Insulated Rainscreens: The Need to Rethink Conventional Design

November 2, 2017

Schöck
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HUNTER
CONTINUOUS INSULATION

HOHMANN & BARNARD, INC.

TECHNOFORM GROUP

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Building Enclosure Council

Today's Presentation

Insulated Rainscreens: The Need to Rethink Conventional Design

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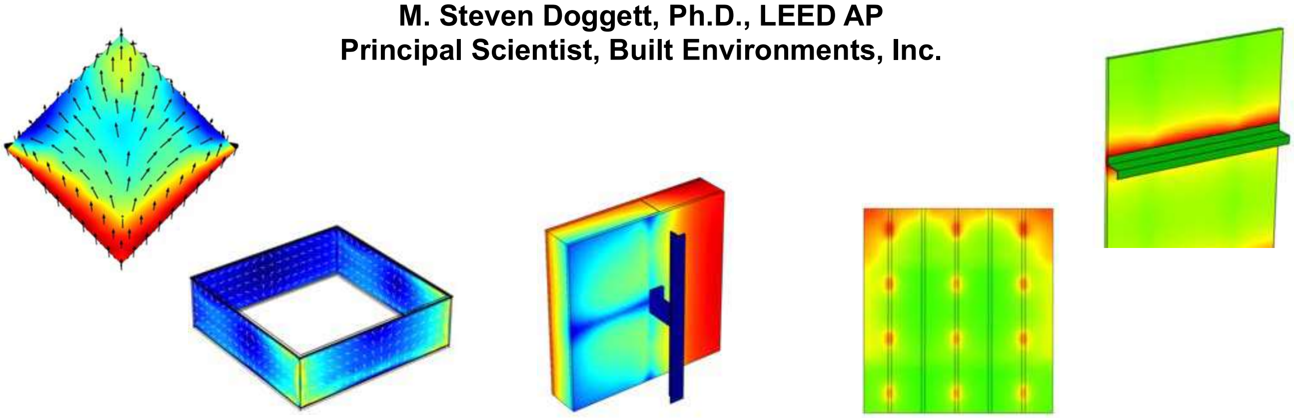
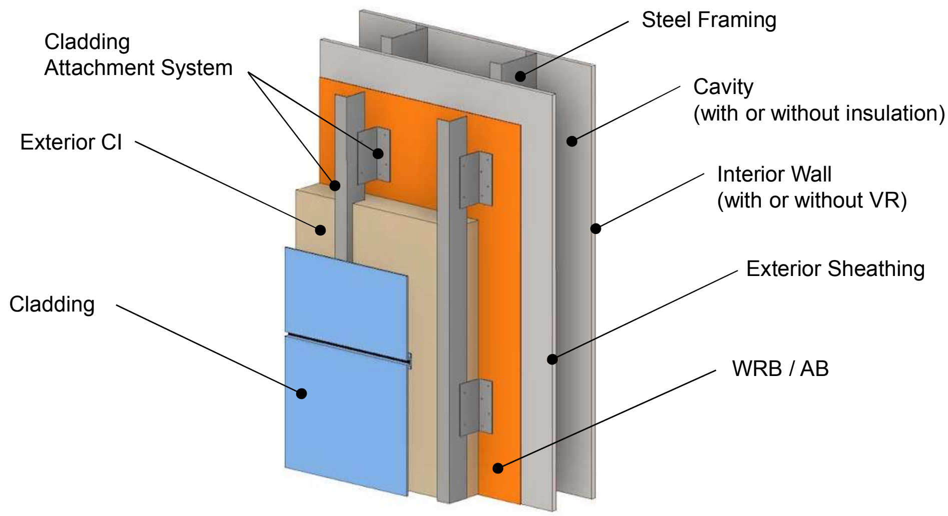
Principal Scientist, Built Environments, Inc.



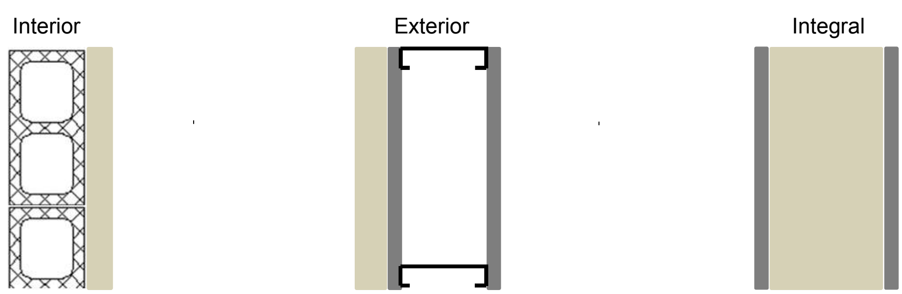
Today's Presentation: Challenging Conventional Design



