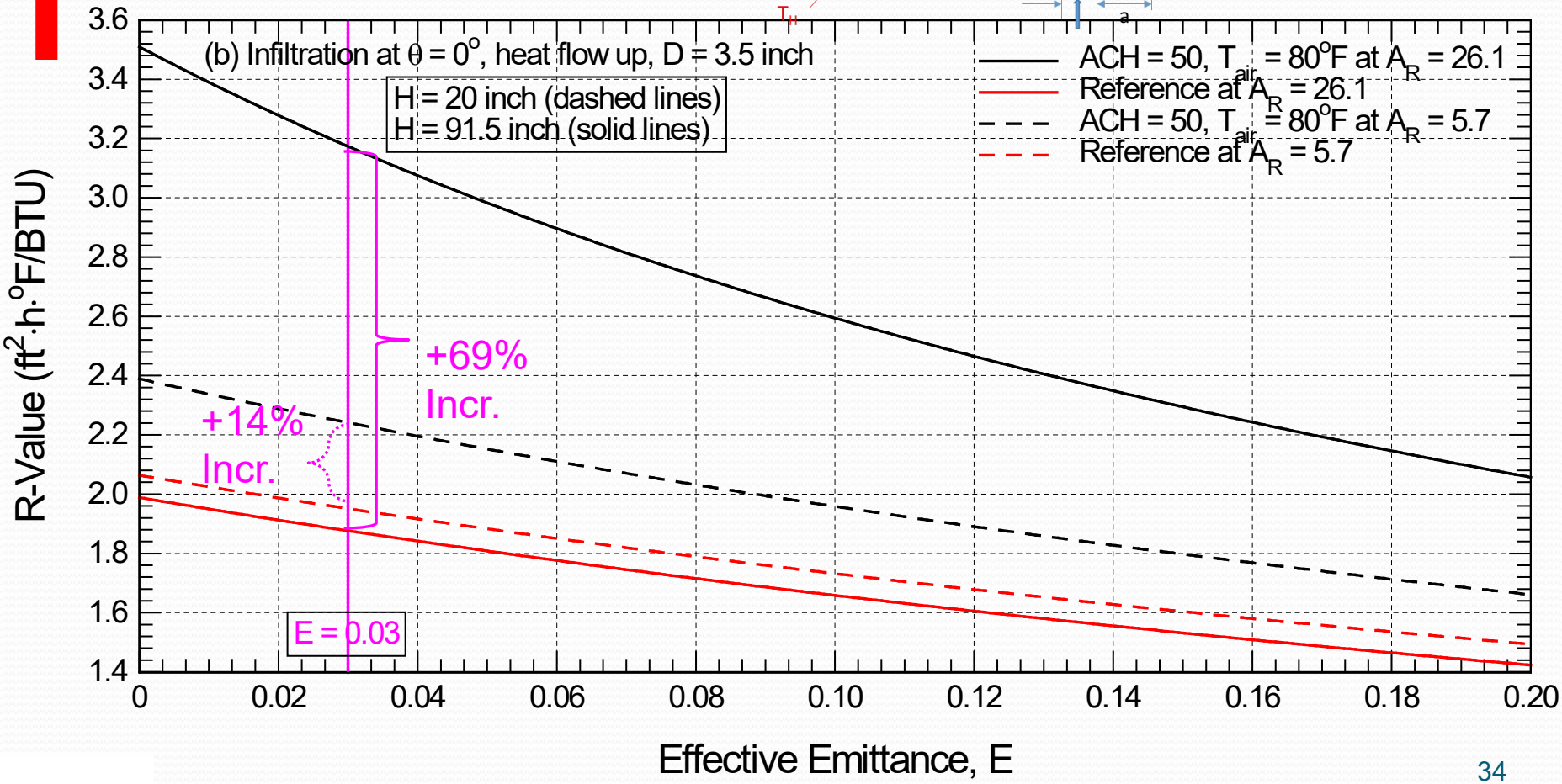
Heat Flow UP

Effect of aspect ratio at the same ACH of 50

Thick Assembly



$$\frac{\dot{V}_{Large\ A_R}}{\dot{V}_{Samall\ A_R}} = 4.58$$

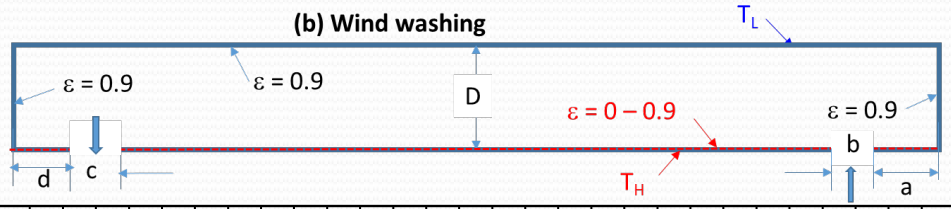


Air Intrusion in RIs with Heat Flow Up (cont.)

