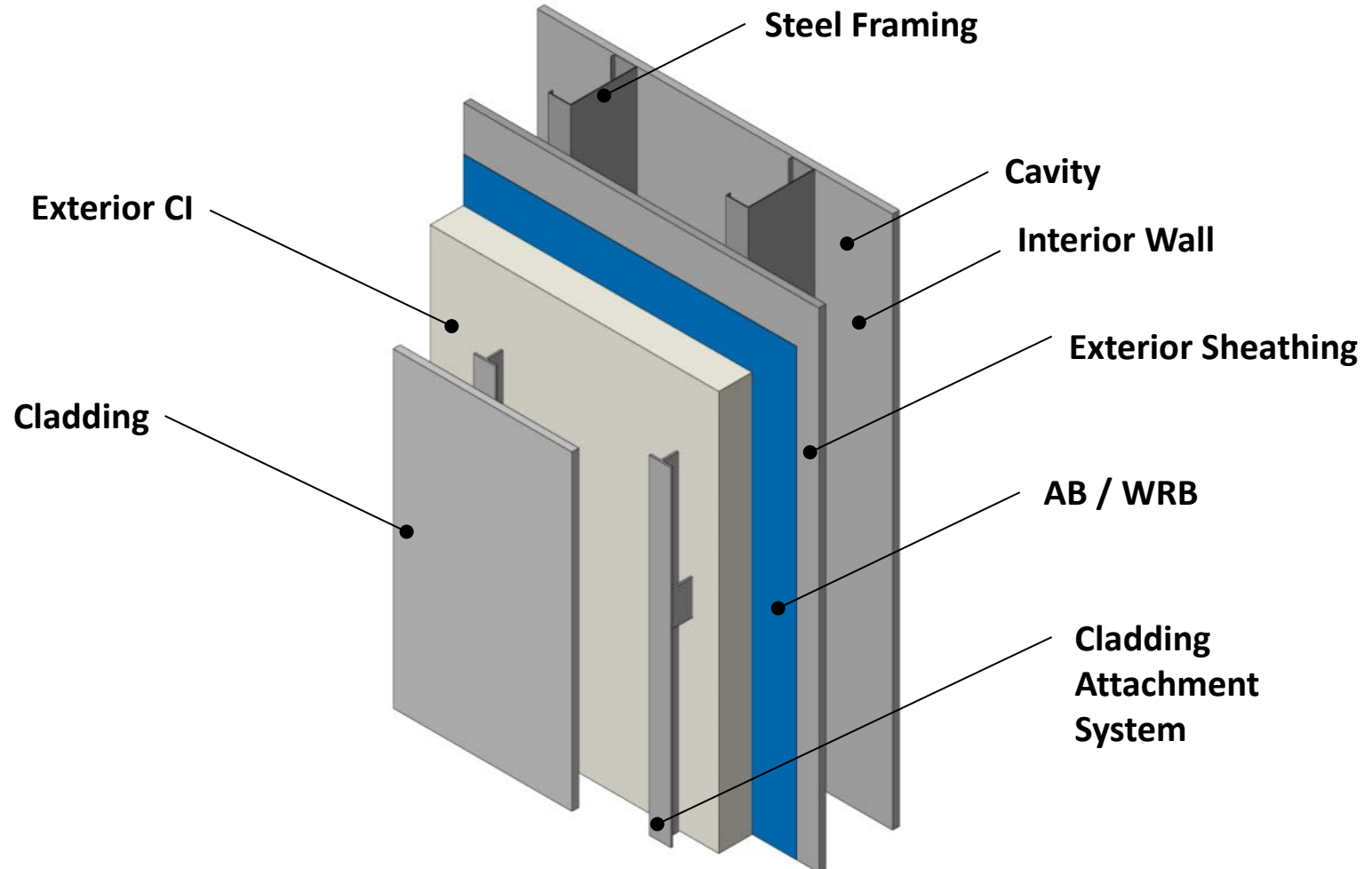


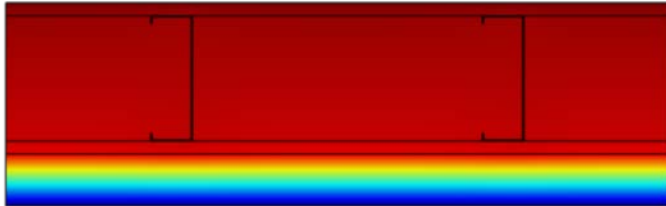
Convective Heat Loss:

A Critical Analysis of Conventional Rainscreen Design

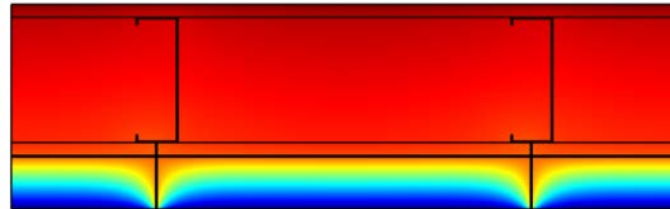
Conventional Rainscreen Design



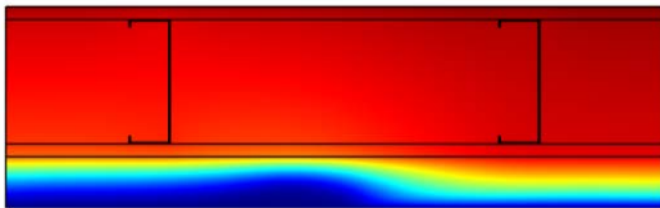
New Design Considerations



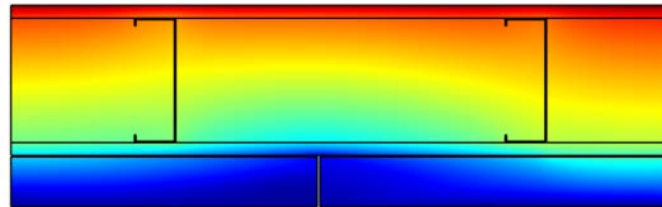
Continuous Insulation



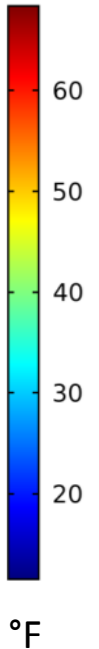
Thermal Bridging



Wind-Washing



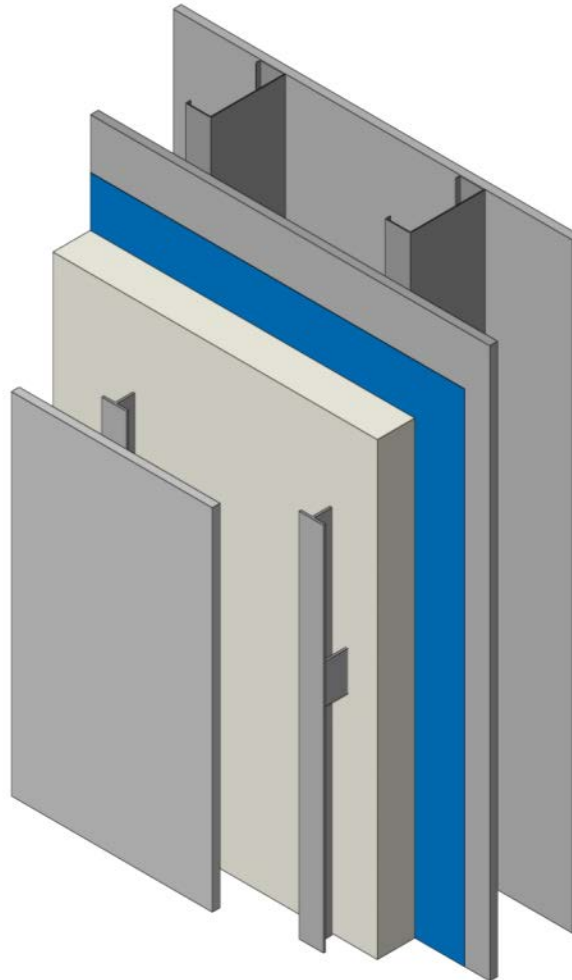
Wind-Washing + Gaps



New Design Considerations

Heat Transfer

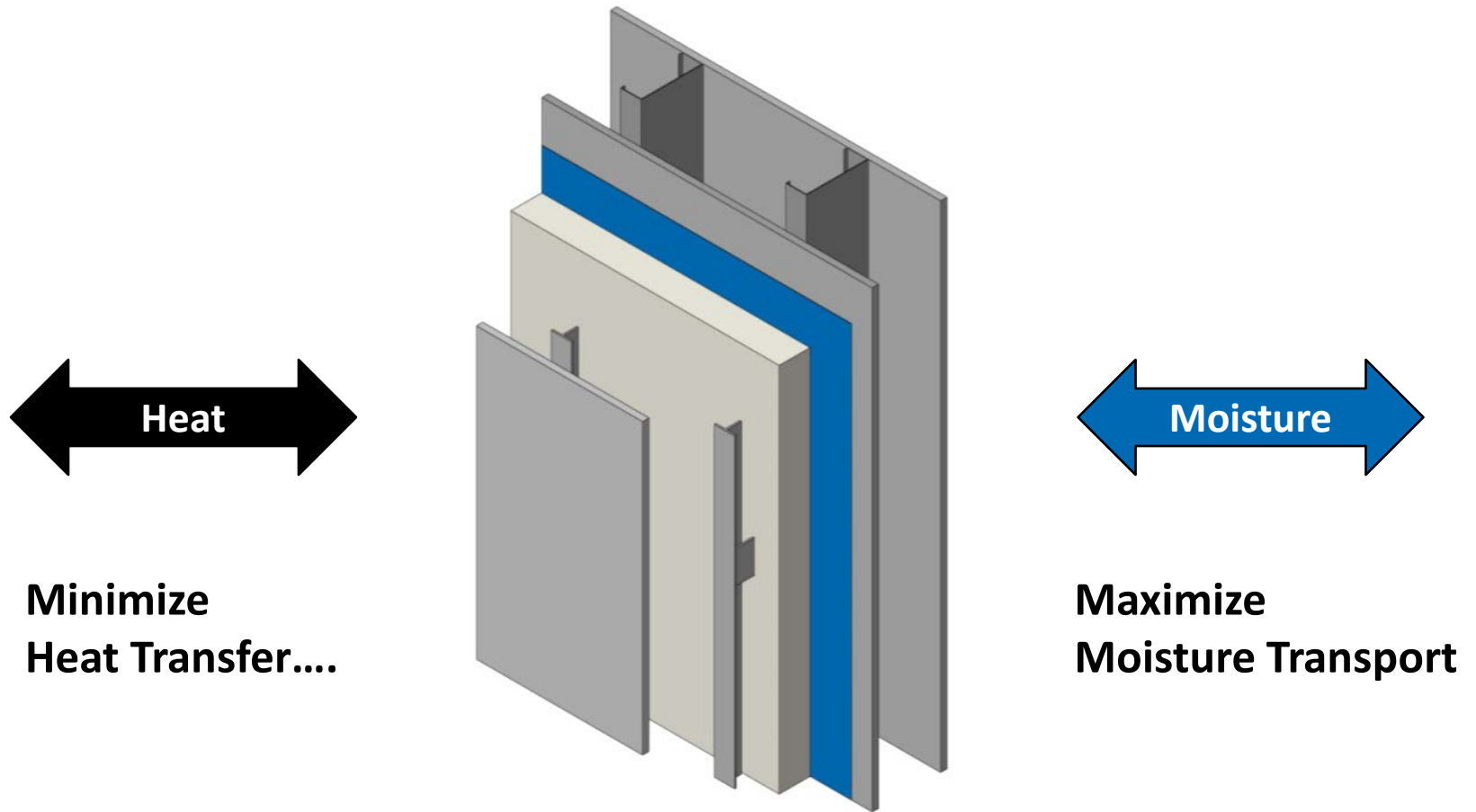
- Thermal Bridging
- Convective Heat Loss



Moisture Transport

- Rainscreen-WRB Disjoined
- Reduced Drainage Efficiency
- Reduced Vapor Transport with Low-Perm WRBs

The Rainscreen Paradox



General Approach

Using Building Simulations to Assess Risks

Heat

Computational Fluid Dynamics: COMSOL

- Rainscreen Airflows in Whole Buildings
- Convective Heat Loss in Decoupled Walls

Moisture

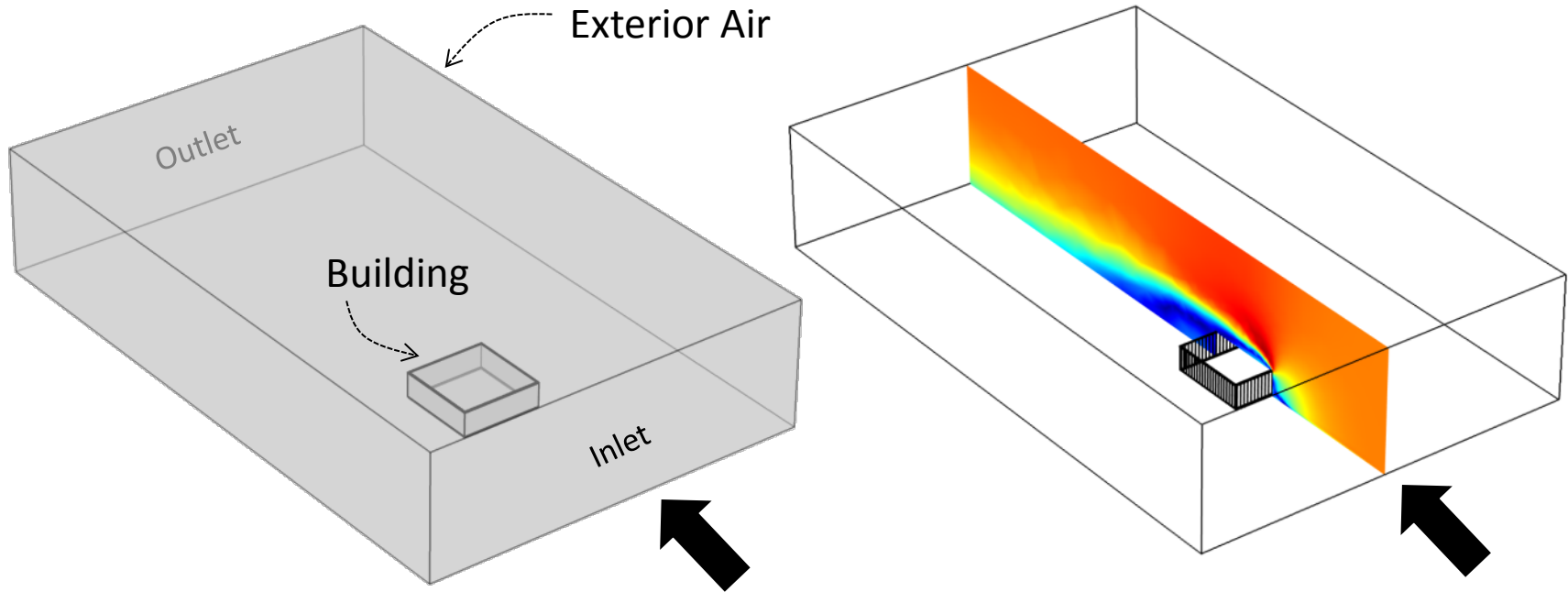
H.A.M. Transfer: COMSOL + WUFI

- Steady-State CFD with 3D Models
- Steady-State & Transient 1D (WUFI)

The Challenge:

Simultaneously assess heat, air, and moisture transport thru porous media.

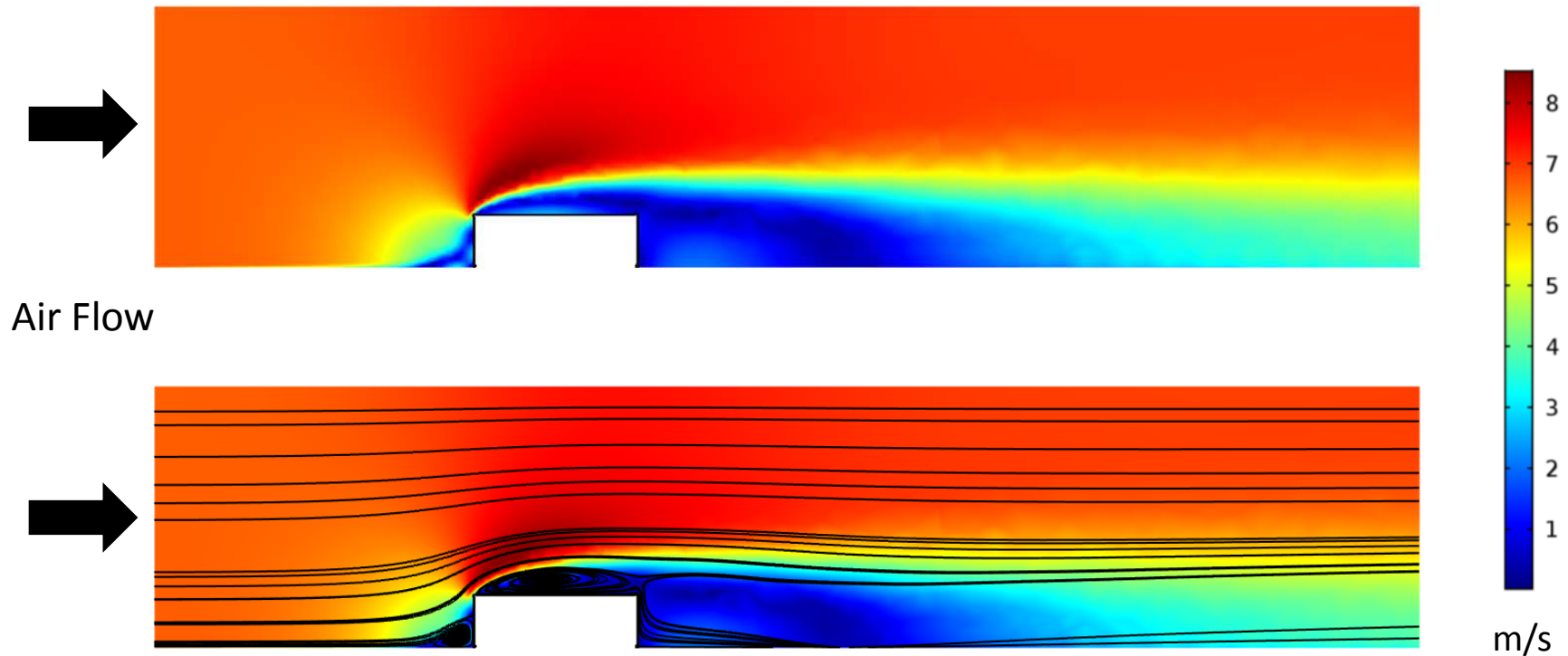
Airflow Around Buildings



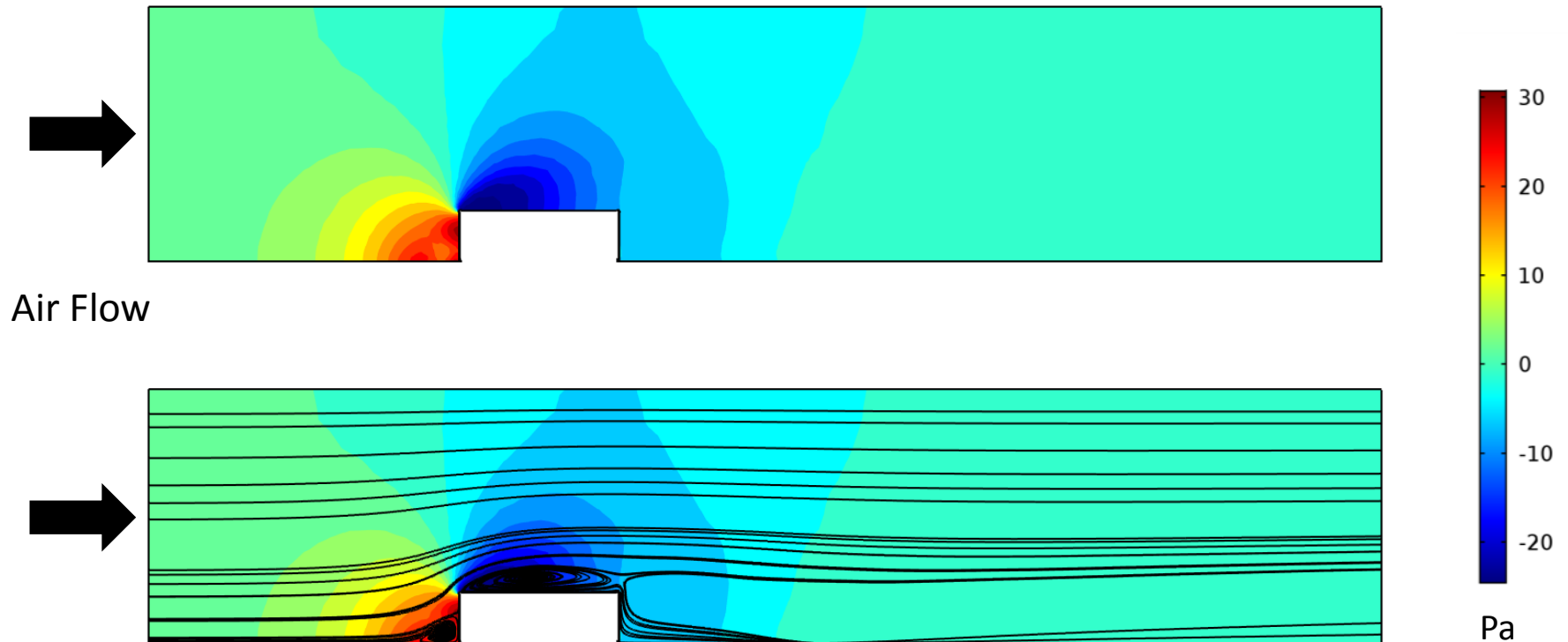
Inlet = 6.7 m/s (15 mph)