Today's Presentation: Exterior CI

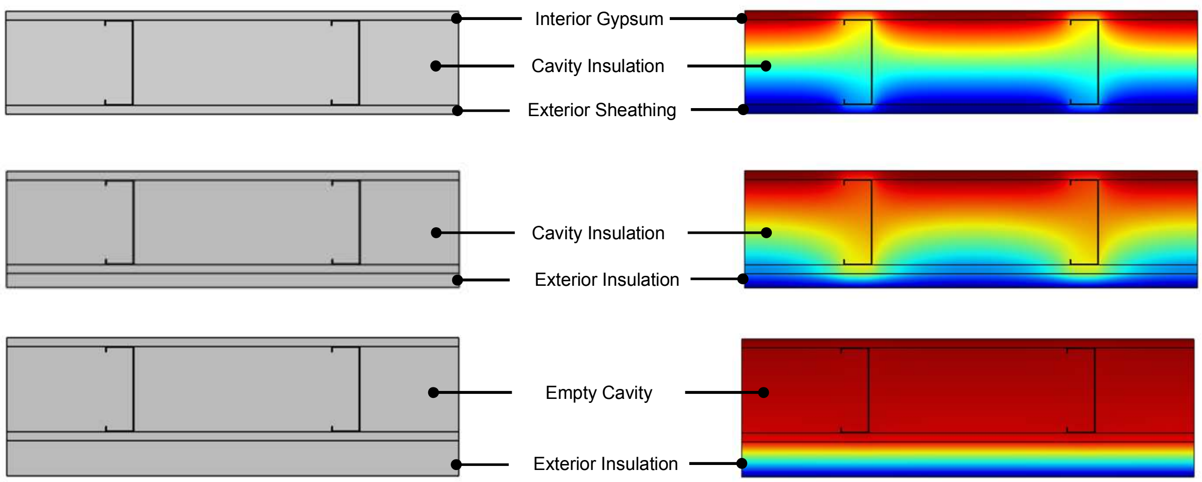
Continuous Insulation Defined – ASHRAE 90.1 2010

"Insulation that is continuous across all structural members without thermal bridges other than fasteners and service openings. It is installed on the interior, exterior or is integral to any opaque surface of the building envelope."



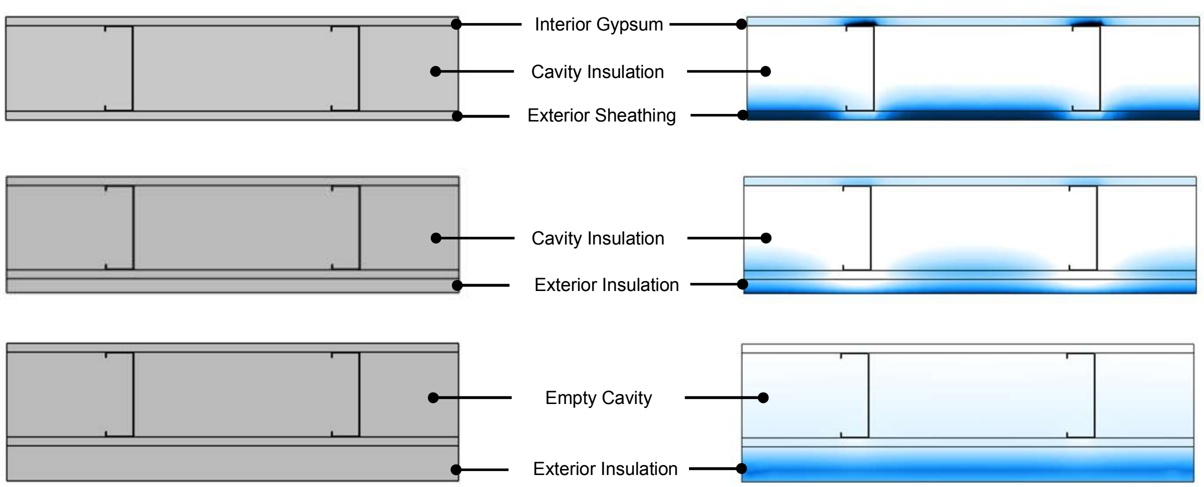
Todays Presentation: Continuous Insulation