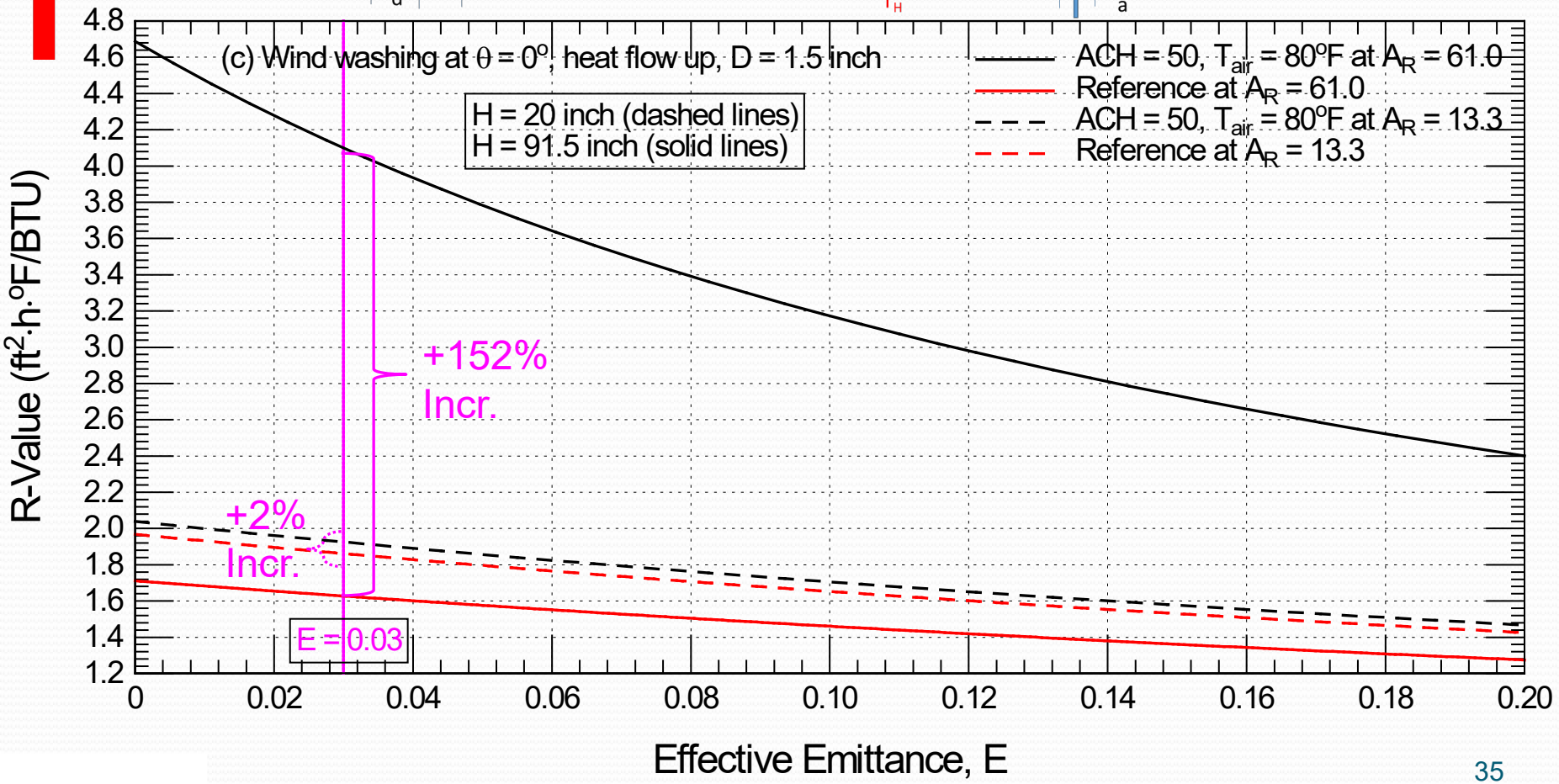
Heat Flow UP

Thin Assembly

Effect of aspect ratio at the same ACH of 50



$$\frac{\dot{V}_{Large\ A_R}}{\dot{V}_{Samall\ A_R}} = 4.58$$

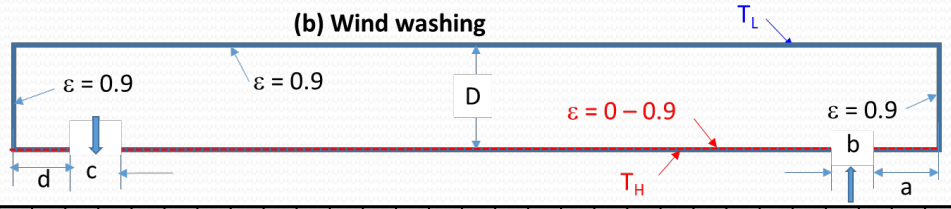


Air Intrusion in RIs with Heat Flow Up (cont.)