Winter Design Conditions ASHRAE Handbook

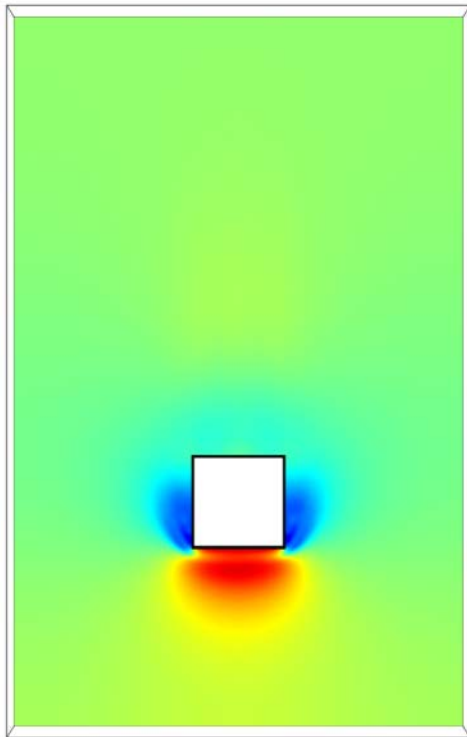
Airflow Around Buildings



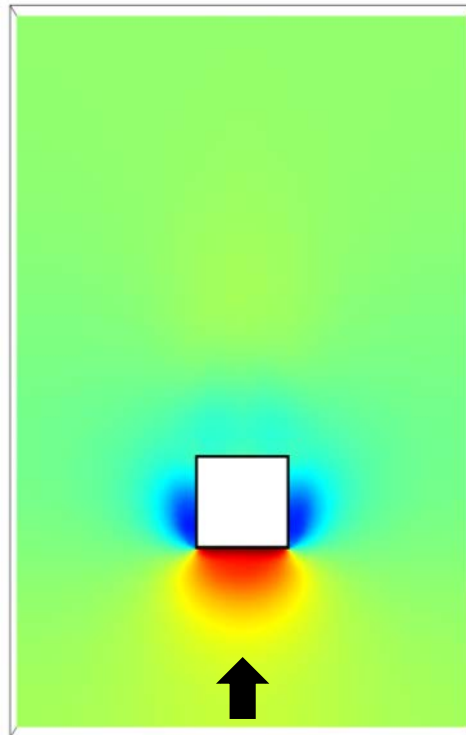
Airflow Around Buildings



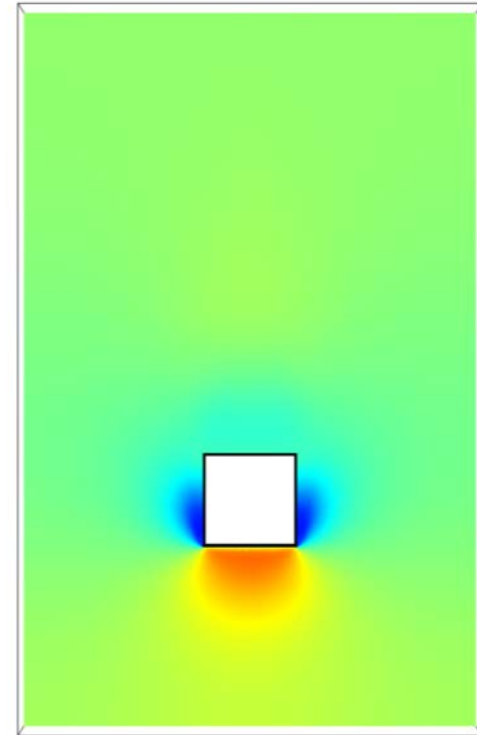
Airflow Around Buildings



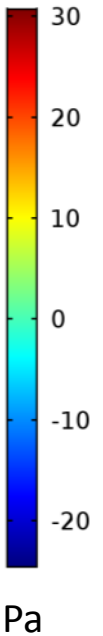
At Grade



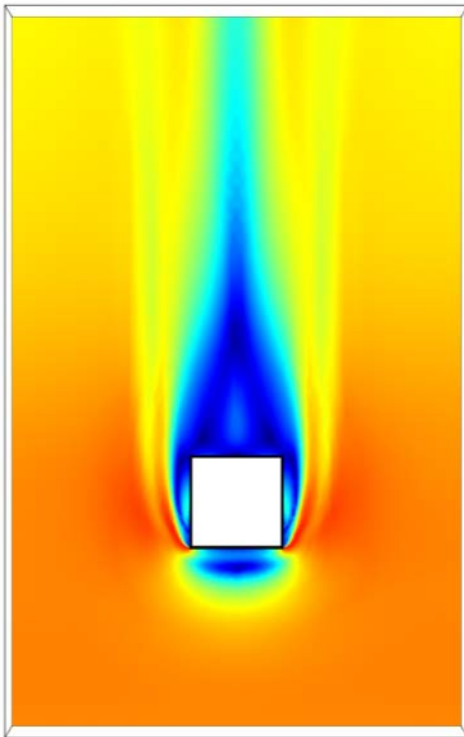
Mid-Height



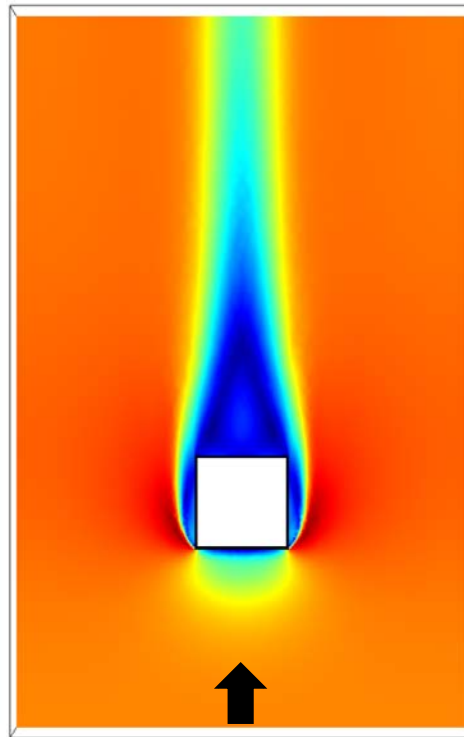
At Roof Coping



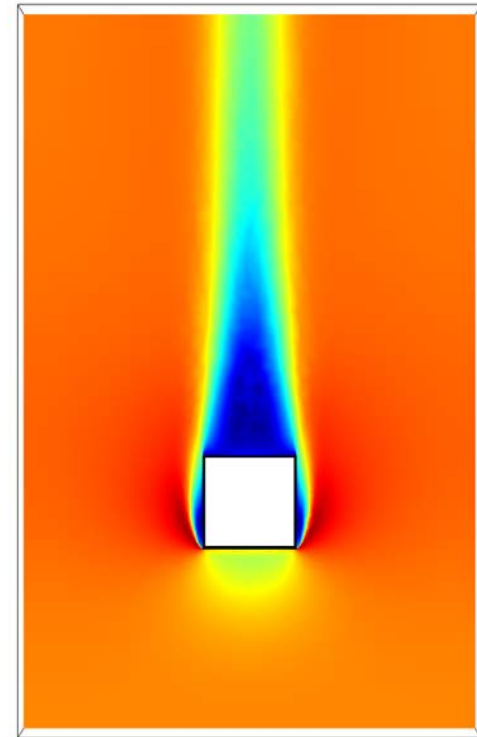
Airflow Around Buildings



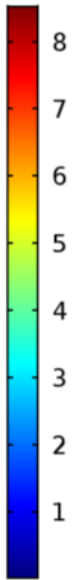
At Grade



Mid-Height



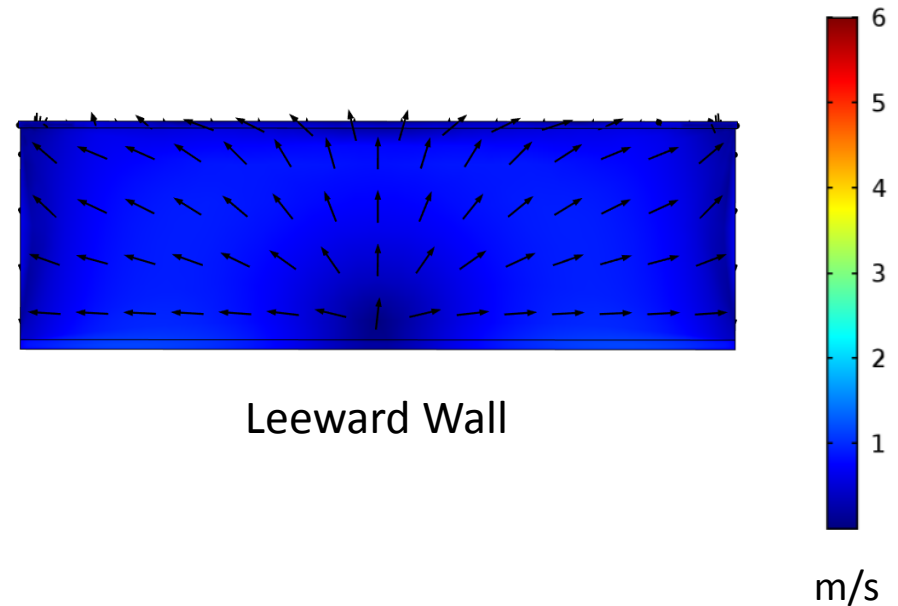
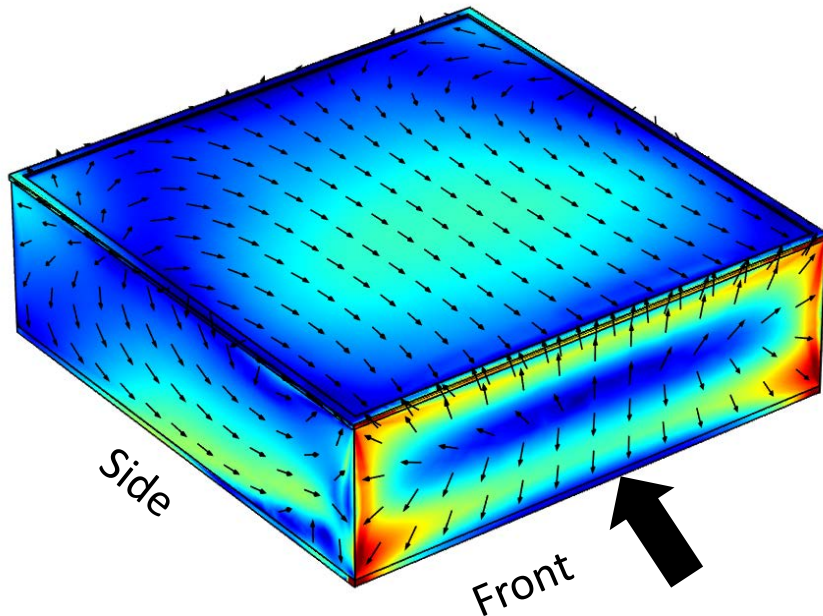
At Roof Coping



m/s

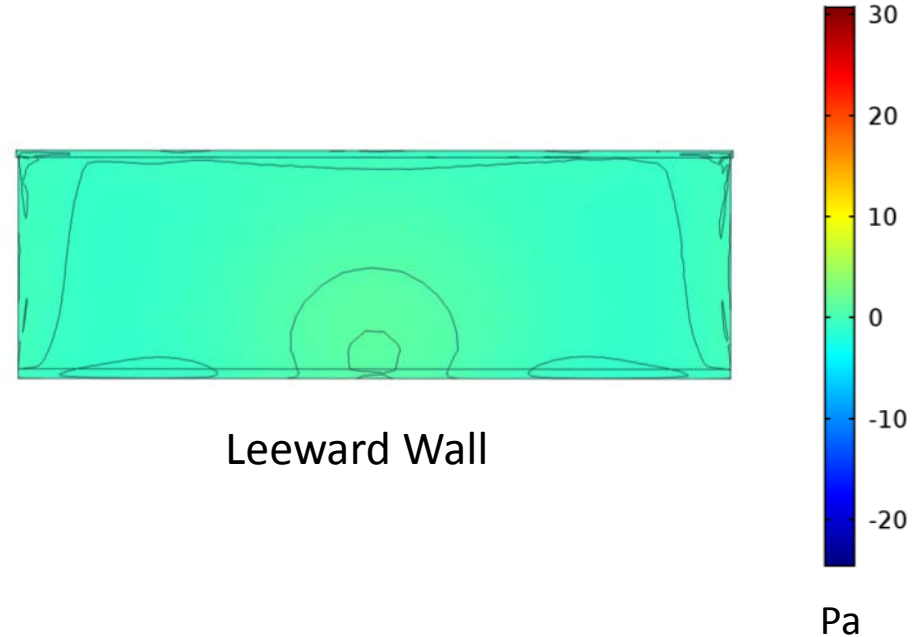
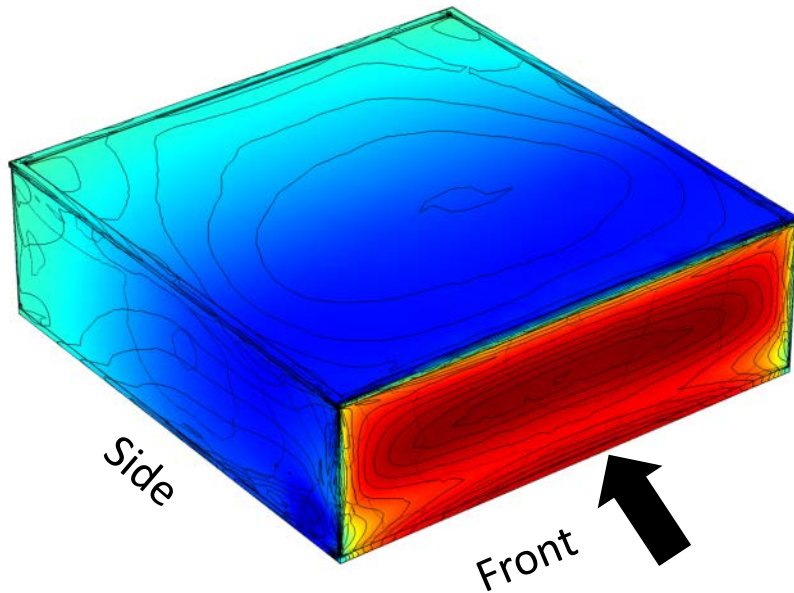
Exterior Building Surfaces