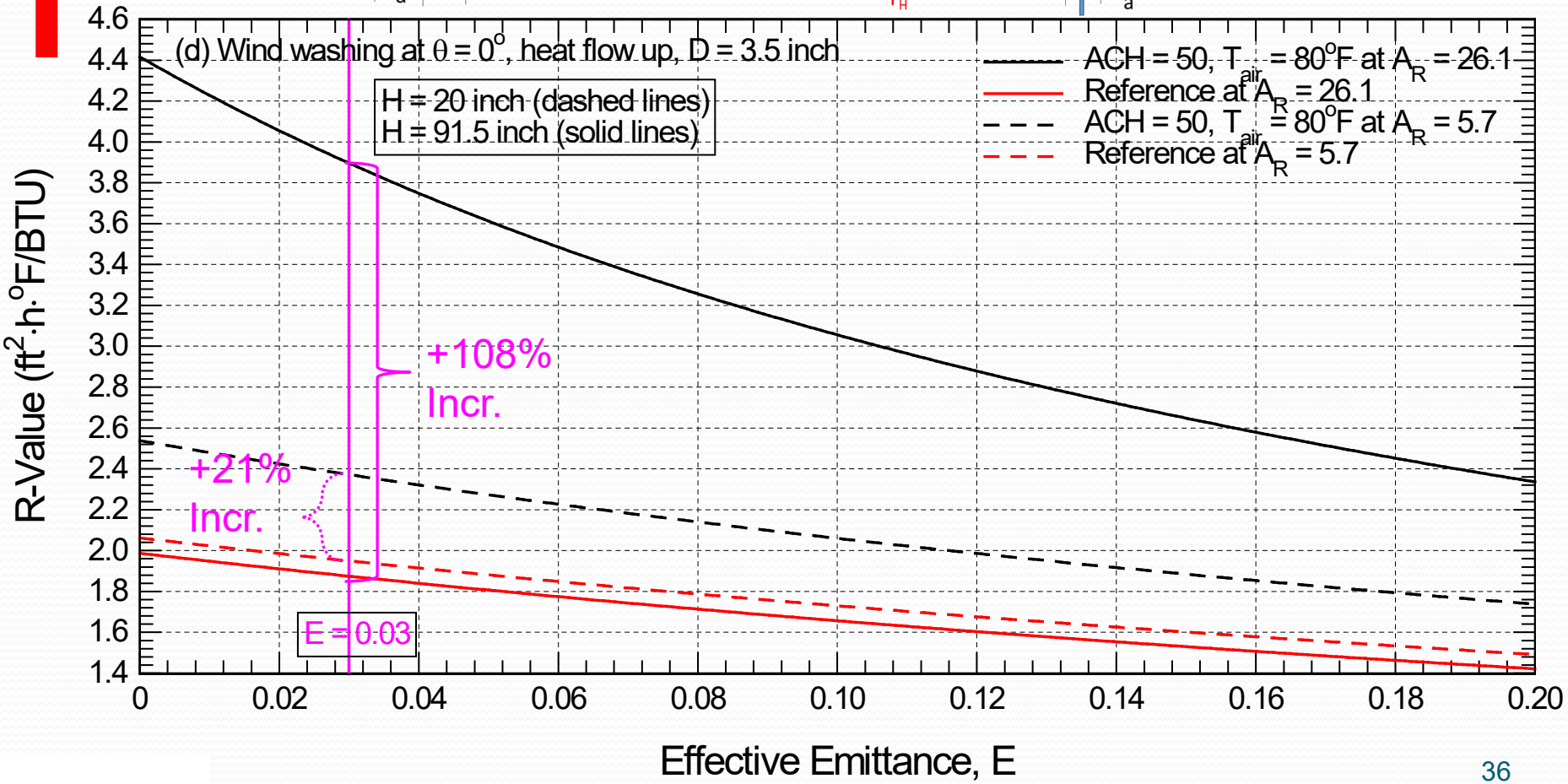
Effect of aspect ratio at the same ACH of 50

Heat Flow UP

Thick Assembly



$$\frac{\dot{V}_{Large\ A_R}}{\dot{V}_{Samall\ A_R}} = 4.58$$

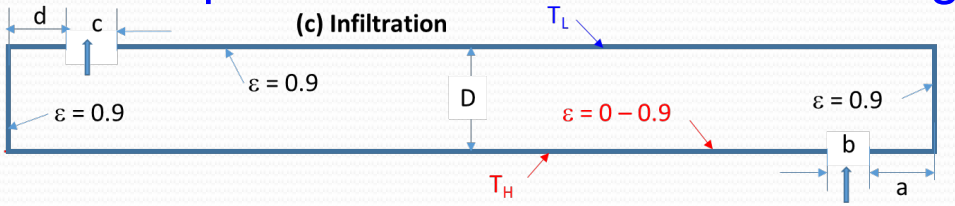


Air Intrusion in RIs with Heat Flow Up (cont.)

Effect of aspect ratio at the same air leakage rate

Heat Flow UP

Thin Assembly



$$\frac{\dot{V}_{Large\ A_R}}{\dot{V}_{Samall\ A_R}} = 1.0$$

(a) Infiltration at θ = 0°, heat flow up, D = 1.5 inch

Volumetric air flow rate for ACH of 100 at A_R = 13.3 is used at A_R = 61.0

T_{air} = 80°F at A_R = 61.0
Reference at A_R = 61.0
T_{air} = 80°F at A_R = 13.3
Reference at A_R = 13.3

+4% Decr.

+59% Incr.

E = 0.03

H = 20 inch (dashed lines)
H = 91.5 inch (solid lines)

R-Value ($ft^2 \cdot h \cdot °F/BTU$)

2.8, 2.6, 2.4, 2.2, 2.0, 1.8, 1.6, 1.4, 1.2

0, 0.02, 0.04, 0.06, 0.08, 0.10, 0.12, 0.14, 0.16, 0.18, 0.20

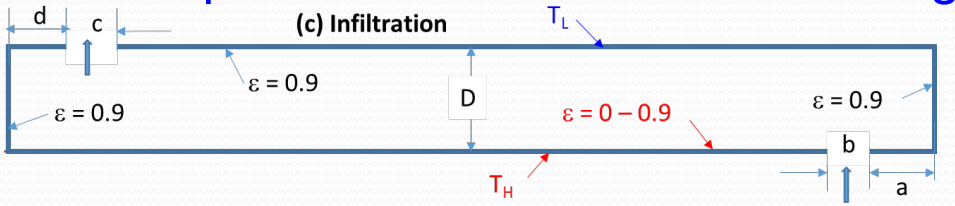
Effective Emittance, E

Air Intrusion in RIs with Heat Flow Up (cont.)

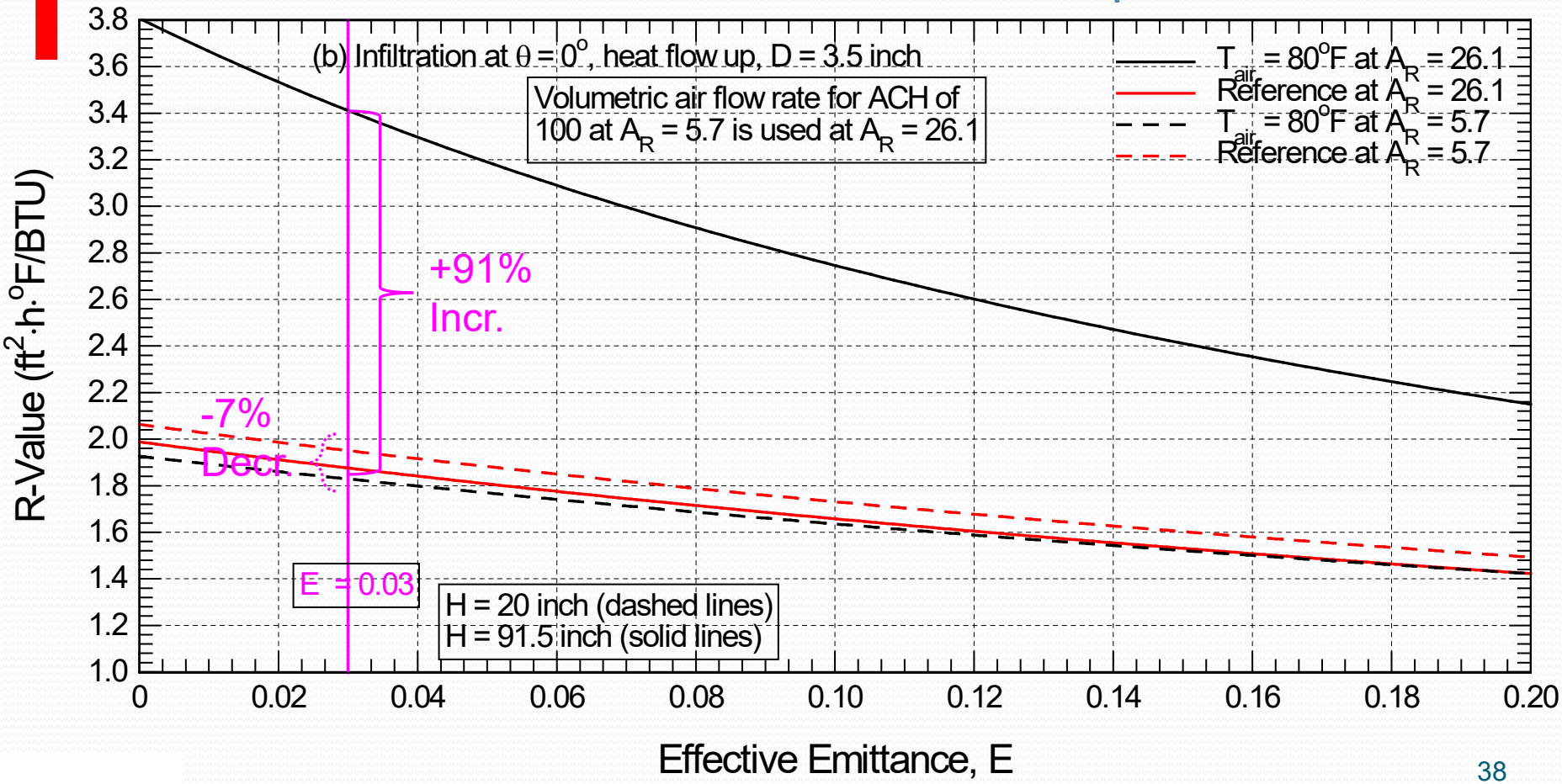
Effect of aspect ratio at the same air leakage rate