Velocity Magnitudes & Flow Patterns

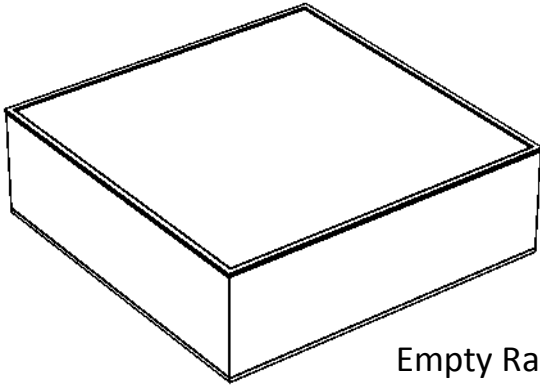


Exterior Building Surfaces

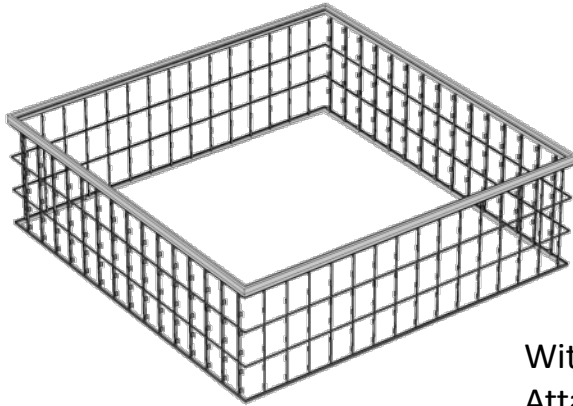
Surface Pressures



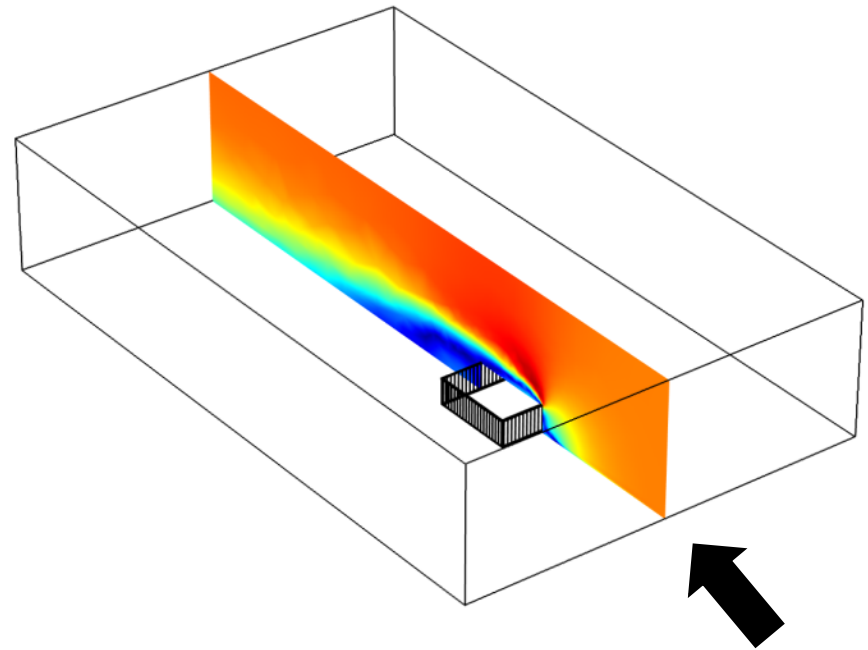
Rainscreen Airflows



Empty Rainscreen Space

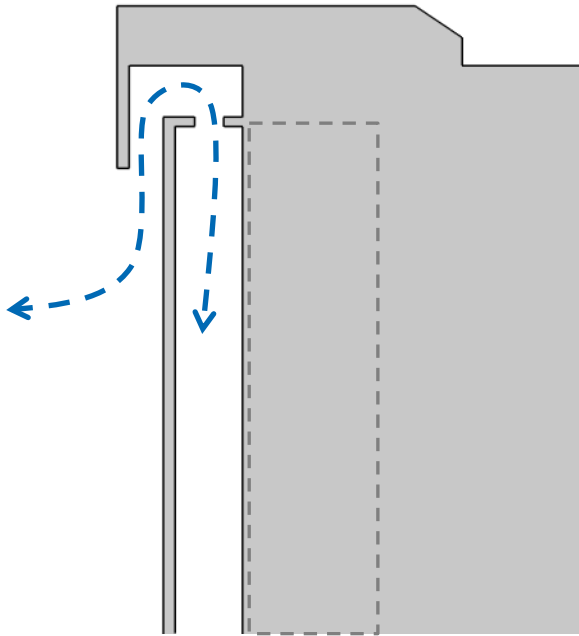


With Cladding
Attachment System

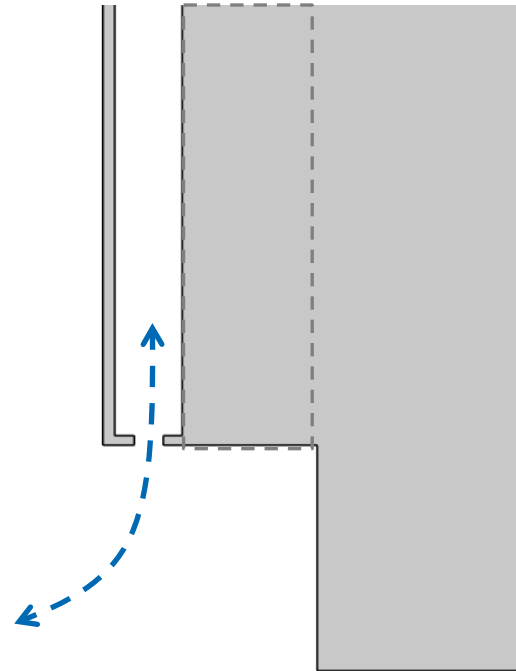


Inlet = 6.7 m/s (15 mph)
Winter Design Conditions ASHRAE Handbook

Ventilation Inlets



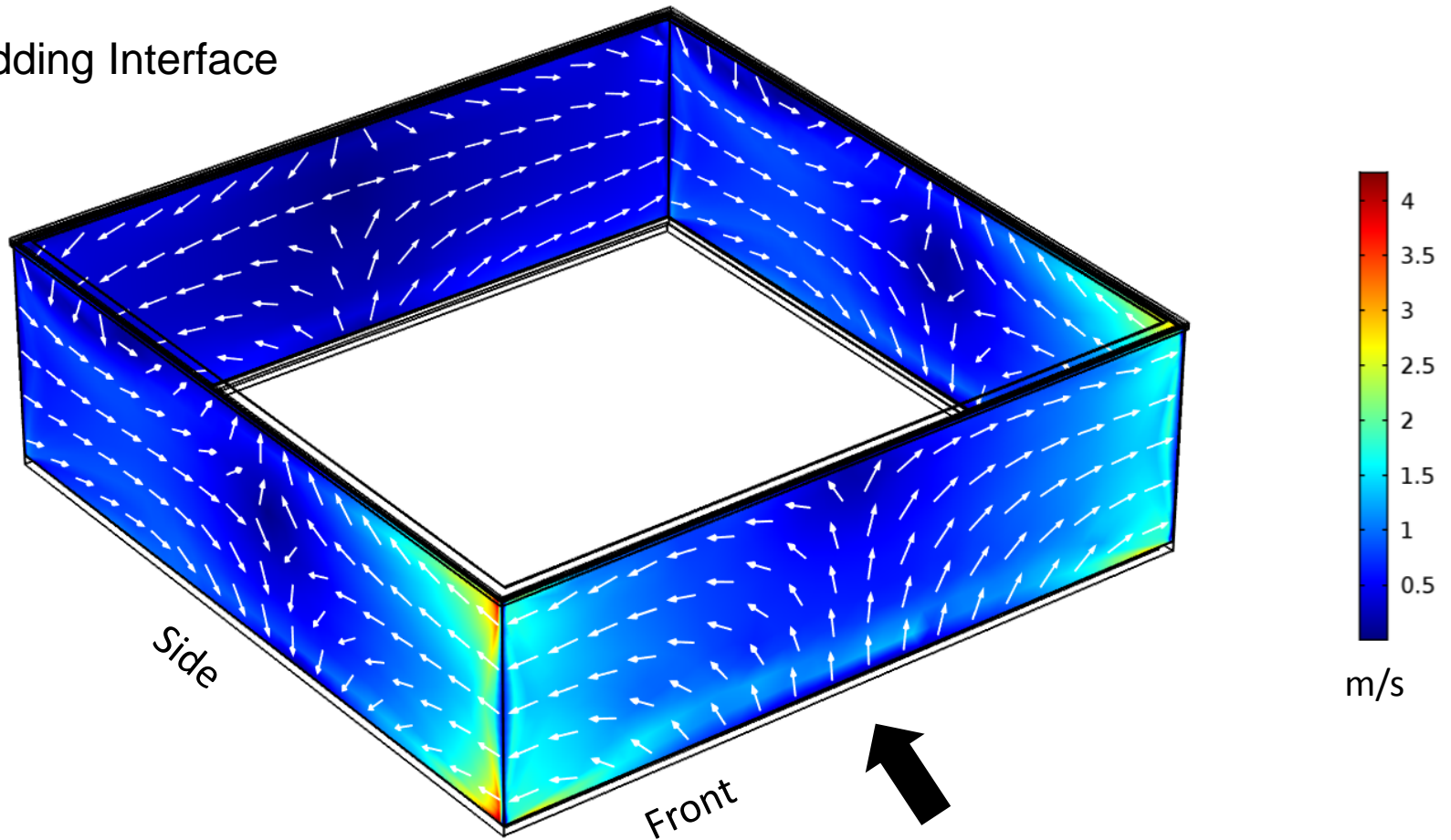
Top of Wall



Base of Wall

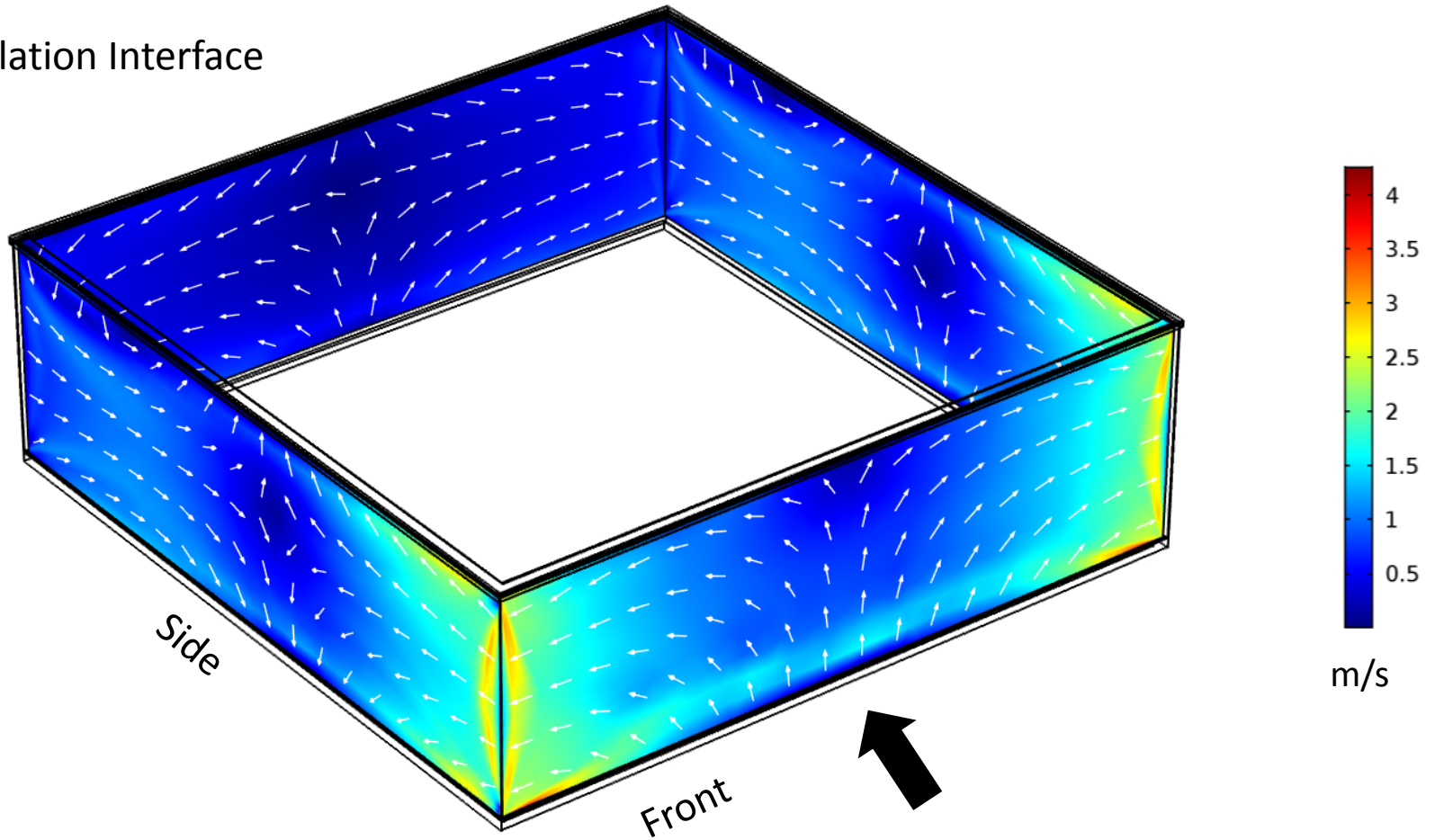
Rainscreen Airflows

At Cladding Interface



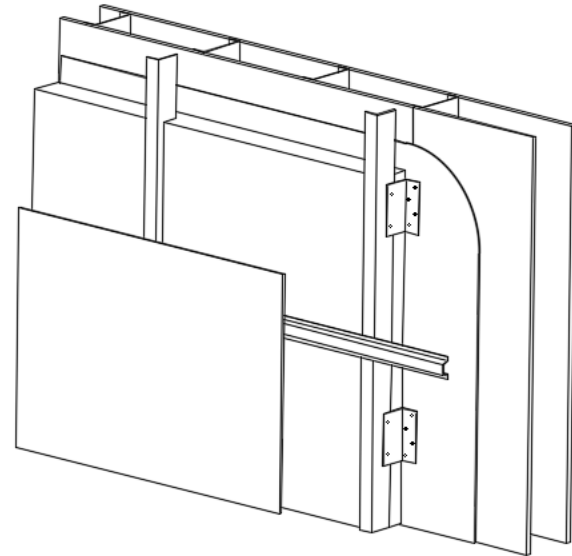
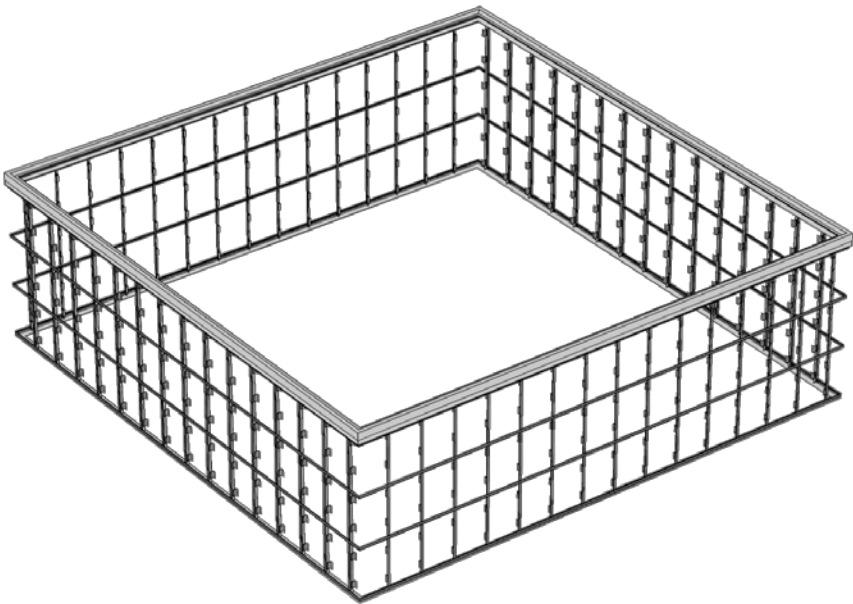
Rainscreen Airflows

At Insulation Interface

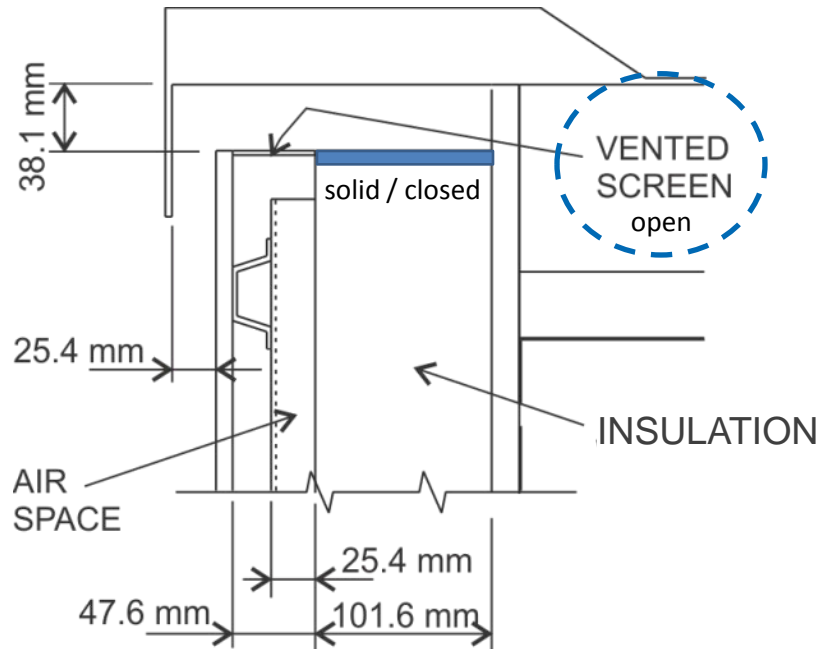


Cladding Attachment System

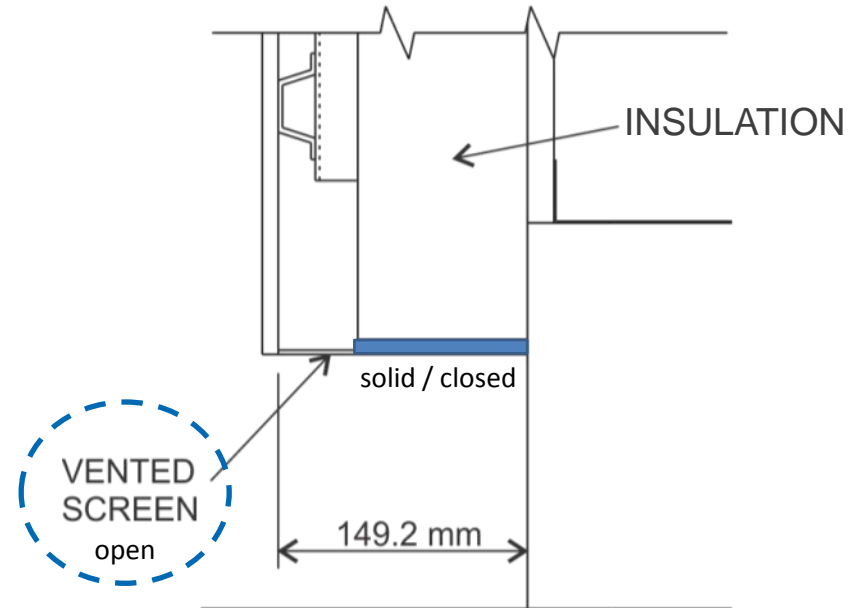
Complex Model Geometries



Ventilation Inlets



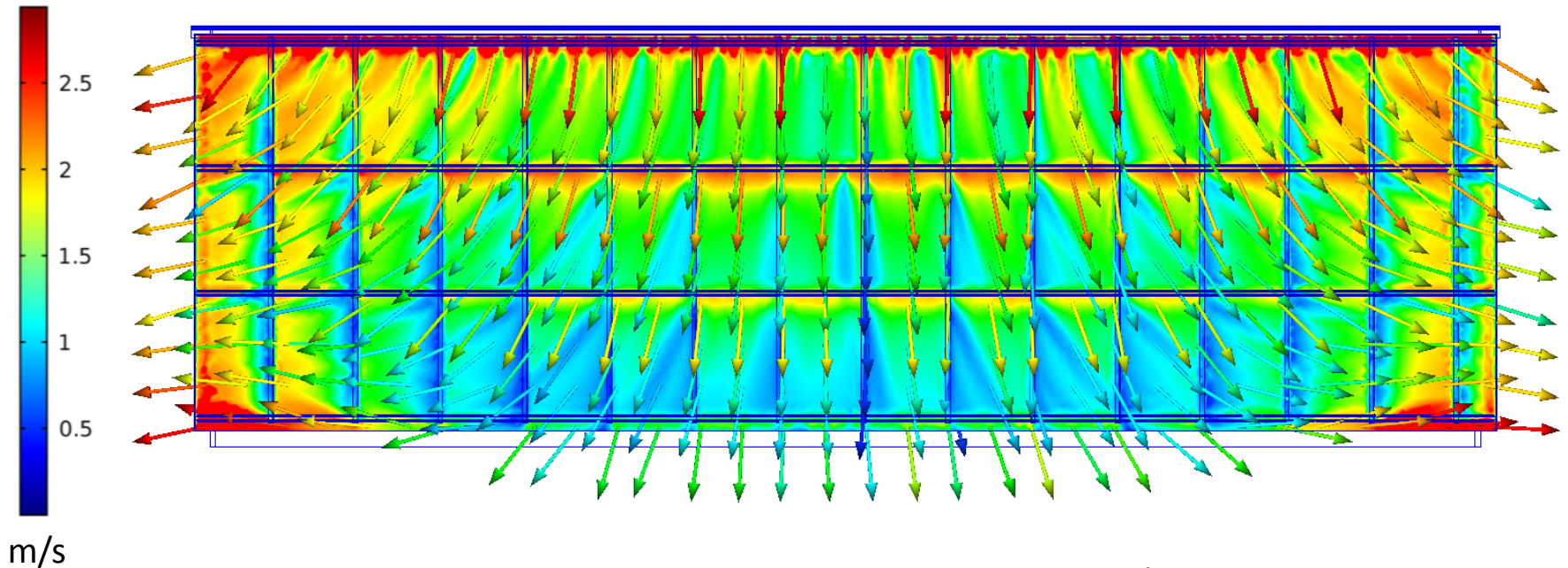
Top of Wall



Base of Wall

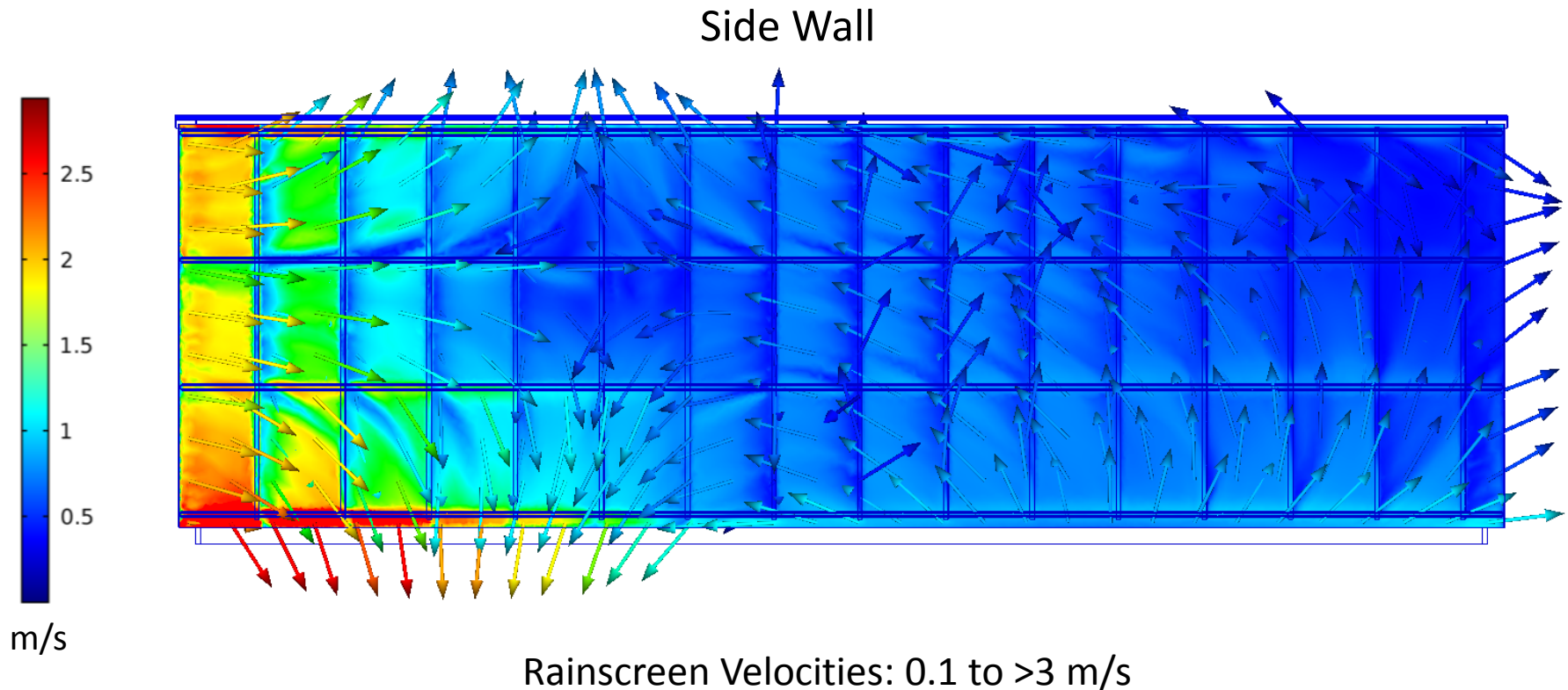
Rainscreen Airflows

Windward Wall

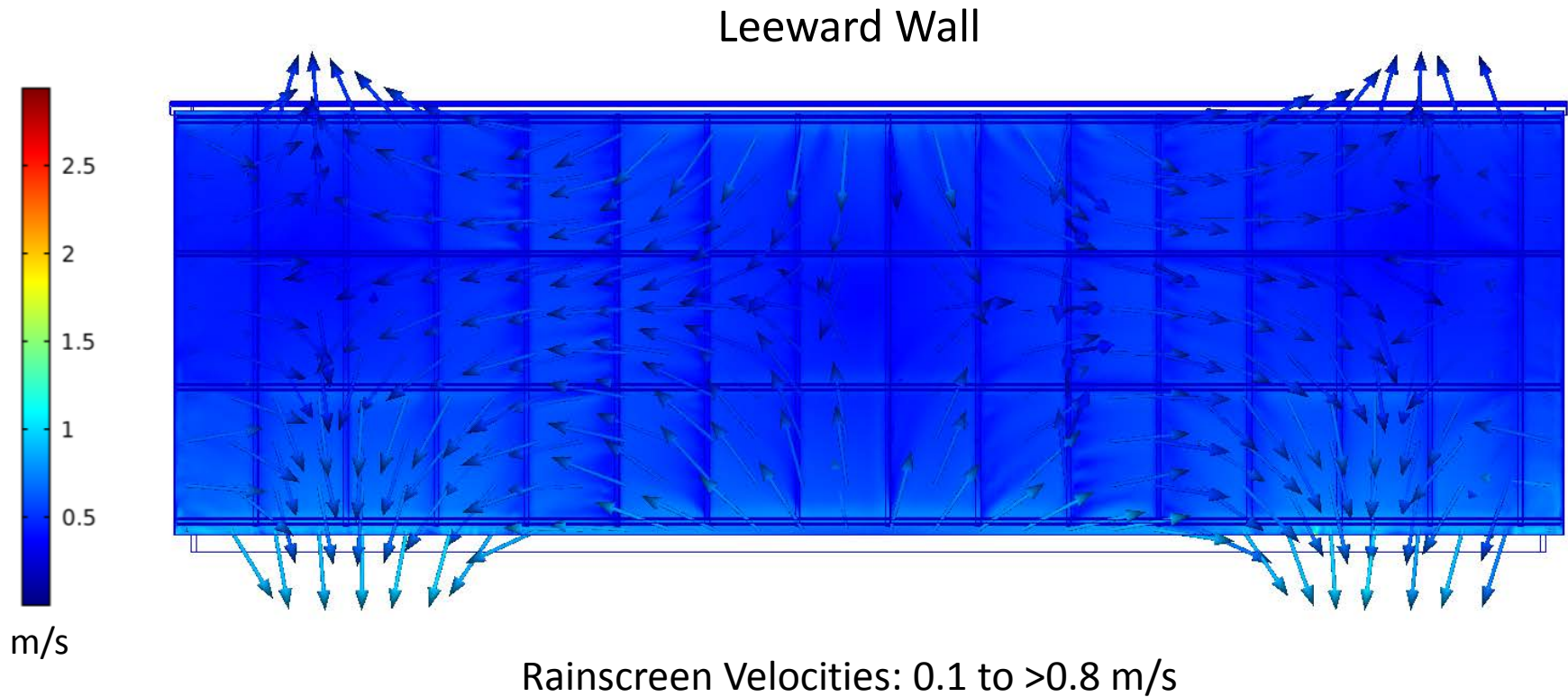


Rainscreen Velocities: 0.1 to >3 m/s

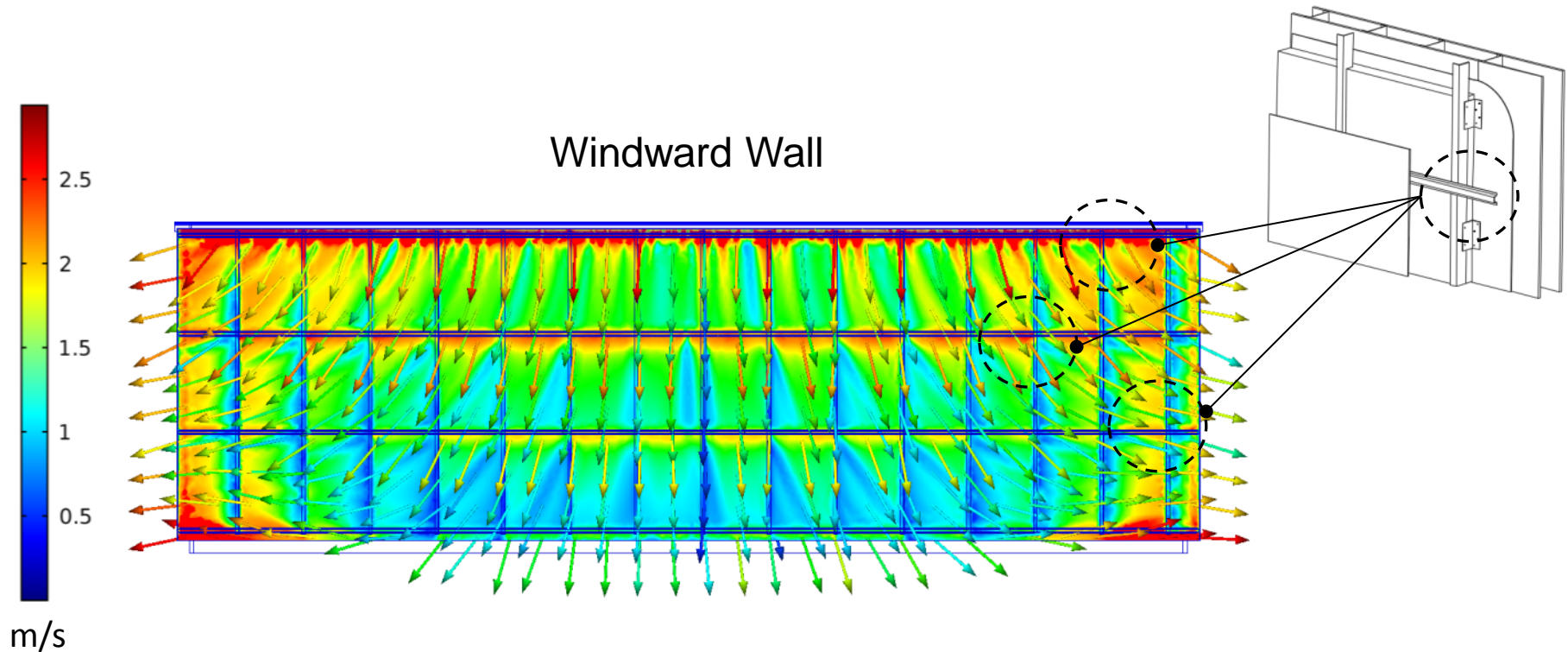
Rainscreen Airflows



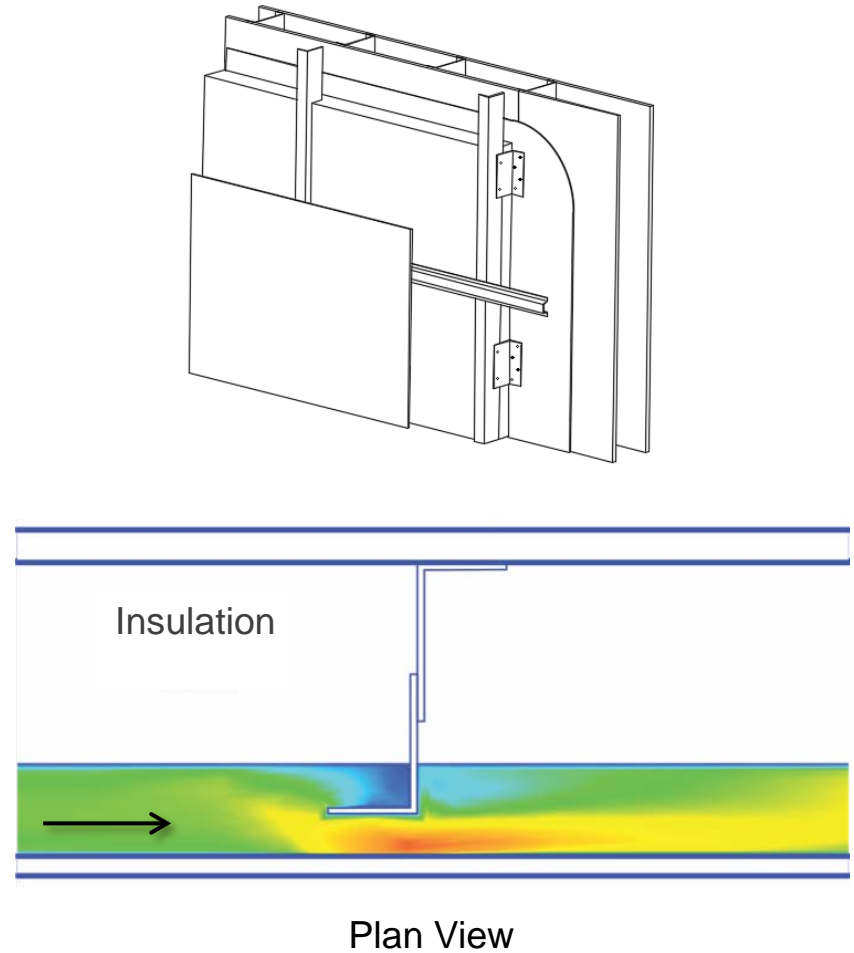
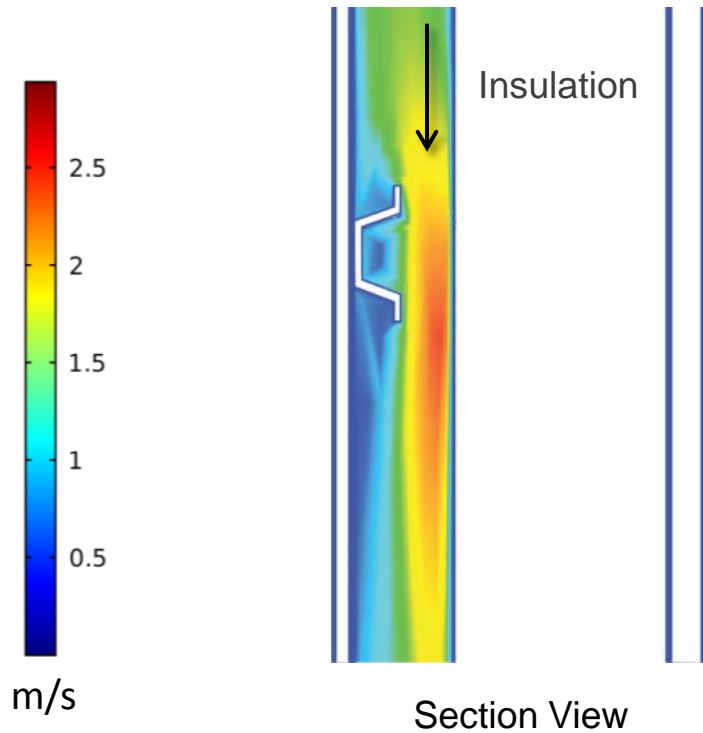
Rainscreen Airflows