Heat Flow UP

Thick Assembly



$$\frac{\dot{V}_{Large\ A_R}}{\dot{V}_{Samall\ A_R}} = 1.0$$

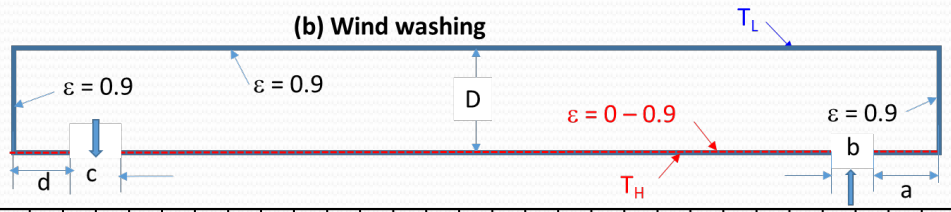


Air Intrusion in RIs with Heat Flow Up (cont.)

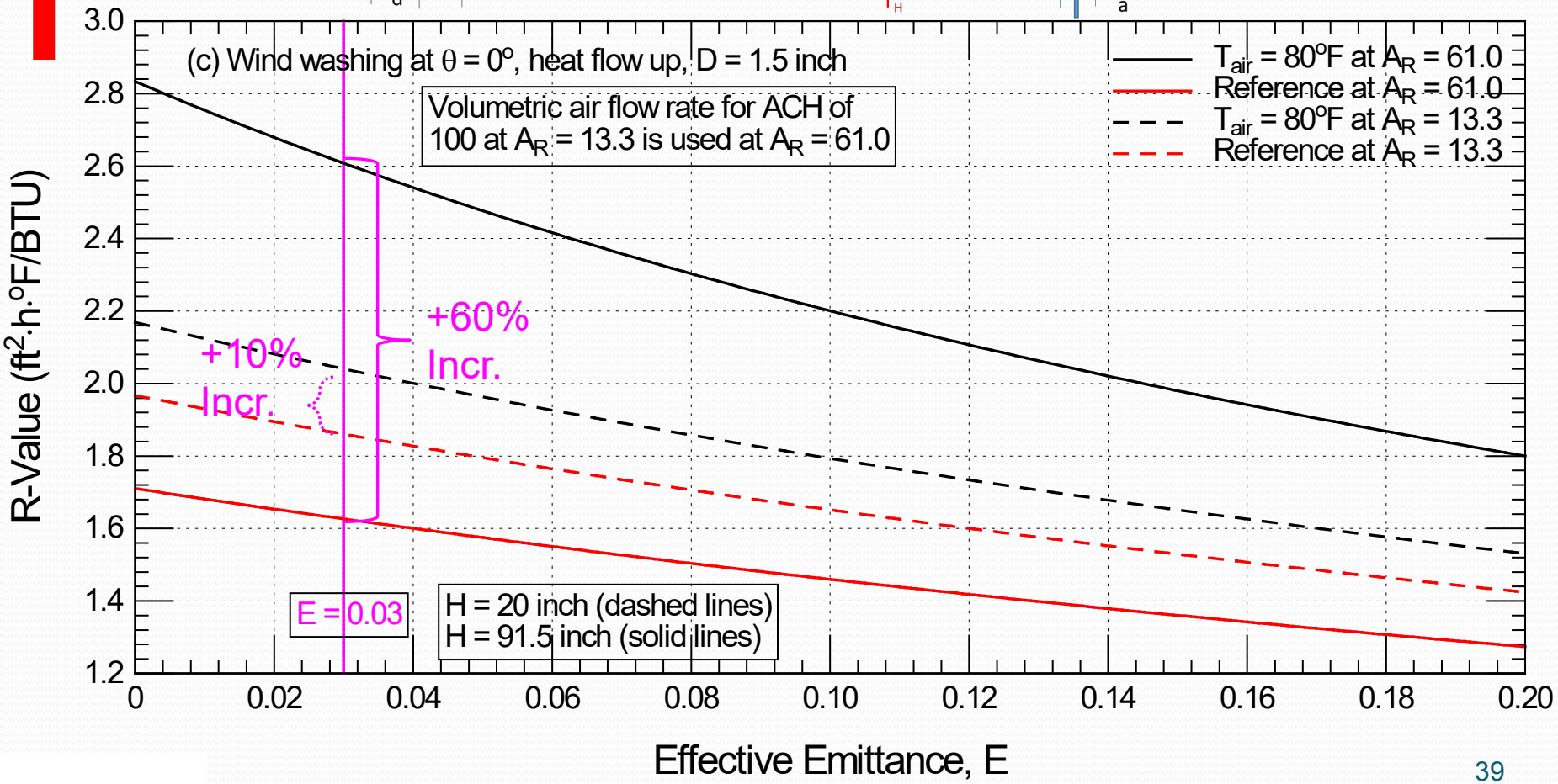
Effect of aspect ratio at the same air leakage rate

Heat Flow UP

Thin Assembly



$$\frac{\dot{V}_{Large\ A_R}}{\dot{V}_{Samall\ A_R}} = 1.0$$

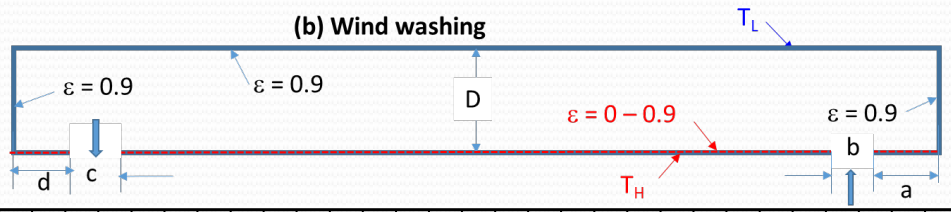


Air Intrusion in RIs with Heat Flow Up (cont.)