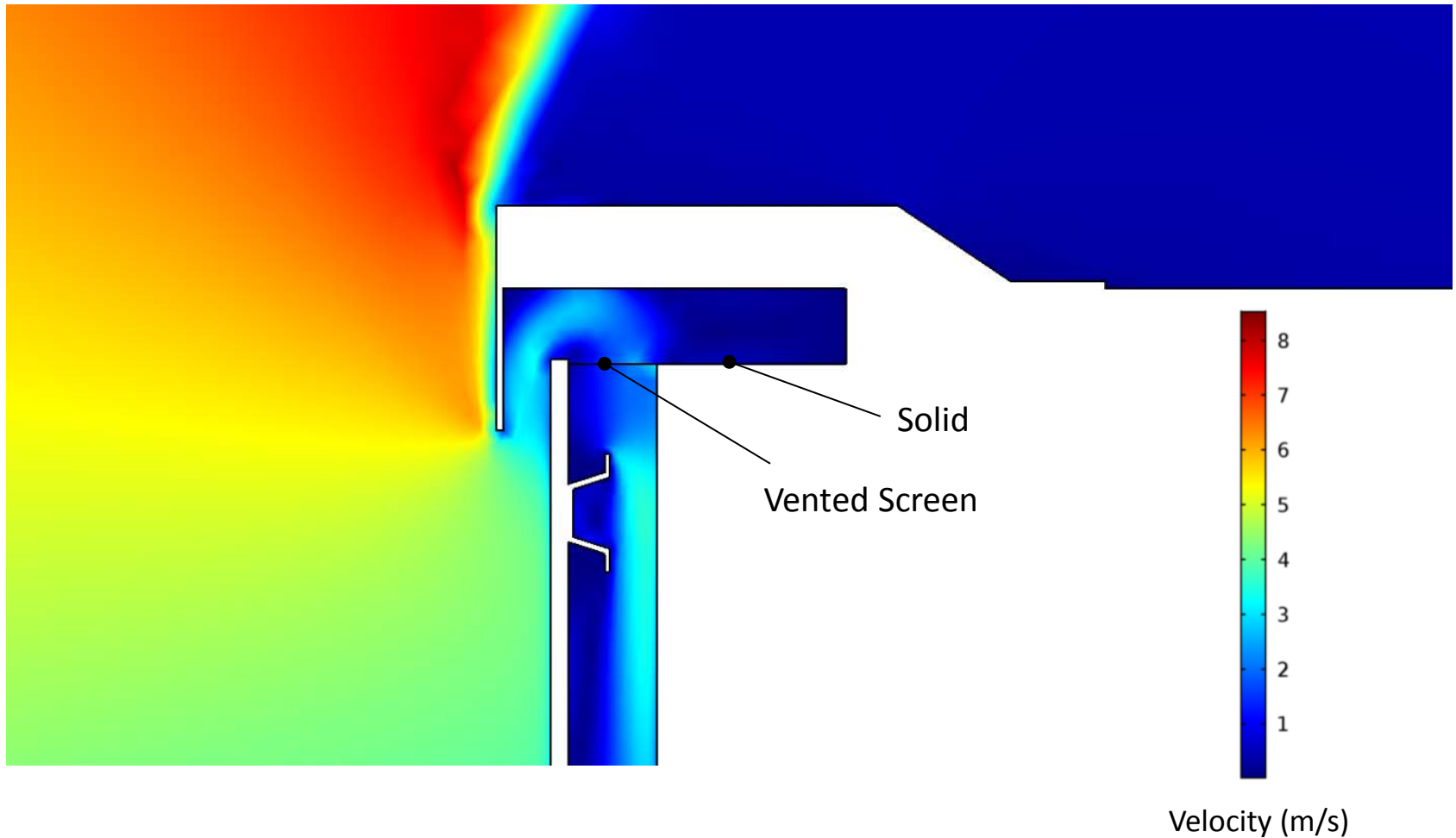
Rainscreen Airflows



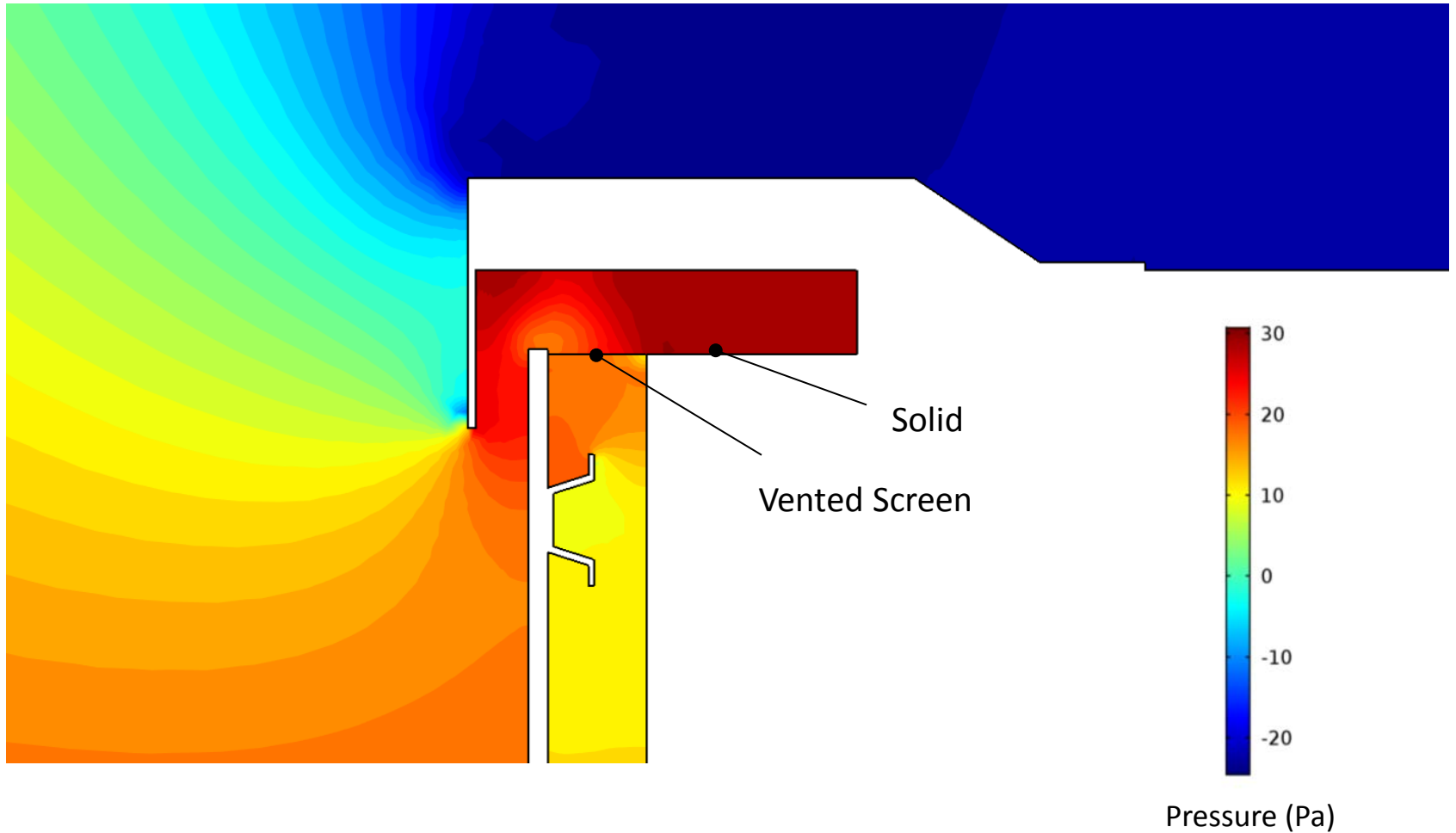
Rainscreen Airflows



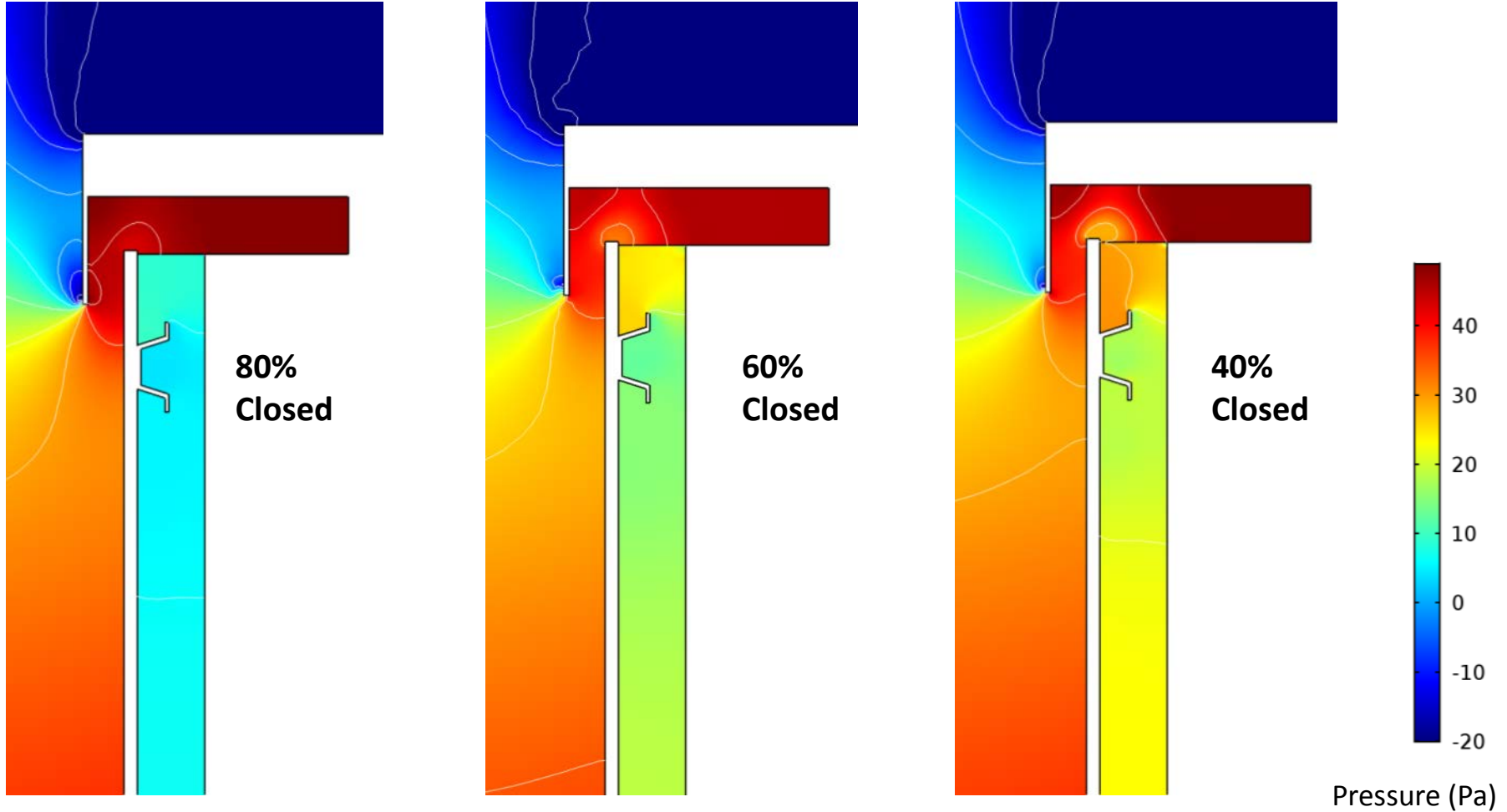
Ventilation Inlets: Velocity



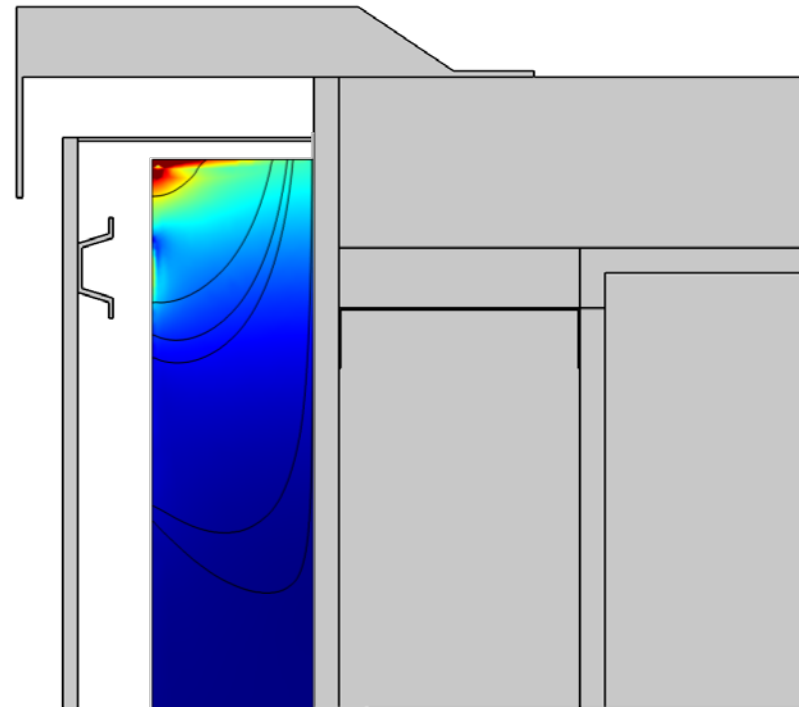
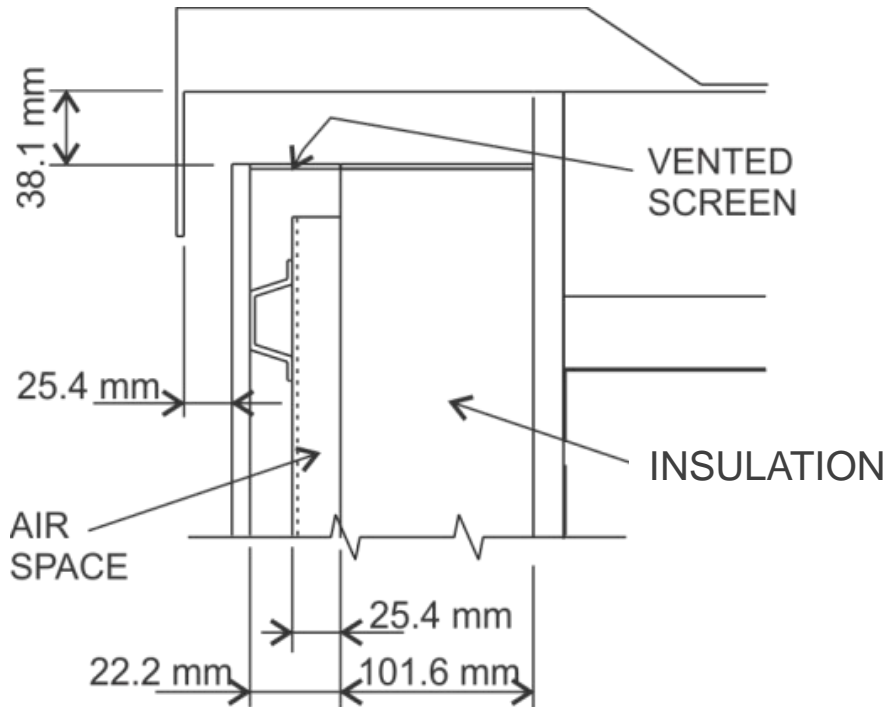
Ventilation Inlets: Pressure



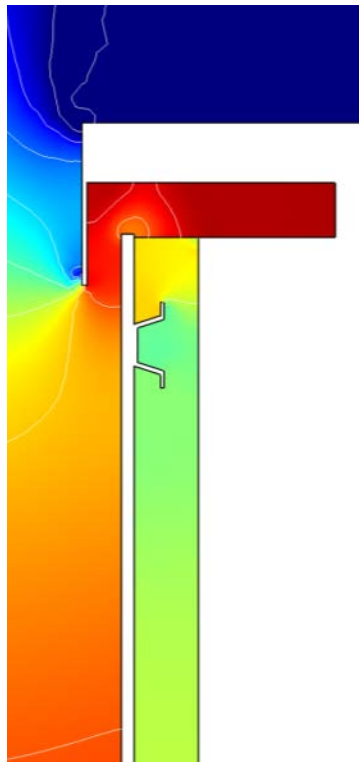
Ventilation Inlets



Rainscreen Airflows



Rainscreen Airflows



01

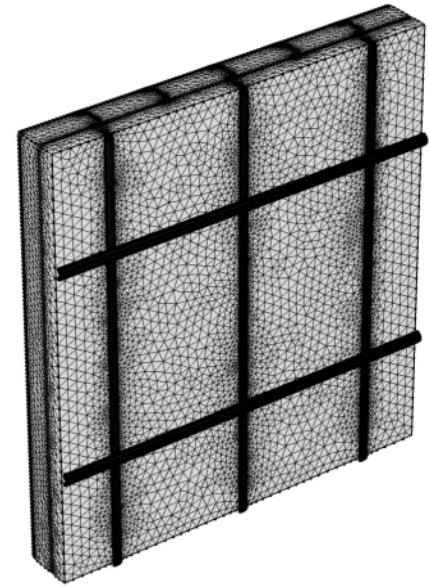
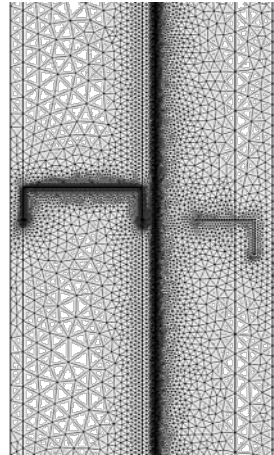
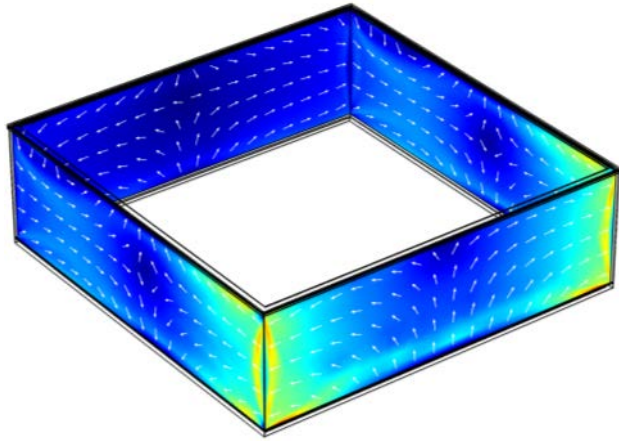
Airflow velocities are 2x – 5x greater than expected.

02

Governing Factors:

- Rainscreen Geometry
- Inlet Configuration
- Wind Speed
- Rainscreen Cavity Depth

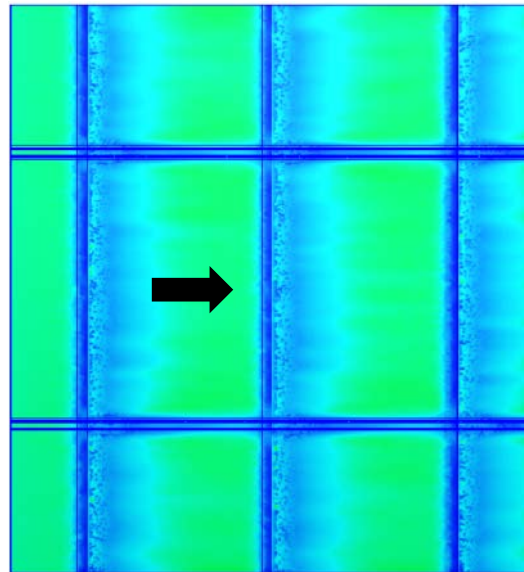
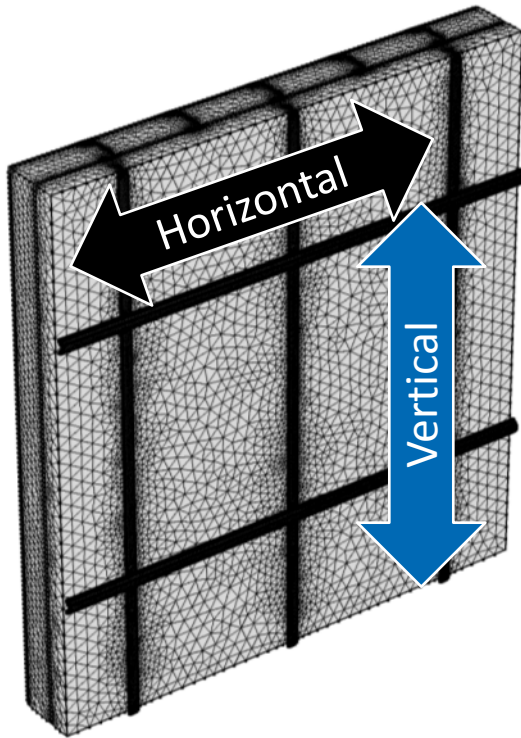
Convective Heat Loss



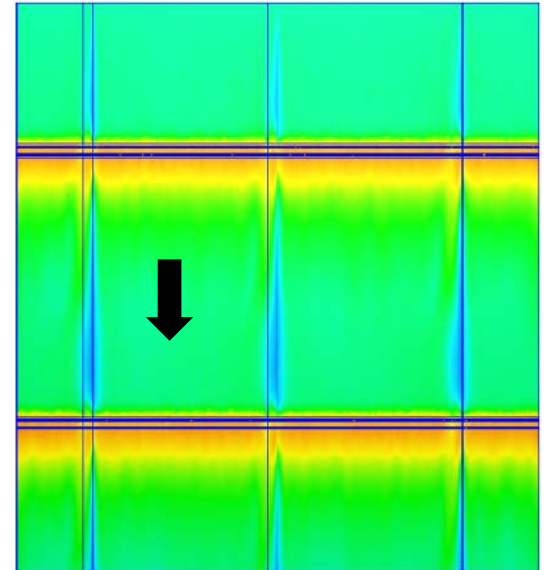
Meshing

**Decoupled
8' x 8'
Panel**

Convective Heat Loss

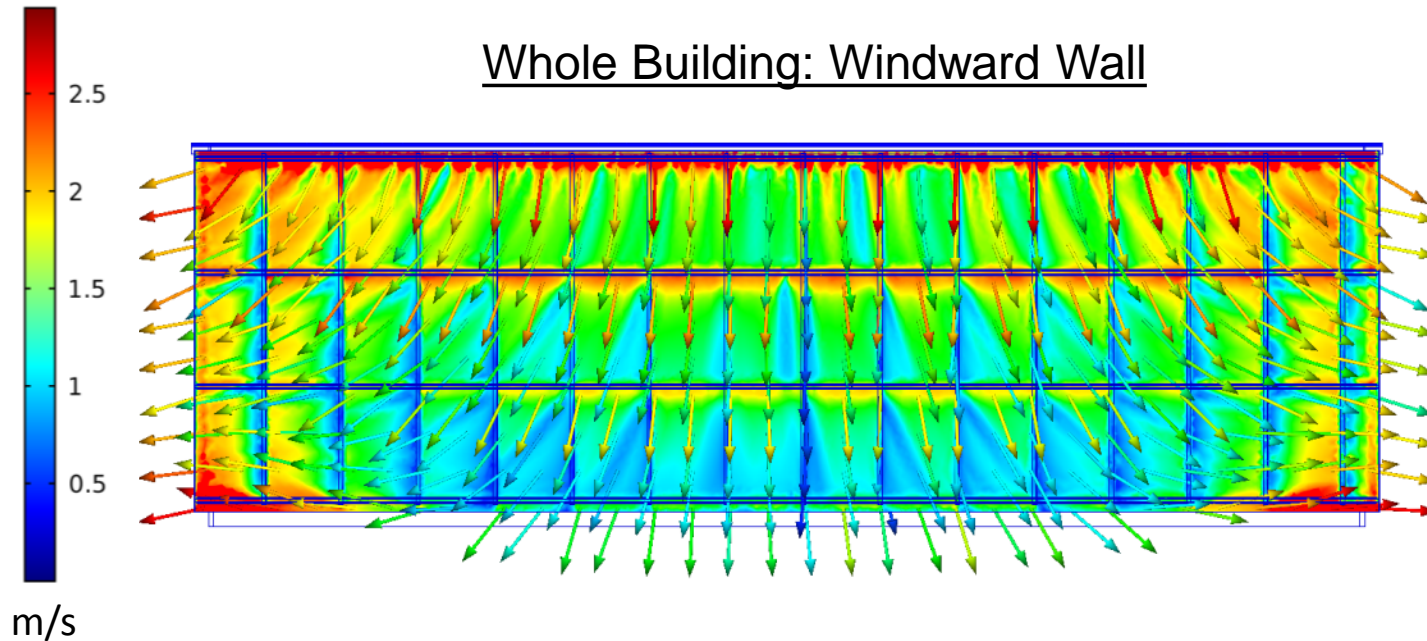


Horizontal Flows

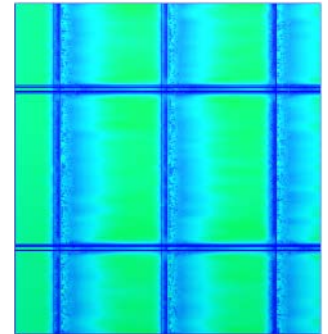


Vertical Flows

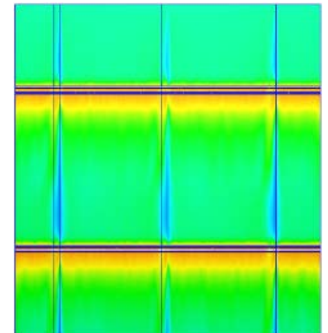
Rainscreen Airflows



Decoupled

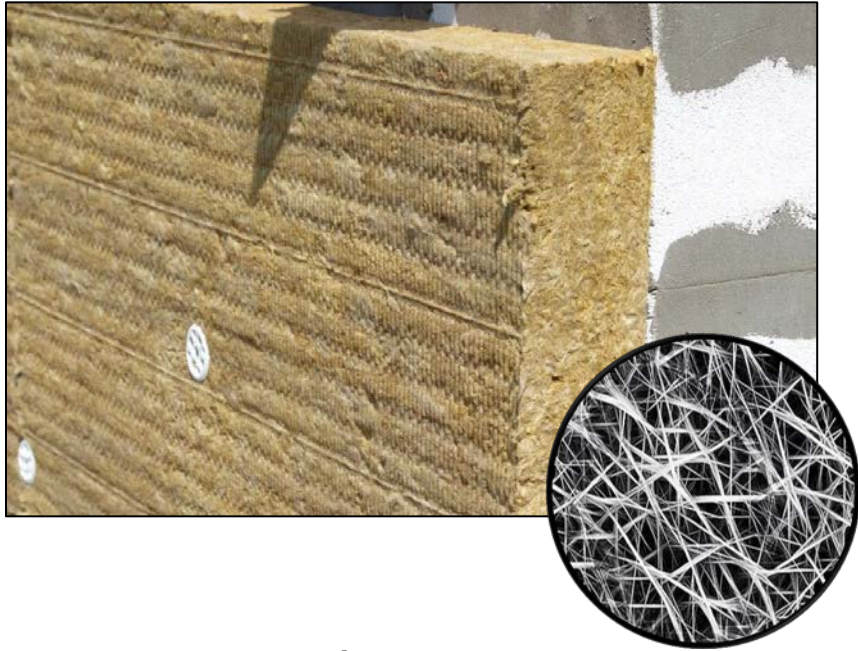


Horizontal Flows
1 m/s



Vertical Flows
1 m/s

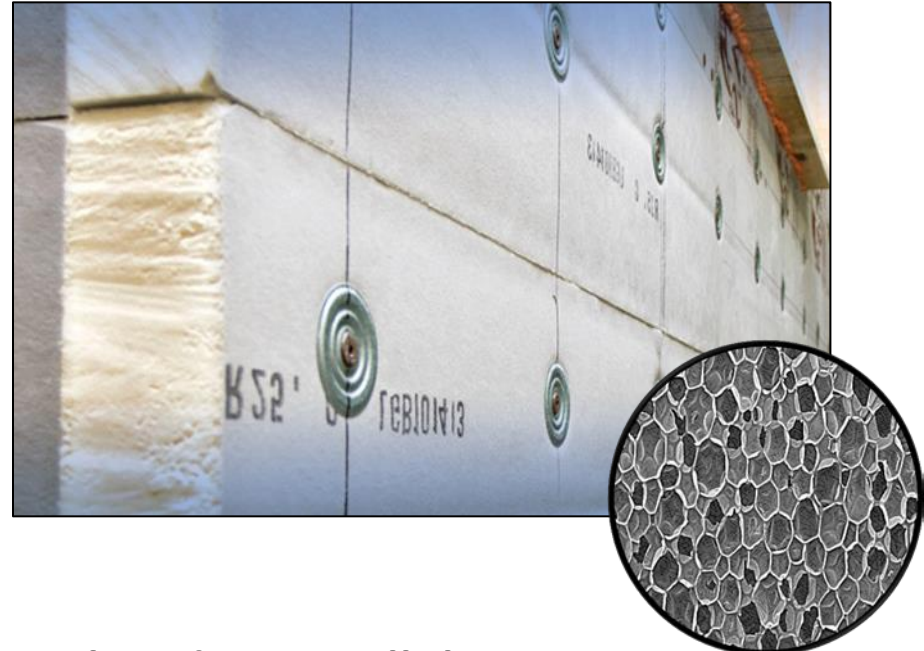
Convective Heat Loss



Open Pore Fibrous

Permeable

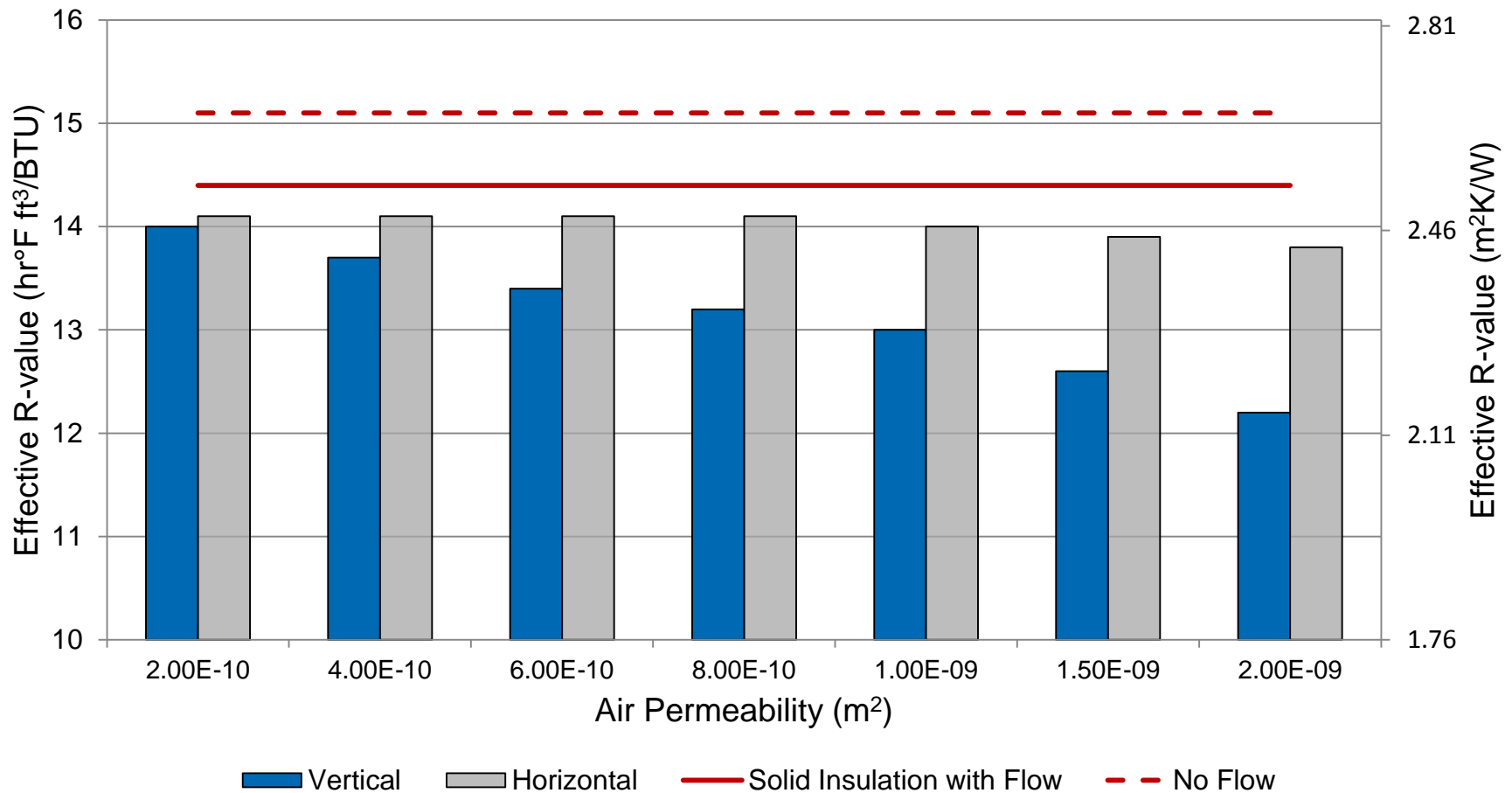
Permeability is density-dependent



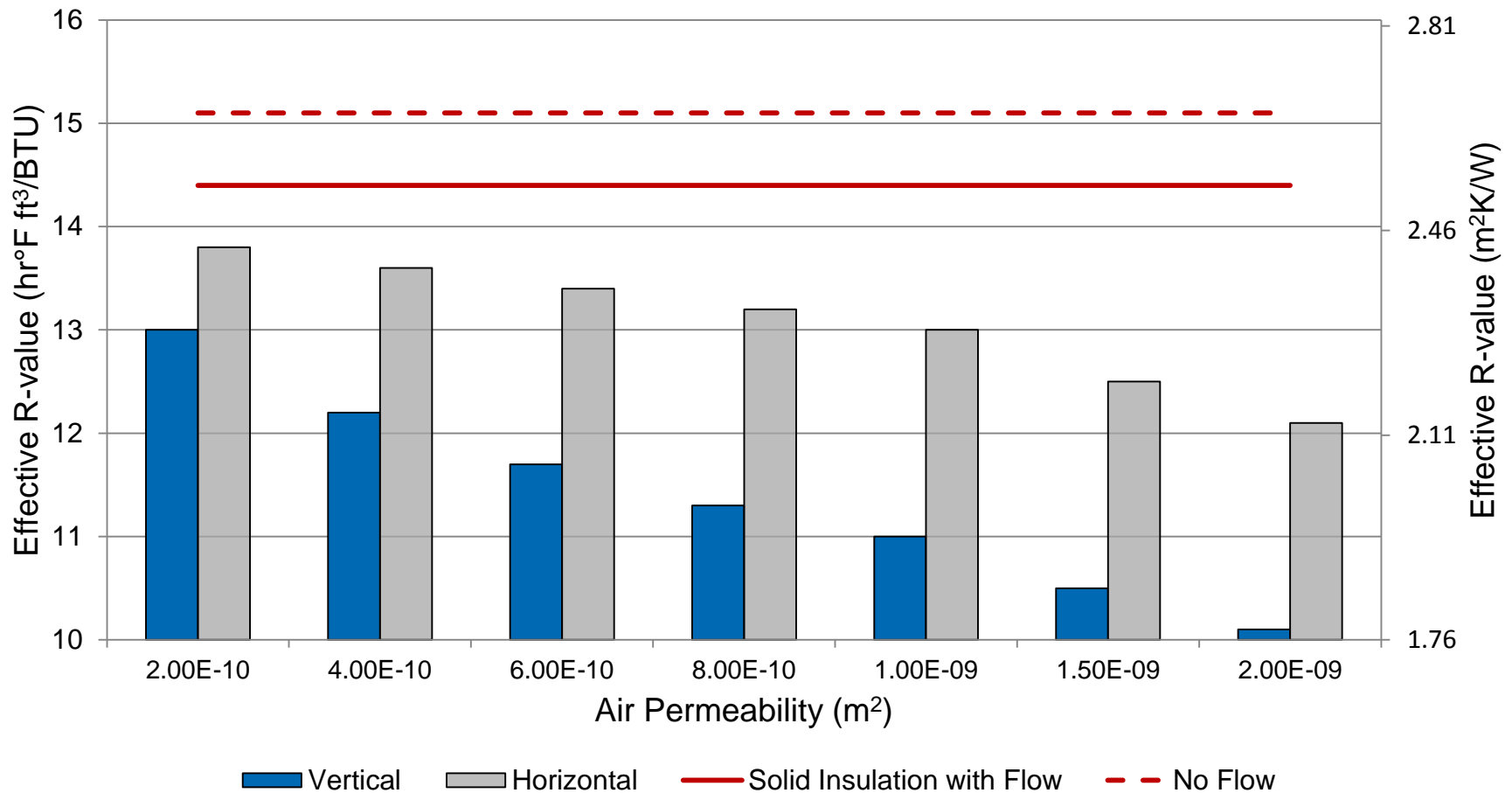
Closed Pore Cellular Foams

Impermeable at encountered pressures

Effective R-Values: 1 m/s

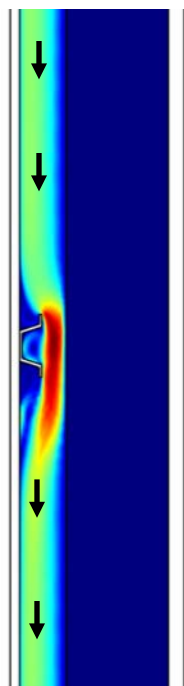


Effective R-Values: 2 m/s

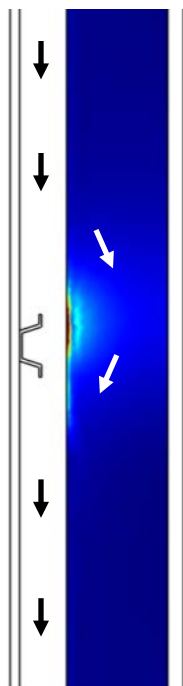


Inlet Velocity: 1 m/s

Velocity

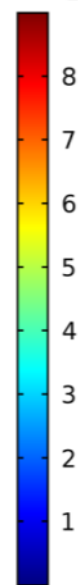


m/s

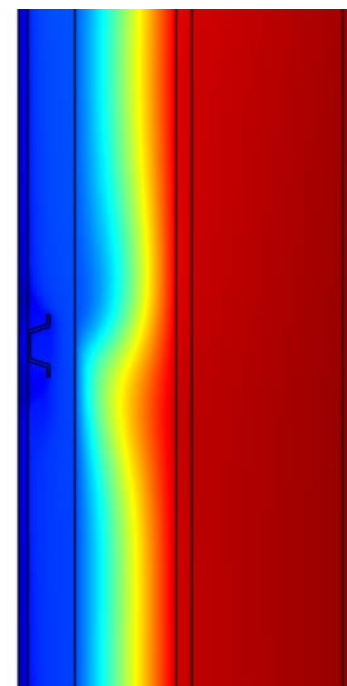


m/s

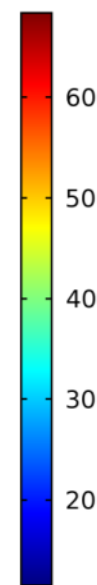
$\times 10^{-3}$



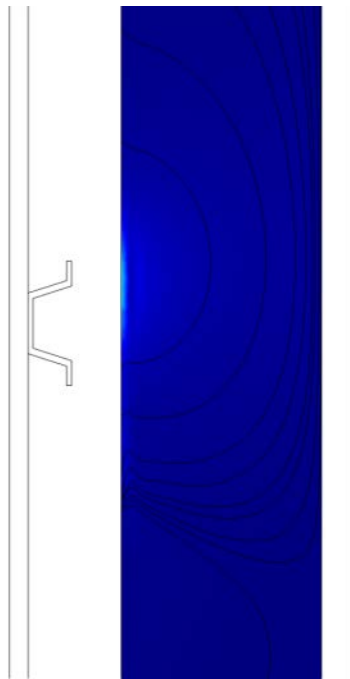
Temperature



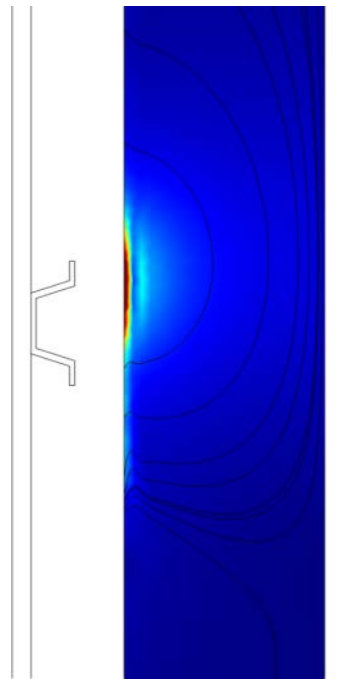
°F



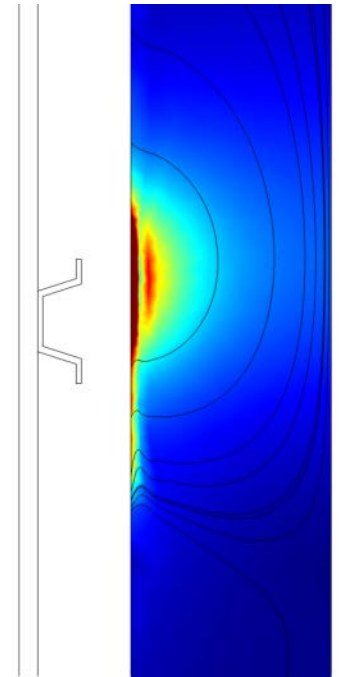
Inlet Velocity: 1 m/s



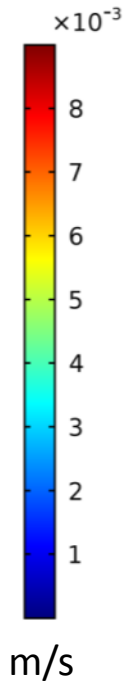
$2 \times 10^{-10} \text{ m}^2$
Density $\sim 160 \text{ kg/m}^3$
Density $\sim 10 \text{ lb/ft}^3$



$8 \times 10^{-10} \text{ m}^2$
Density $\sim 70 \text{ kg/m}^3$
Density $\sim 4.4 \text{ lb/ft}^3$

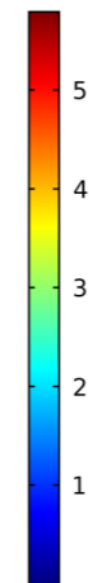
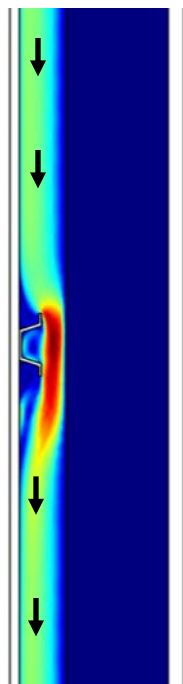