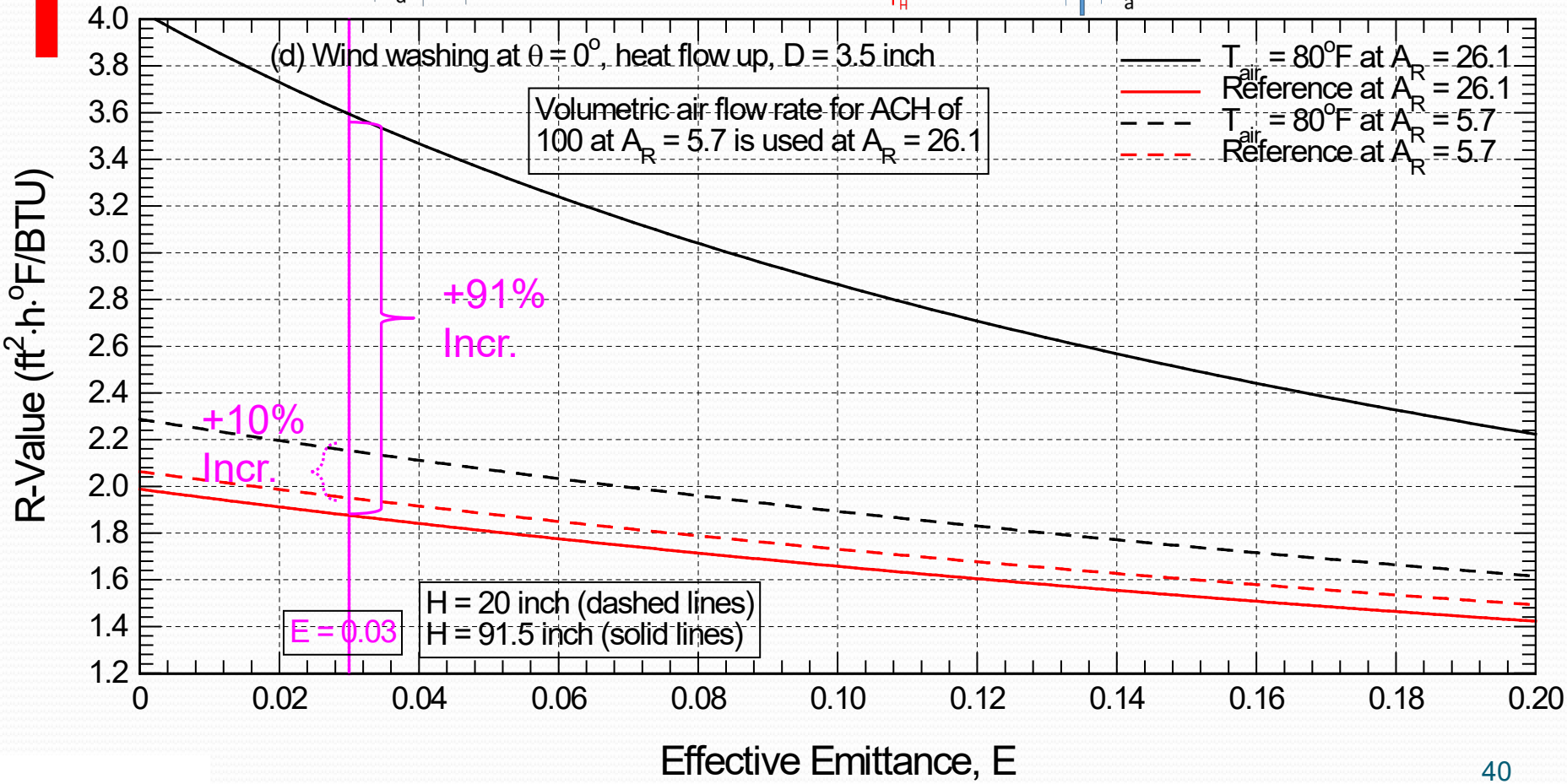
Effect of aspect ratio at the same air leakage rate

Heat Flow UP

Thick Assembly



$$\frac{\dot{V}_{Large\ A_R}}{\dot{V}_{Samall\ A_R}} = 1.0$$



SUMMARY

- Validated numerical model was used to investigate the effect of air intrusion on the thermal performance of RI assemblies
- Provided sample results to show the effect of air leakage on the R-value of RI assemblies with heat flow horizontal
- With and without air intrusion, the aspect ratio has a significant effect on the R-value
- For heat flow down, R-value decreases with increasing ACH
- For heat flow up, R-value increases with increasing ACH

Questions?

Thank You

H.H. Saber and D.W. Yarbrough