$2 \times 10^{-9} \text{ m}^2$
Density $\sim 30 \text{ kg/m}^3$
Density $\sim 1.9 \text{ lb/ft}^3$

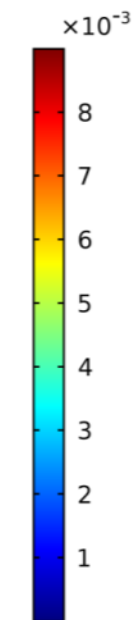
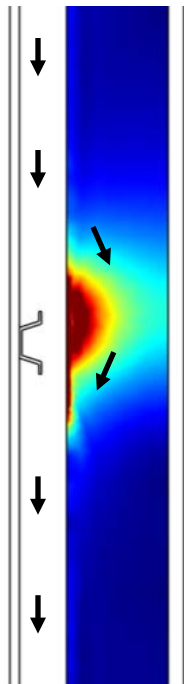


Inlet Velocity: 2 m/s

Velocity

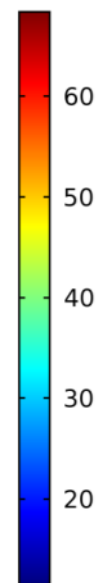
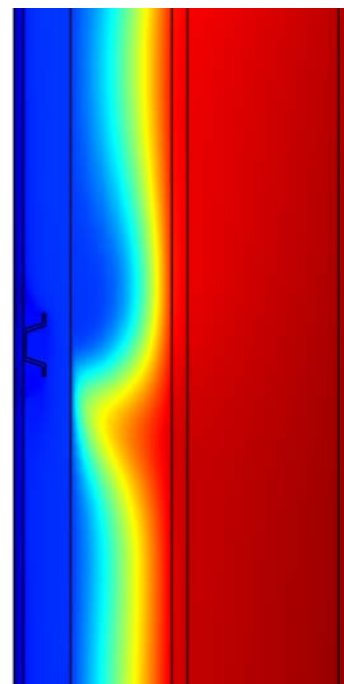


m/s



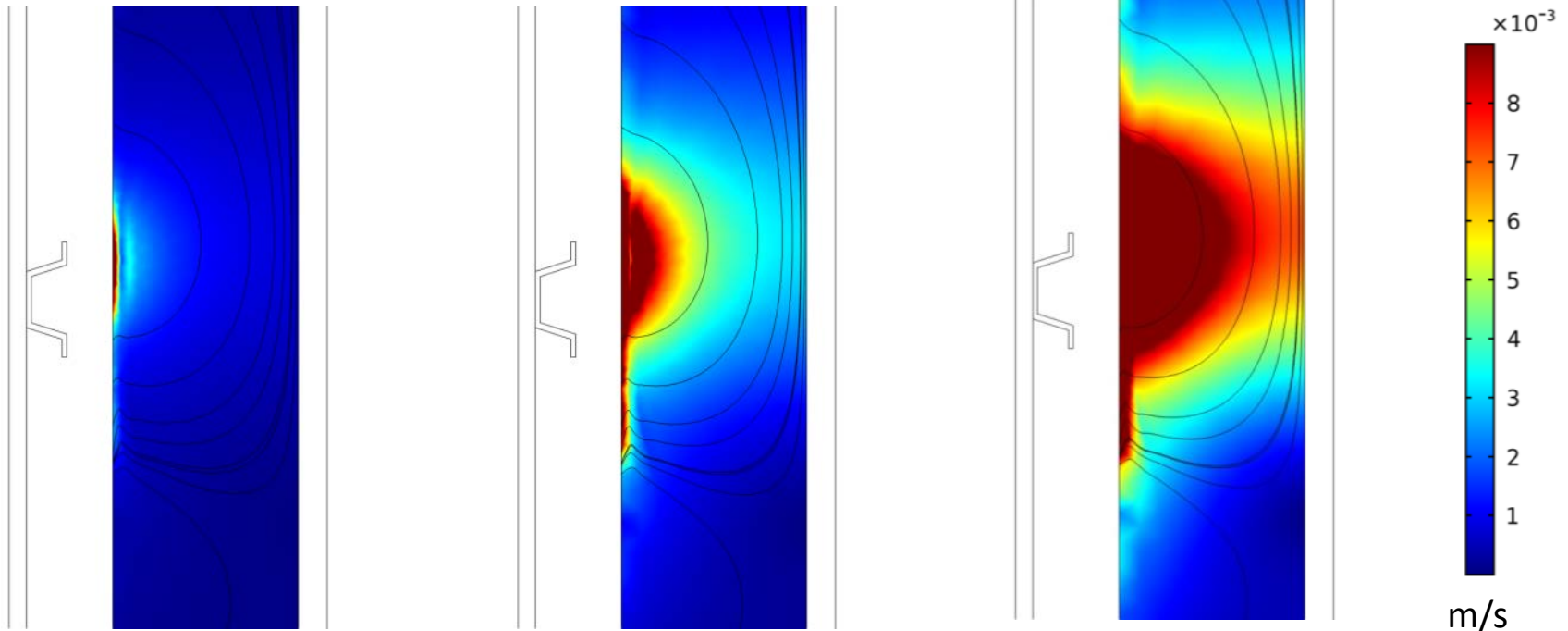
m/s

Temperature



°F

Inlet Velocity: 2 m/s

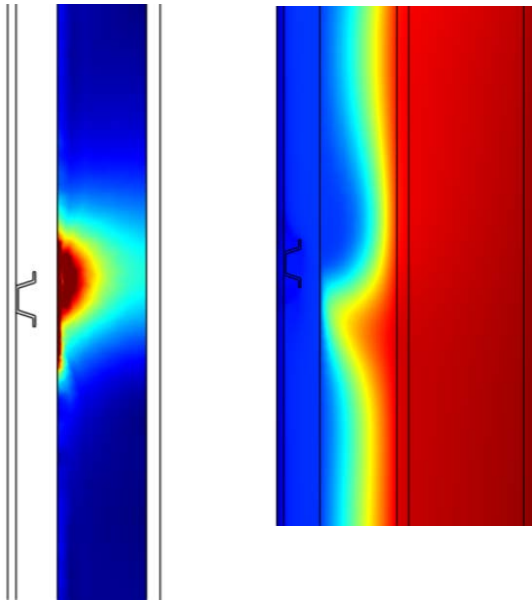


$2 \times 10^{-10} \text{ m}^2$
Density $\sim 160 \text{ kg/m}^3$
Density $\sim 10 \text{ lb/ft}^3$

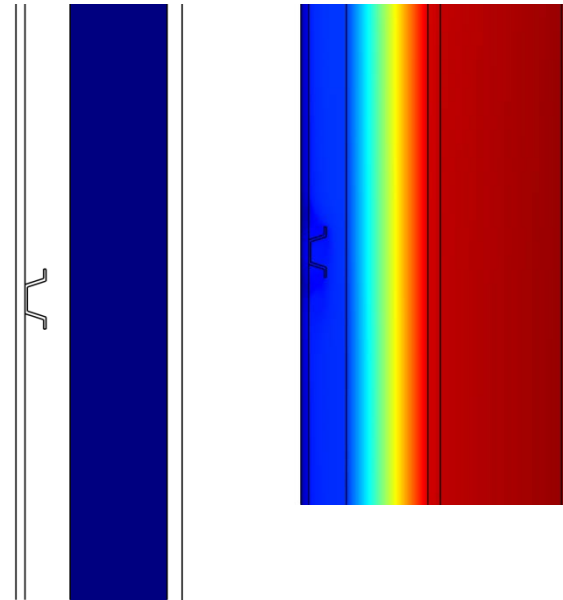
$8 \times 10^{-10} \text{ m}^2$
Density $\sim 70 \text{ kg/m}^3$
Density $\sim 4.4 \text{ lb/ft}^3$

$2 \times 10^{-9} \text{ m}^2$
Density $\sim 30 \text{ kg/m}^3$
Density $\sim 1.9 \text{ lb/ft}^3$

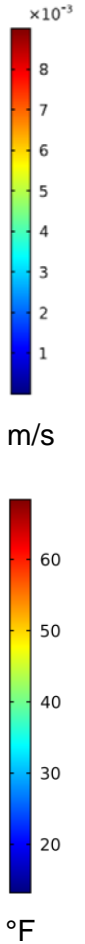
Inlet Velocity: 2 m/s



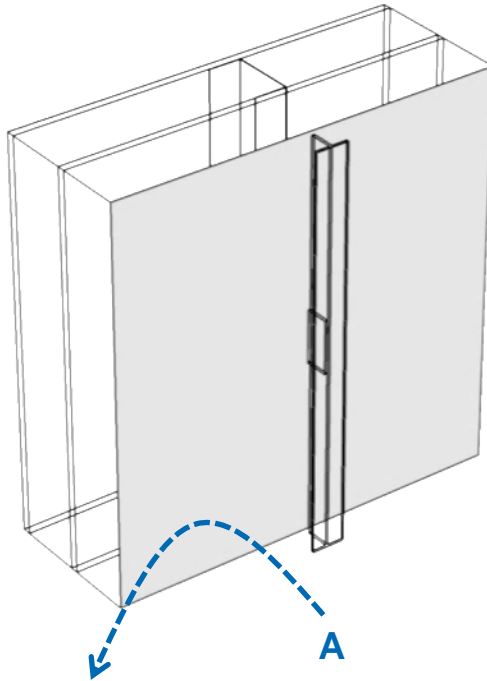
Open Pore / Fibrous Insulation
(2 m/s; Density $\sim 70 \text{ kg/m}^3$)



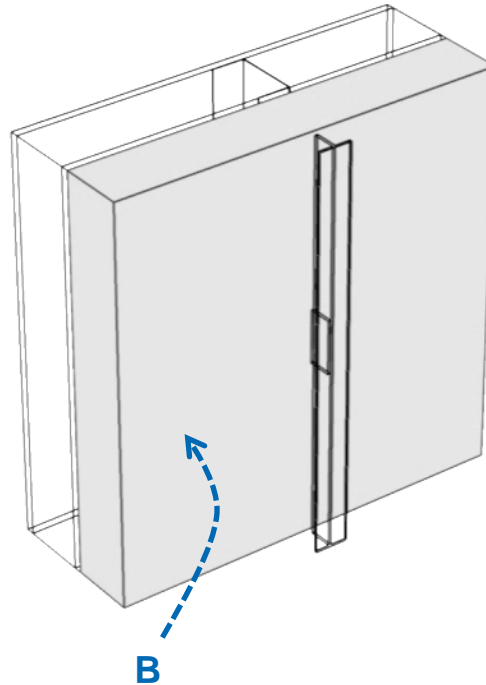
Closed Pore / Cellular Insulation
(2 m/s)



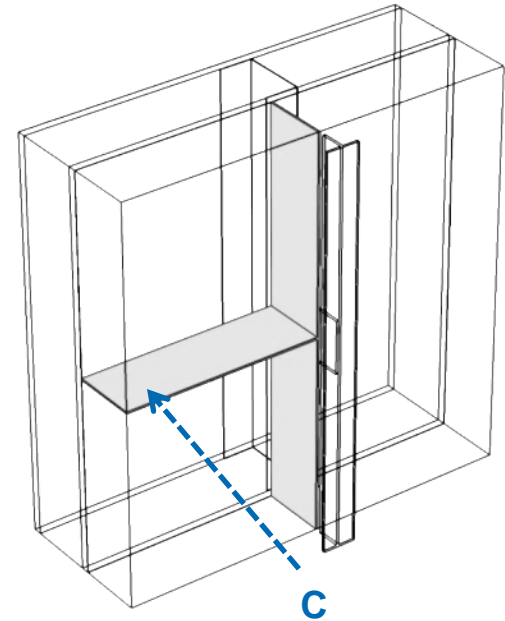
Convective Mechanisms



A) Surface Convection

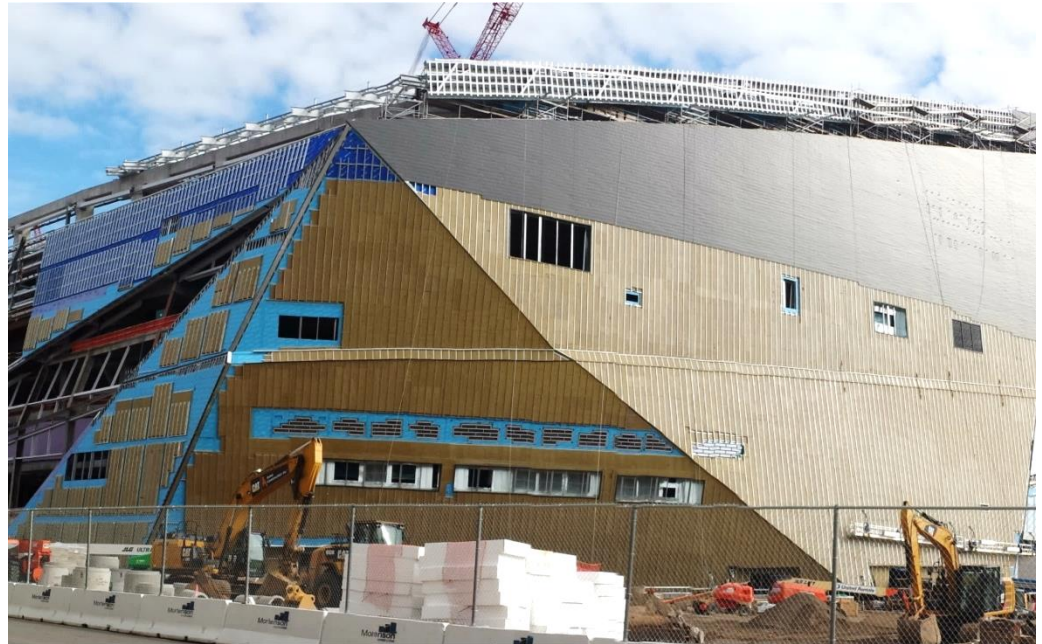


B) Open Pore Volume



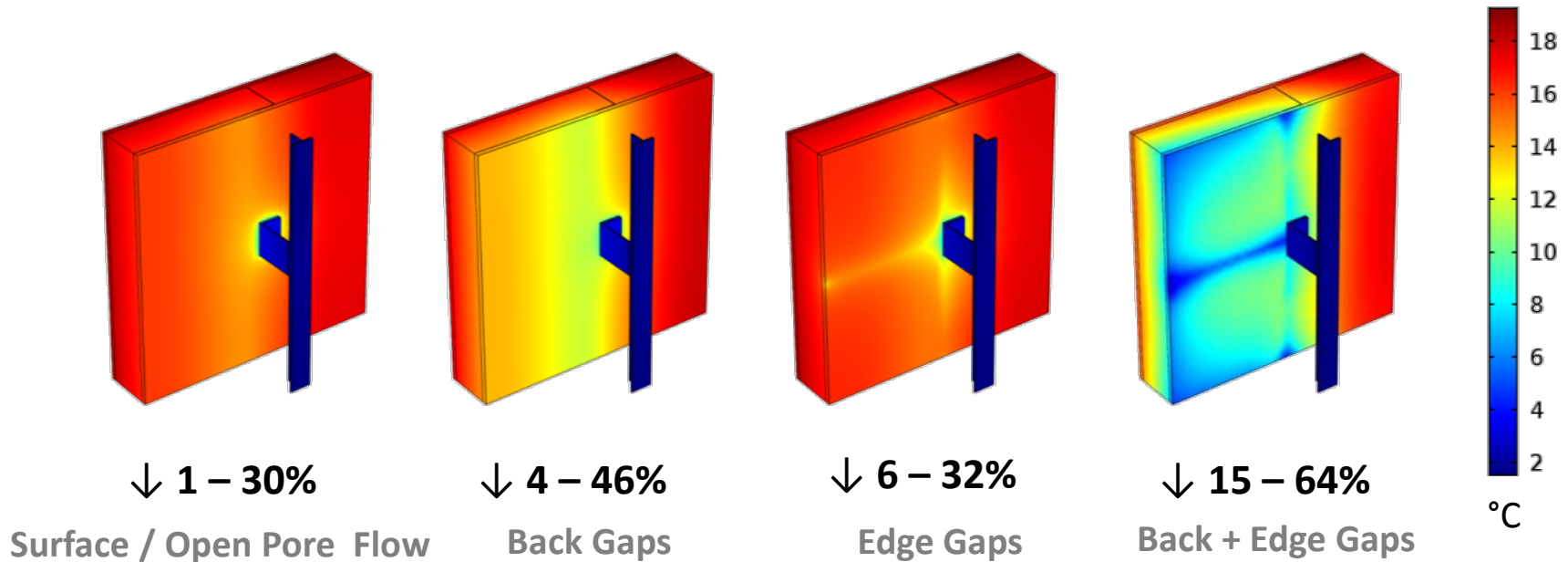
C) Gaps

Insulation Gaps



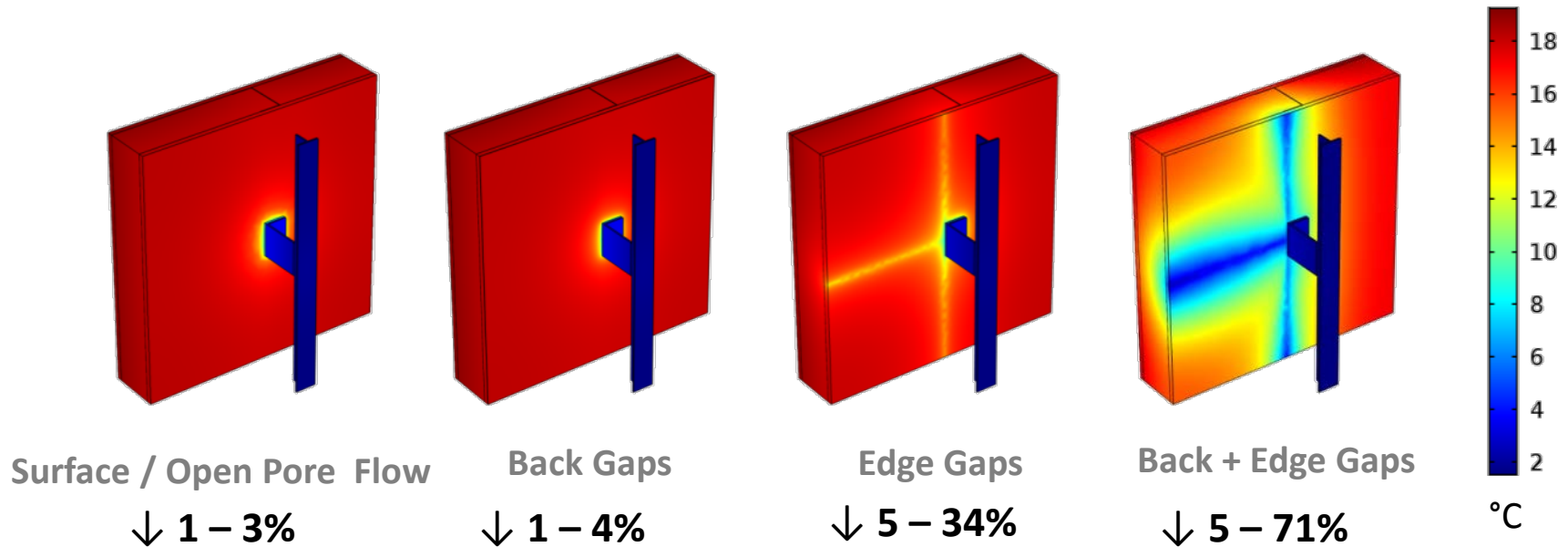
Effective R-Values

Open Pore Fibrous Insulation



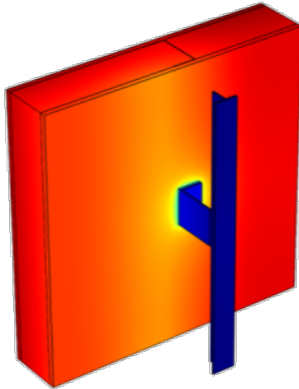
Effective R-Values

Closed Pore Cellular Insulation



Effective R-Values

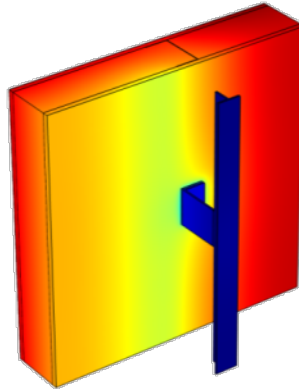
Fibrous Insulation



↓ 1 – 30%

Surface / Open Pore Flow

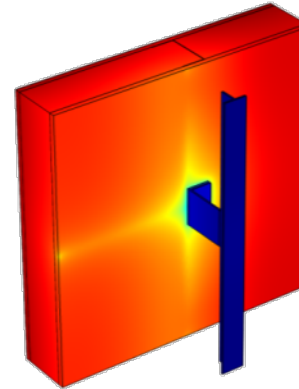
↓ 1 – 3%



↓ 4 – 46%

Back Gaps

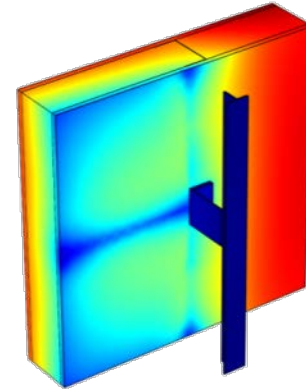
↓ 1 – 4%



↓ 6 – 32%

Edge Gaps

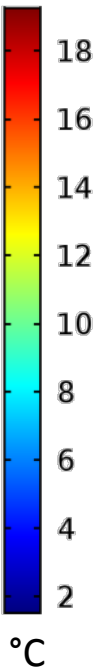
↓ 5 – 34%



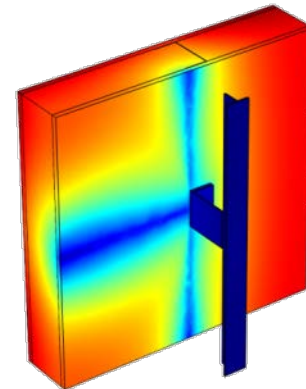
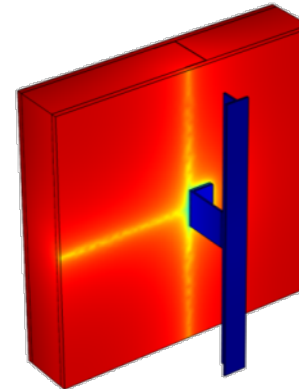
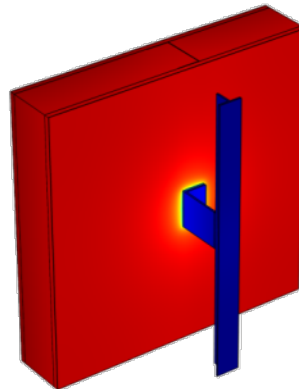
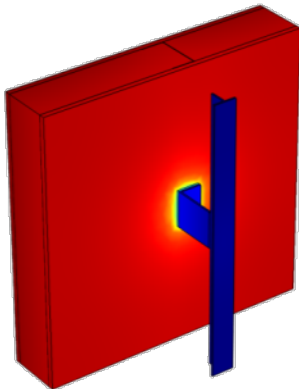
↓ 15 – 64%

Back + Edge Gaps

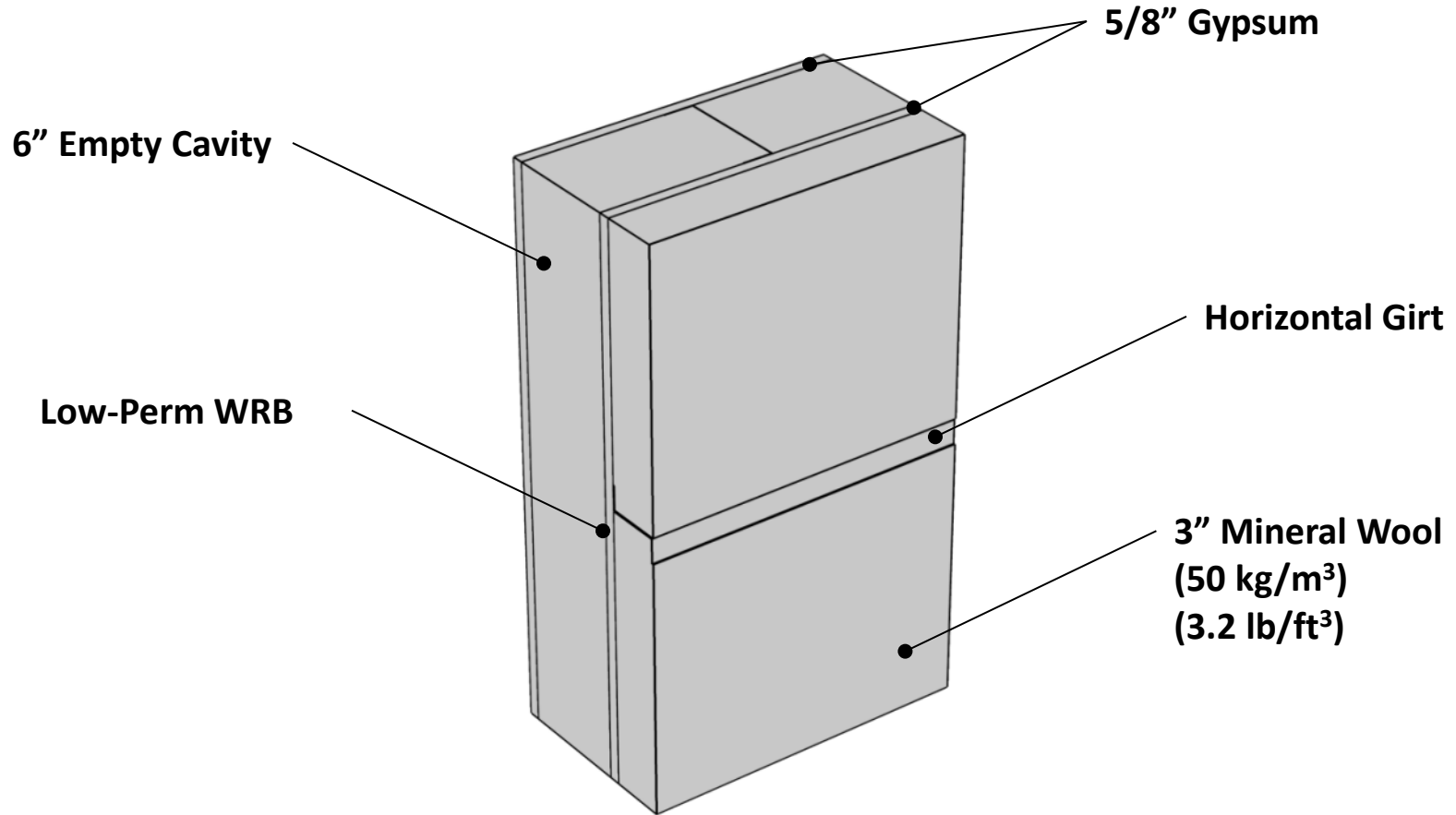
↓ 5 – 71%



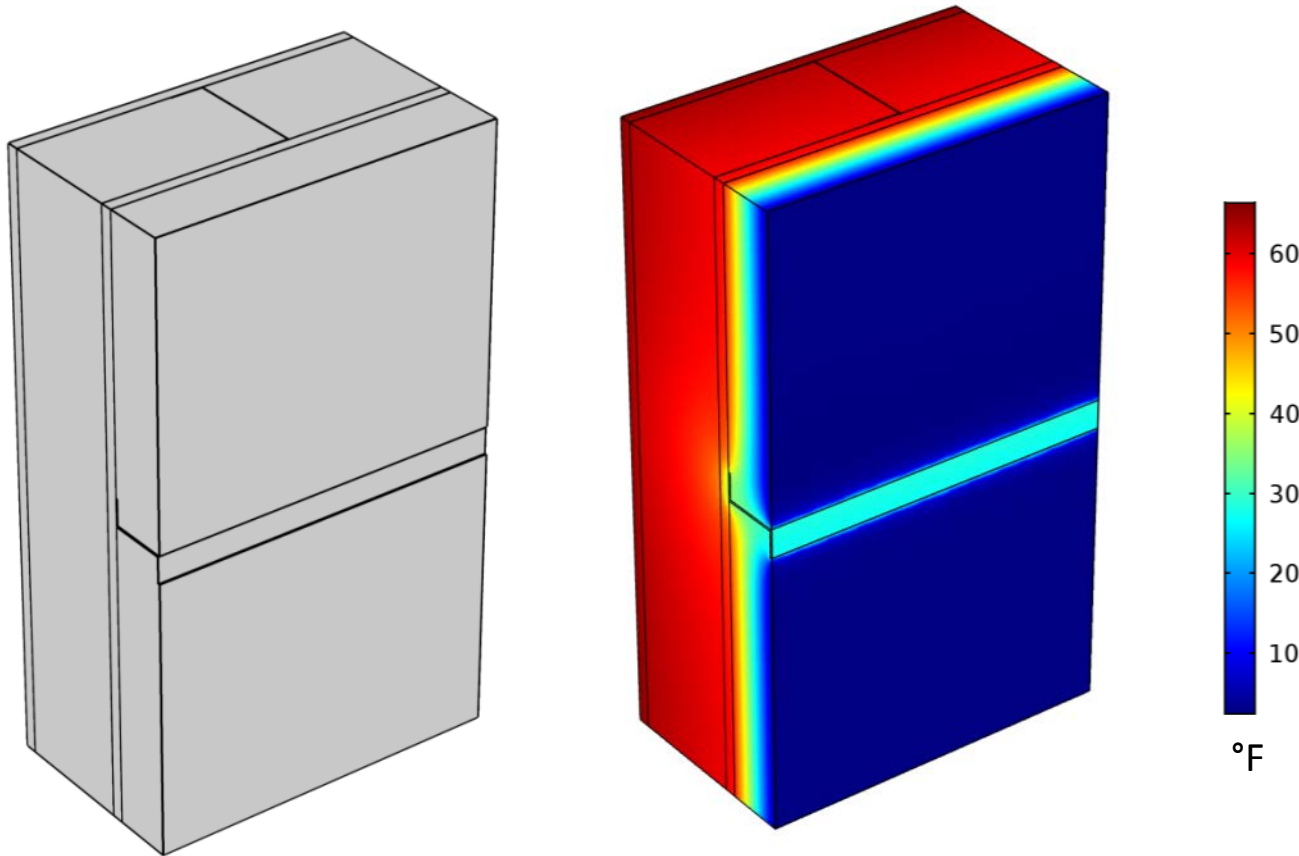
Cellular Insulation



Thermal Bridging & Condensation



Thermal Bridging & Condensation



U-Factor

0.064

(R = 15.6)

Nominal R

15.6

Effective R

7.6 to 11.7

Reduction

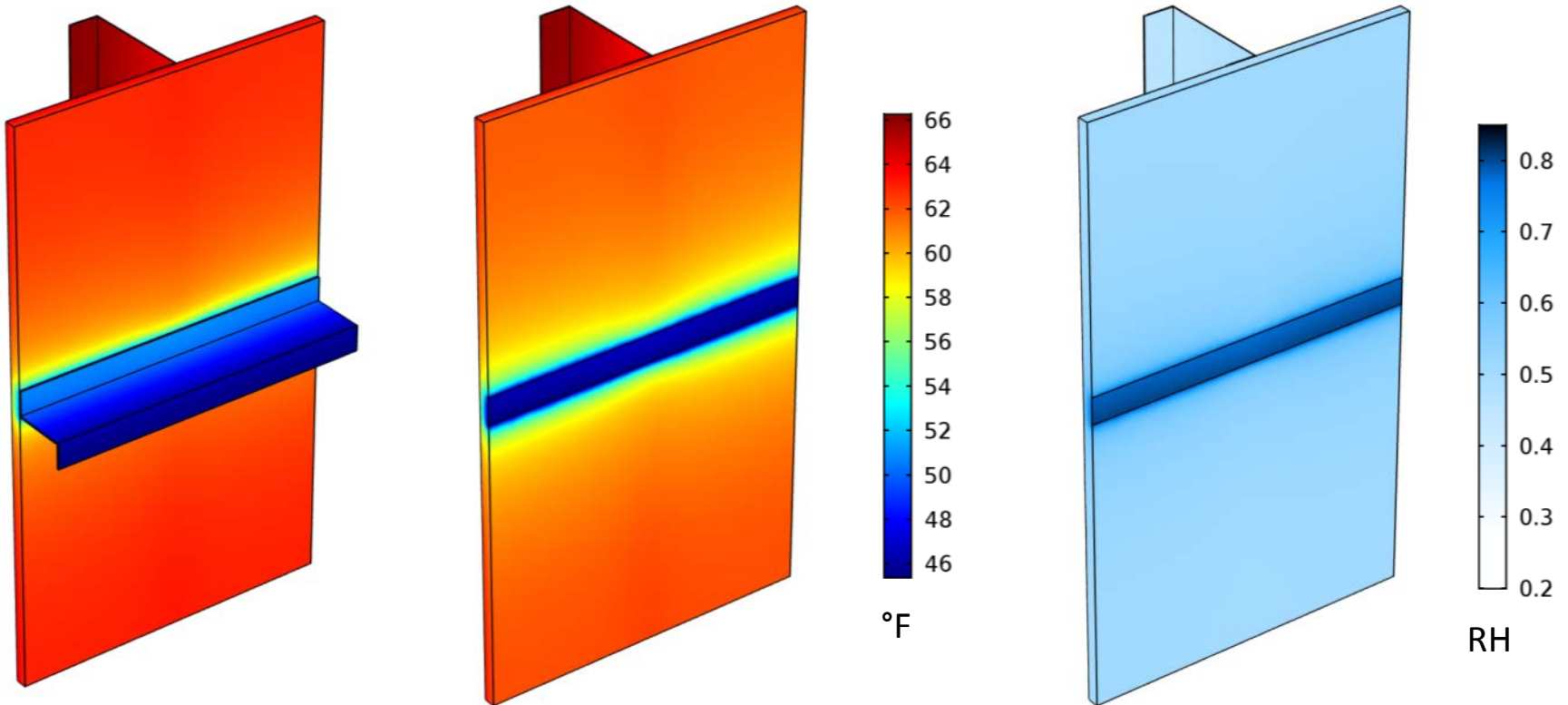
24.1 - 51.9%

(excludes fasteners)

Thermal Bridging & Condensation

Interior: 40% RH; 70°F

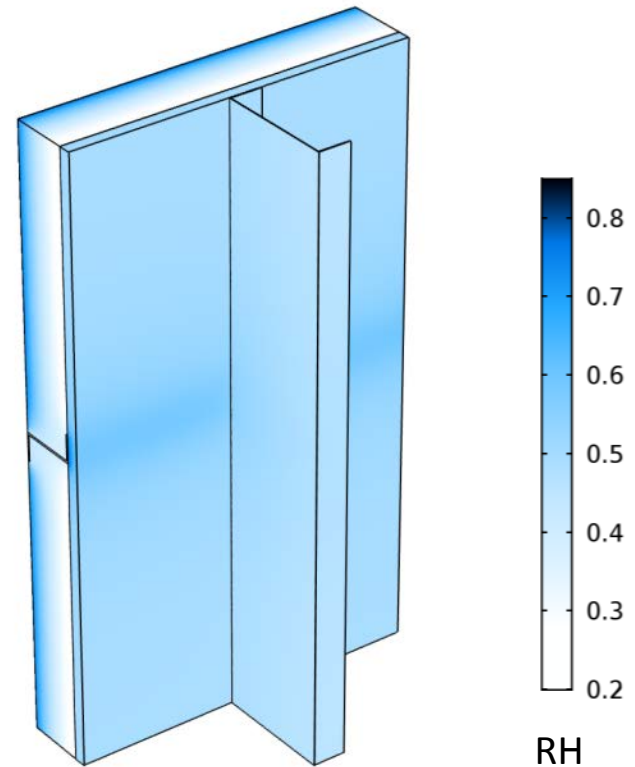
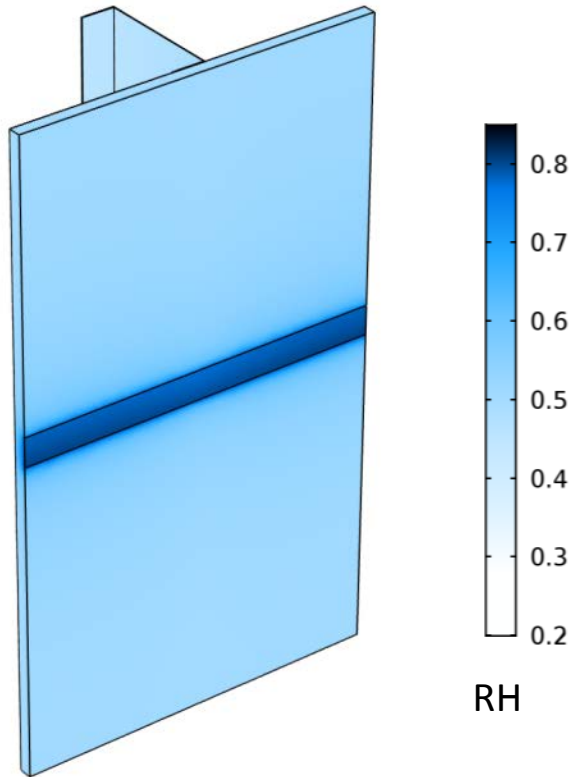
Exterior: 80% RH; 0°F or 30°F



Thermal Bridging & Condensation

Interior: 40% RH; 70°F

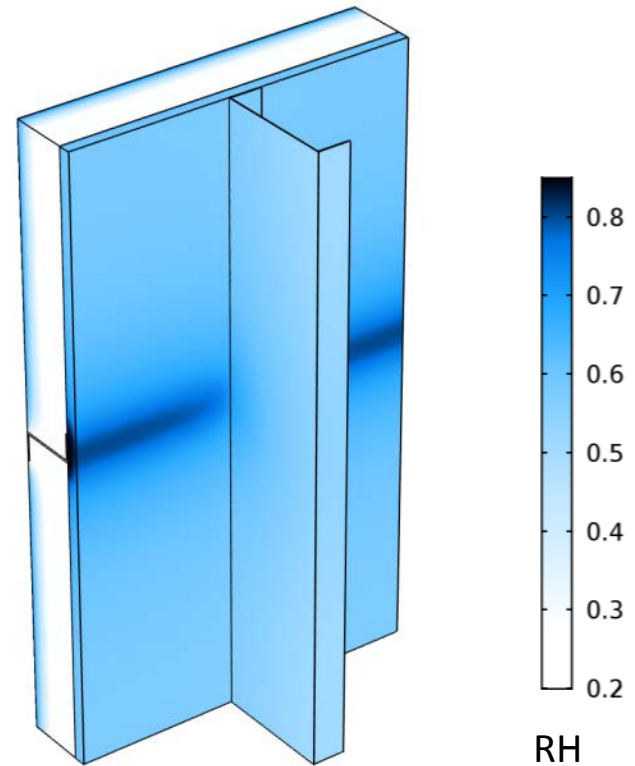
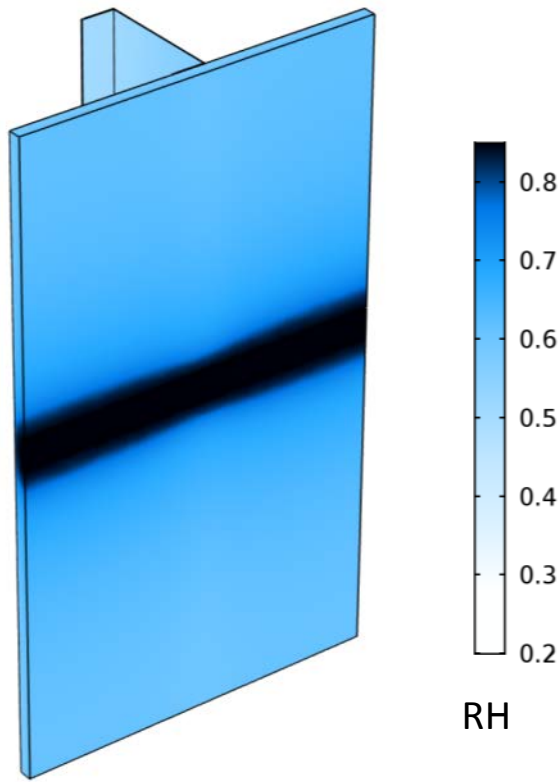
Exterior: 80% RH; 30°F



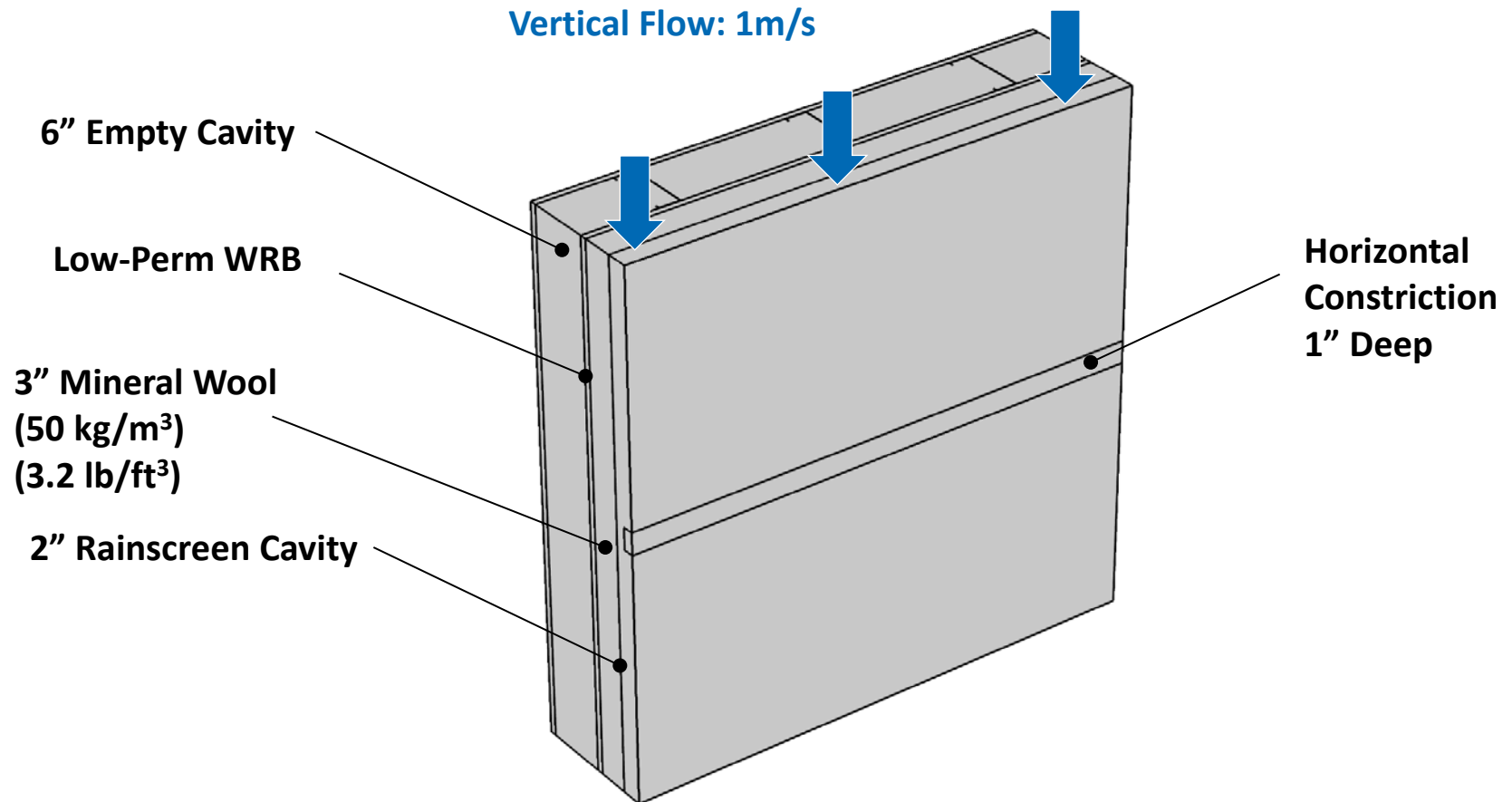
Thermal Bridging & Condensation

Interior: 40% RH; 70°F

Exterior: 80% RH; 0°F



Convective Cooling & Condensation

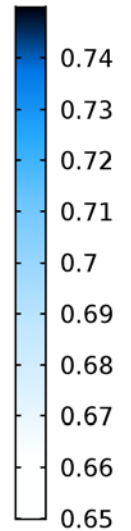
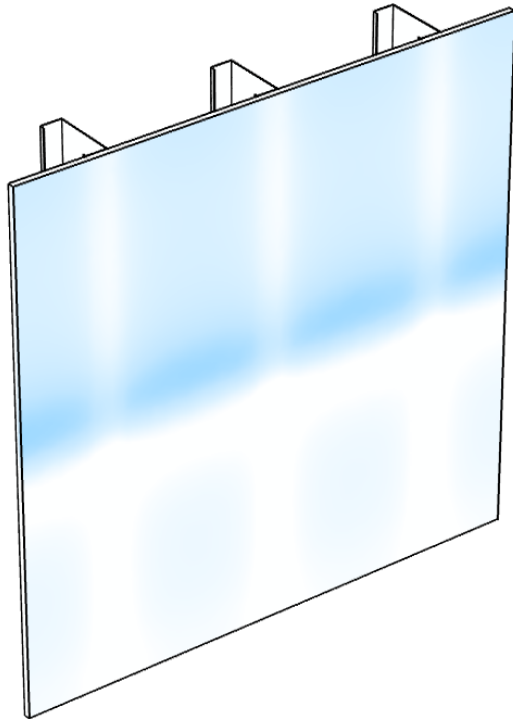


Convective Cooling & Condensation

Interior: 40% RH; 70°F

Exterior: 80% RH; 0°F

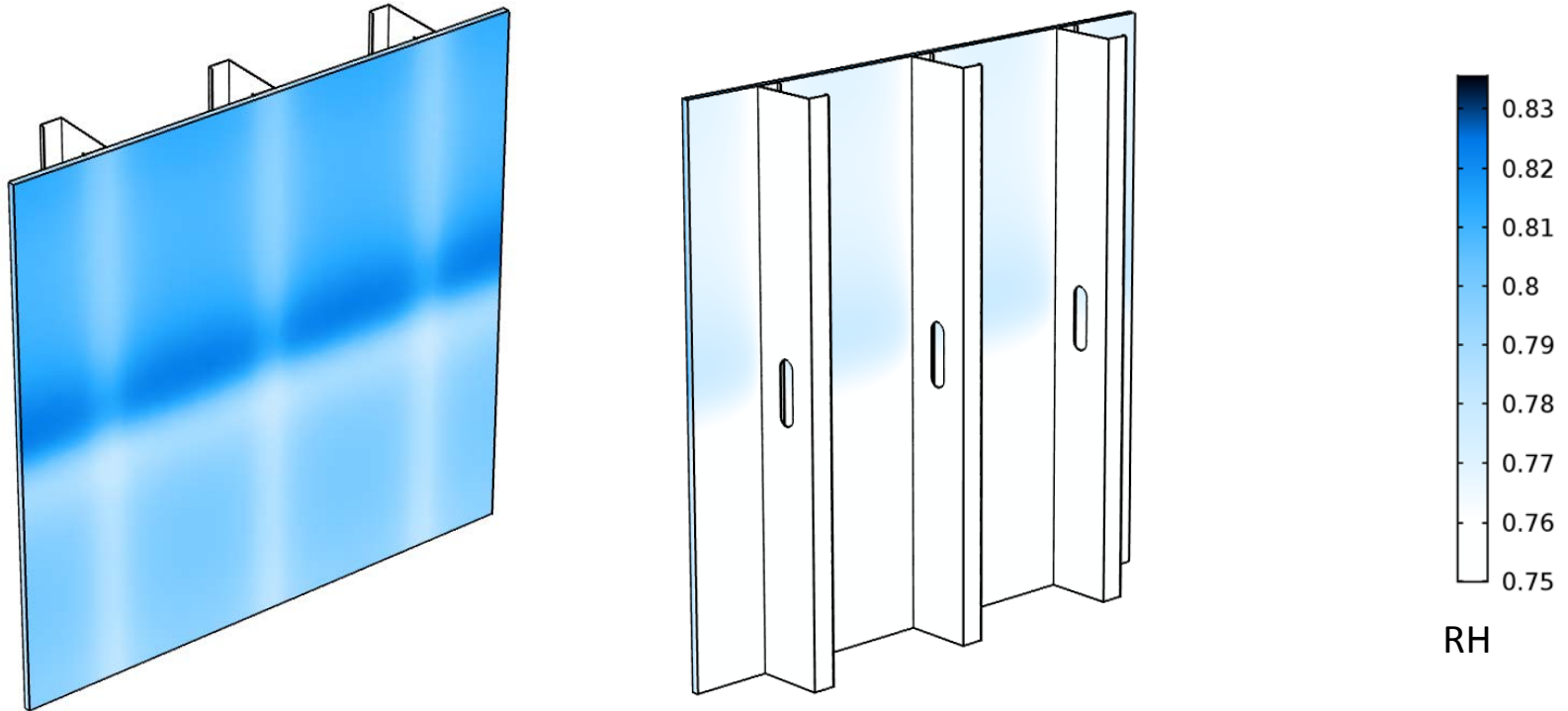
Flow = 1 m/s



RH

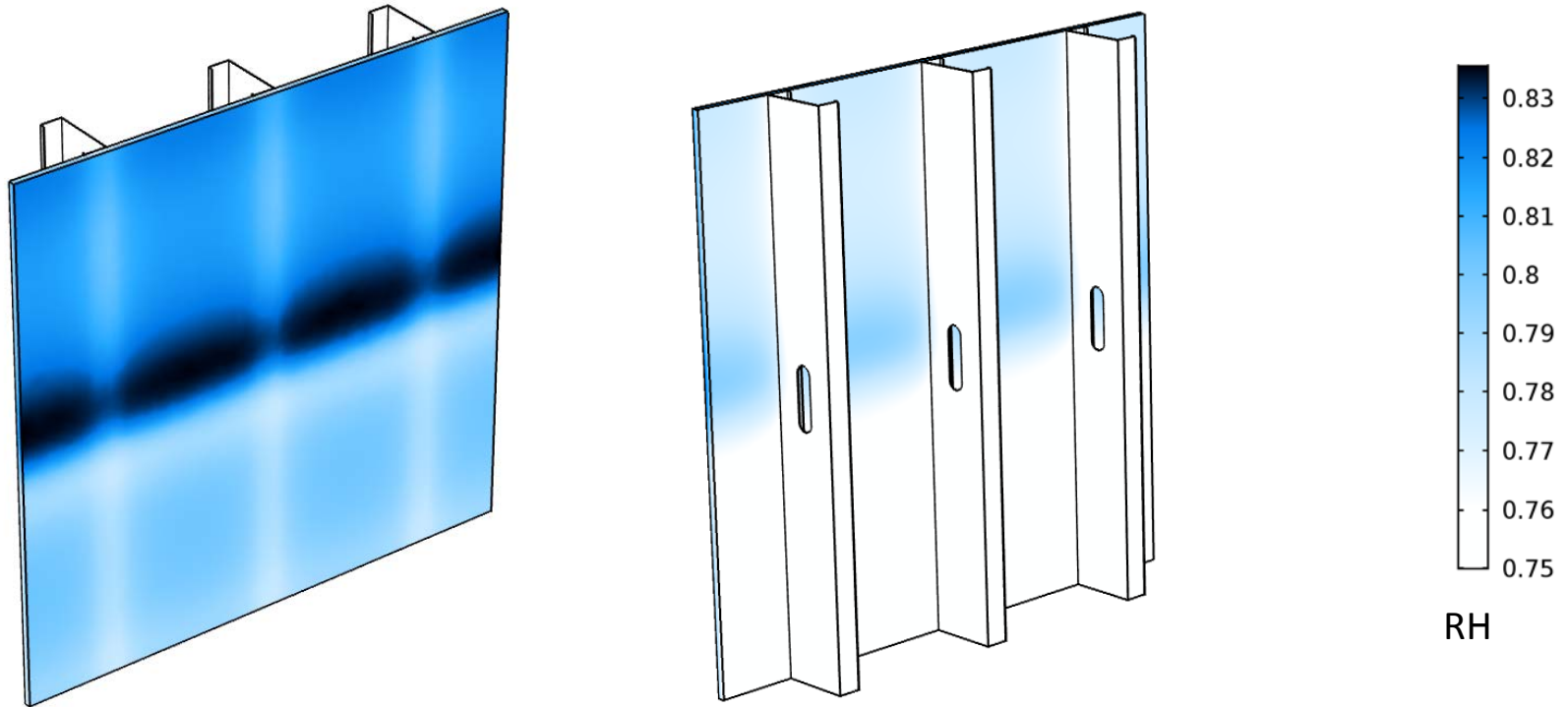
Convective Cooling & Condensation

1) Increase Flow or Indoor RH; or 2) Decrease Temperature or Insulation Density



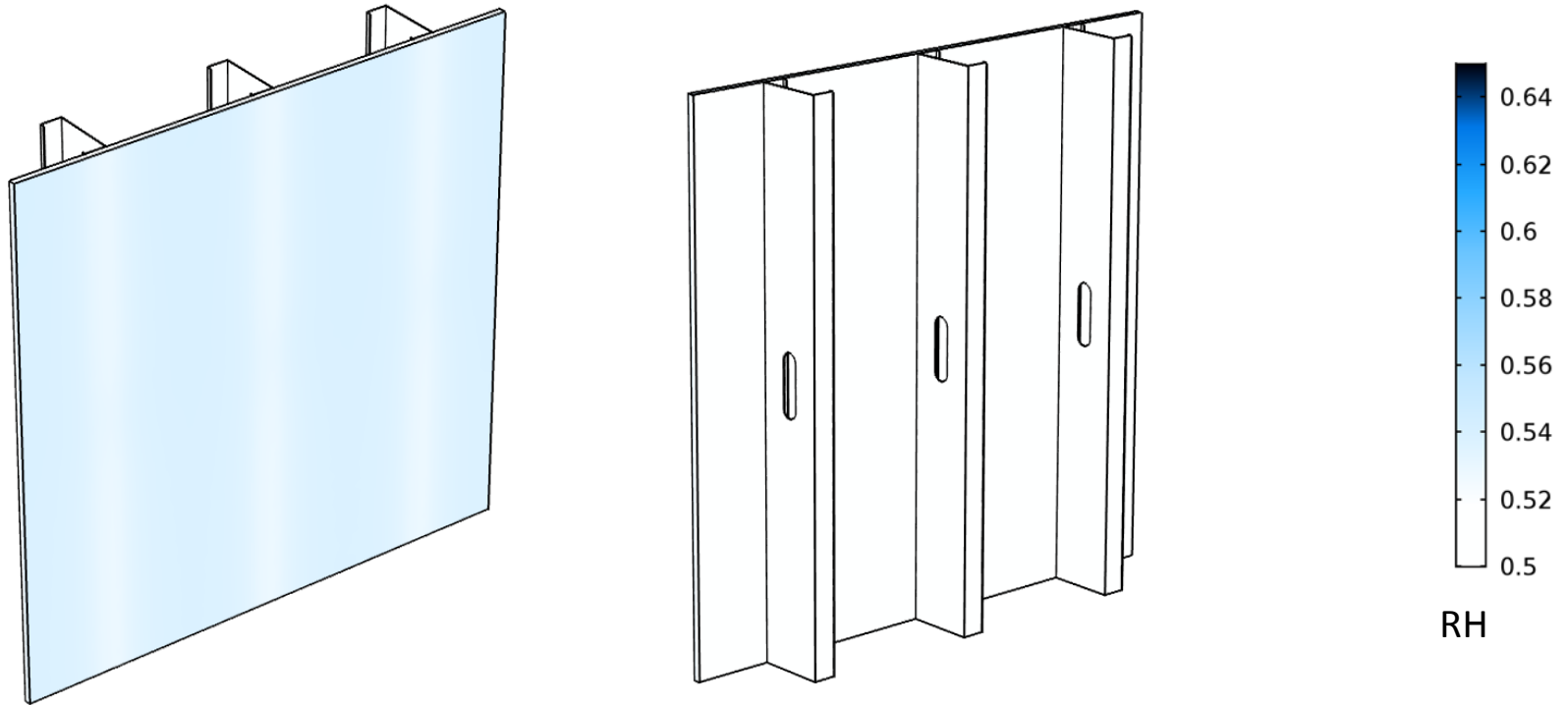
Convective Cooling & Condensation

1) Further Increase Flow or Indoor RH; or 2) Further Decrease Temp. or Density

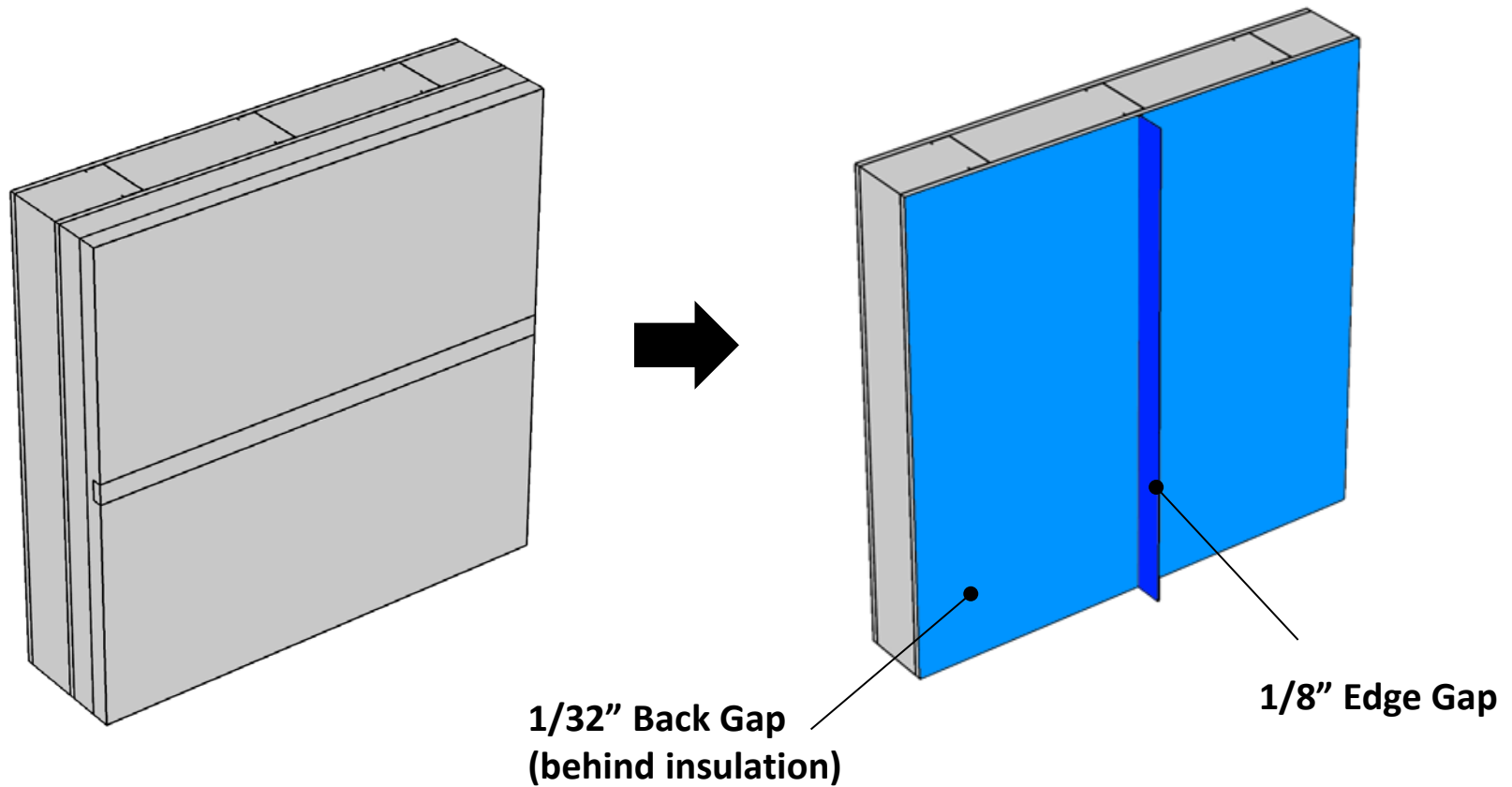


Convective Cooling & Condensation

Same Conditions with Solid Insulation



Gaps & Convective Cooling

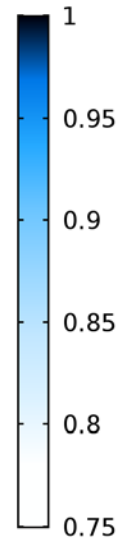
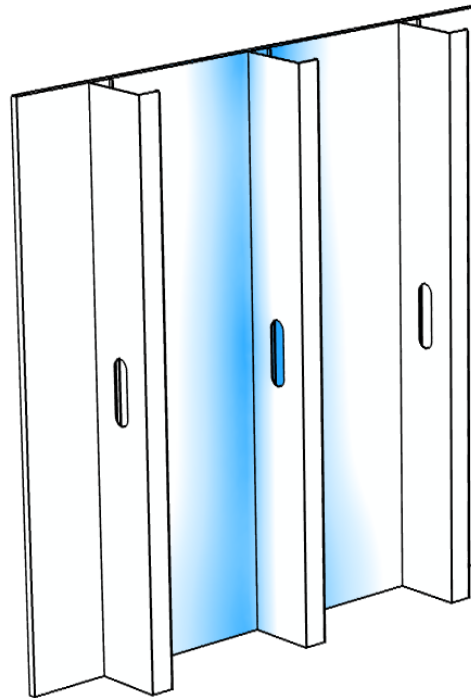
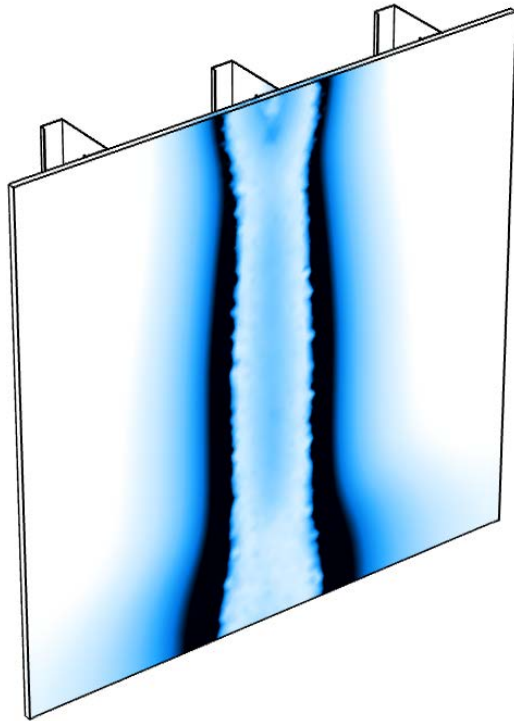


Gaps & Convective Cooling

Interior: 40% RH; 70°F

Exterior: 80% RH; 30°F

Flow = 1 m/s



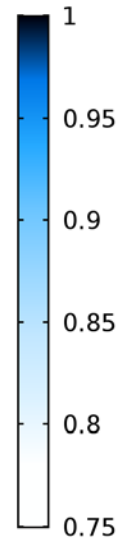
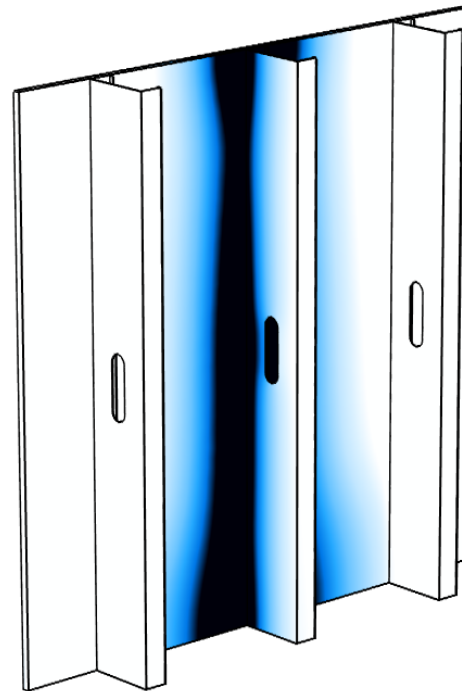
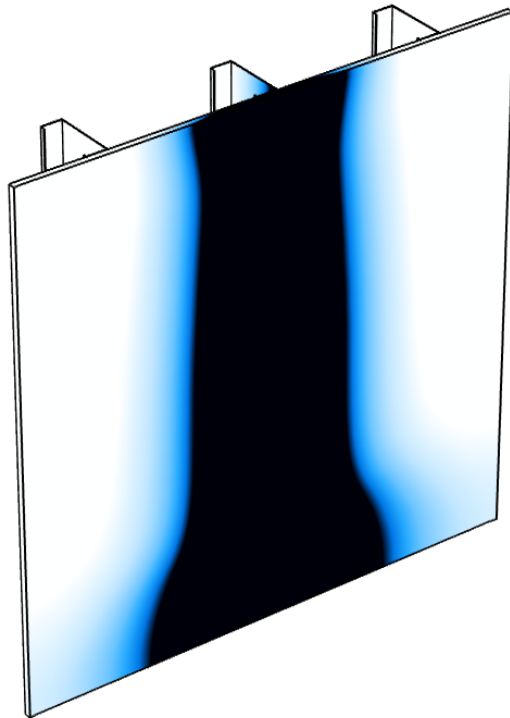
RH

Gaps & Convective Cooling

Interior: 40% RH; 70°F

Exterior: 80% RH; 0°F

Flow = 1 m/s



RH

Addressing the Rainscreen Paradox

01

Smart Rainscreen Geometries

Avoid airflow diversion against insulation surfaces.

02

Ventilation Openings

Understand inlet areas & prevent airflow against insulation edges.

03

Product Selection

Use higher density fibrous insulation or cellular insulation.

04

Gaps

Treat edge gaps. Adhere / securely fasten to prevent back gaps.

Addressing the Rainscreen Paradox

05

Ventilation Rates

Avoid over-ventilation. Reduce air change rates where possible.

06

Prescriptive Approaches

Avoid prescriptive minimalistic U-factors. Avoid hybrid approaches.

07

Low-Perm WRB

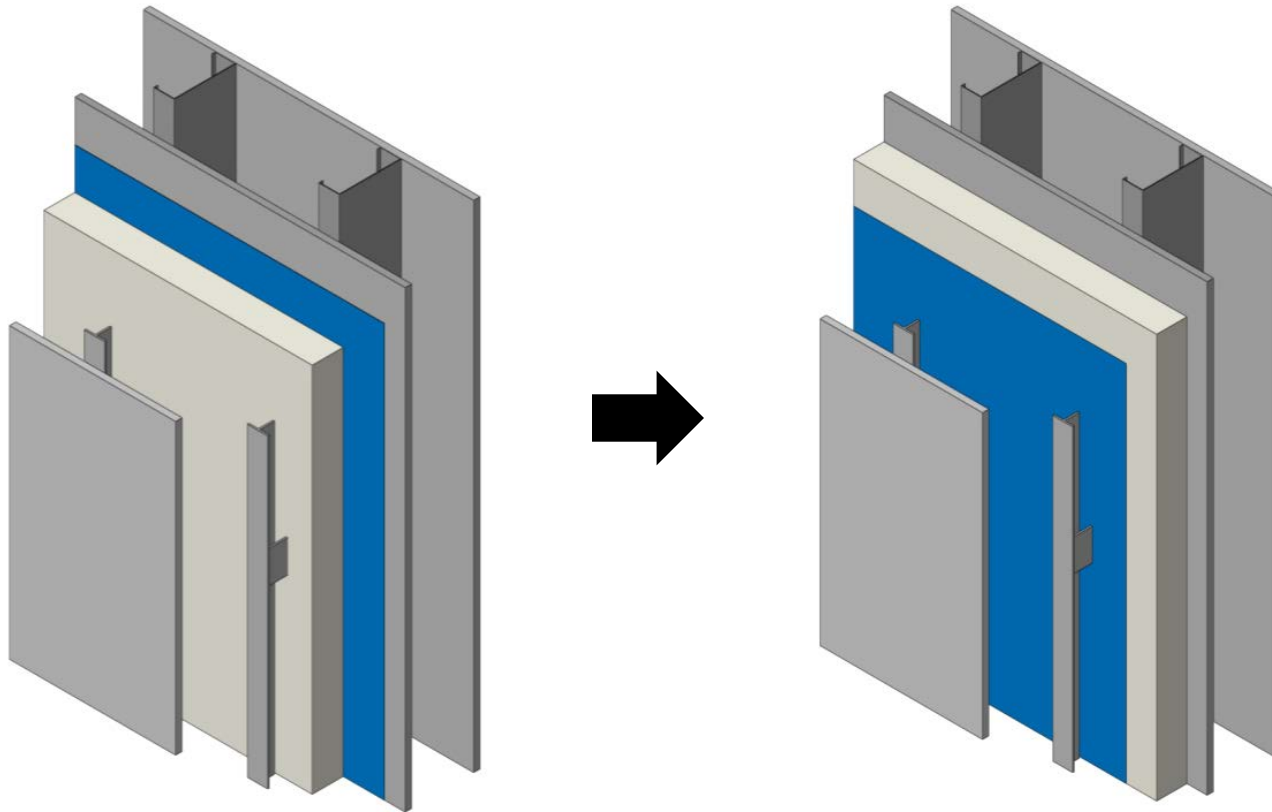
Avoid low-perm Air / WRBs.

08

WRB Placement

Move AB / WRB to exterior face of insulation.

Addressing the Rainscreen Paradox



Thank You!

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