Int. 20°C | Ext. -5°C

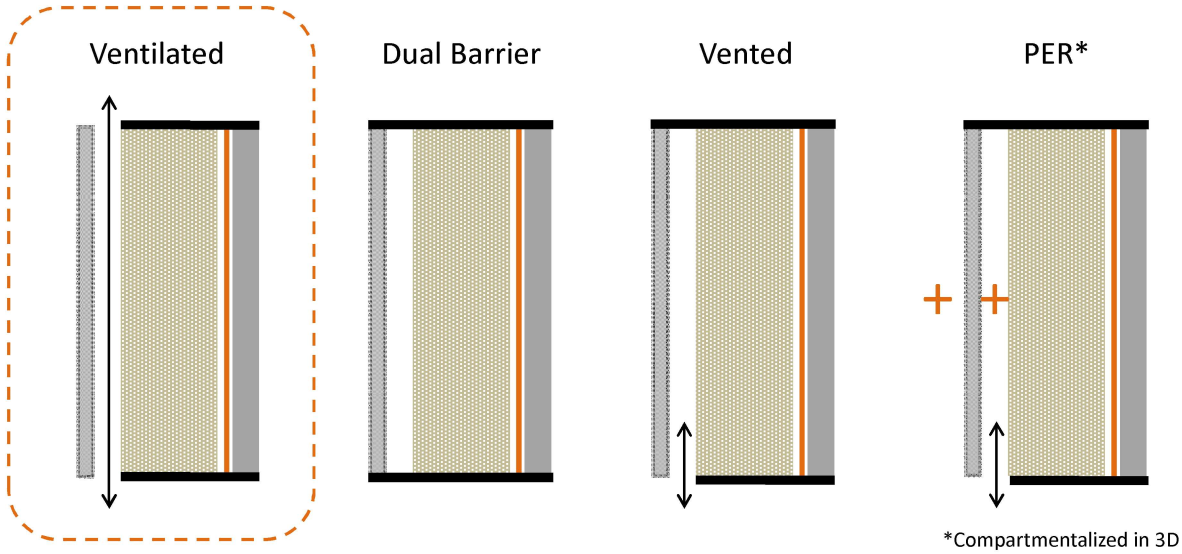


Todays Presentation: Continuous Insulation

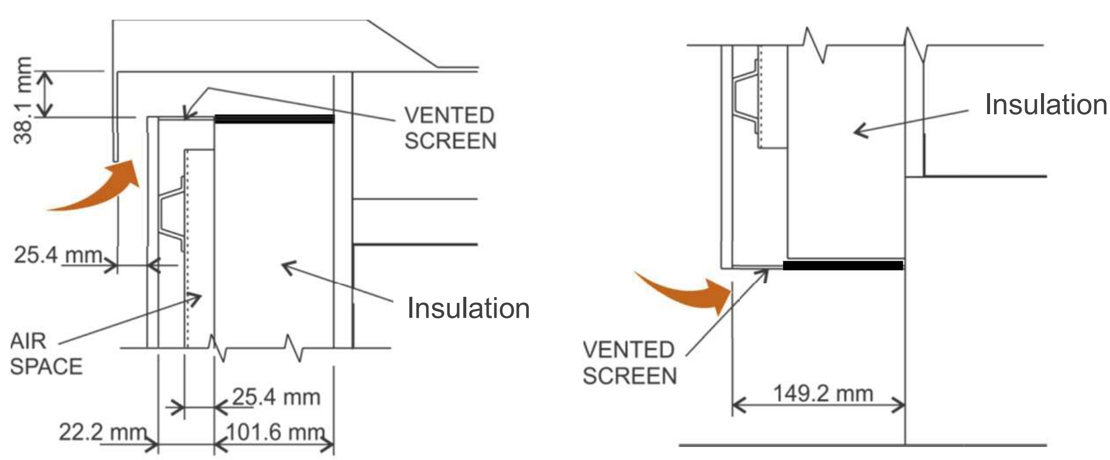
Int. 20°C, 50% RH | Ext. -5°C, 80% RH



Today's Presentation: Ventilated Rainscreens

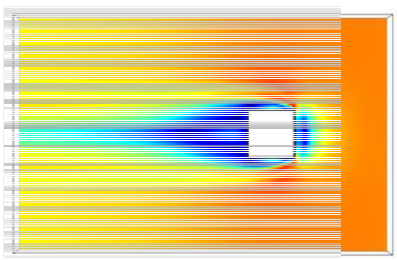


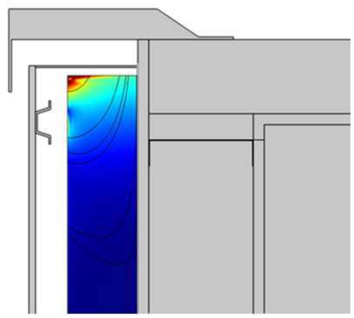
Today's Presentation: Ventilated Rainscreens

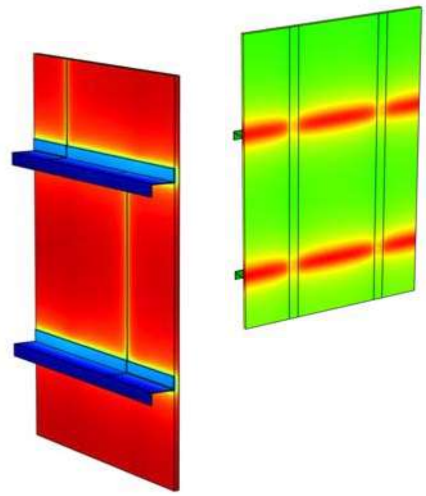


Today's Presentation: Computational Fluid Dynamics

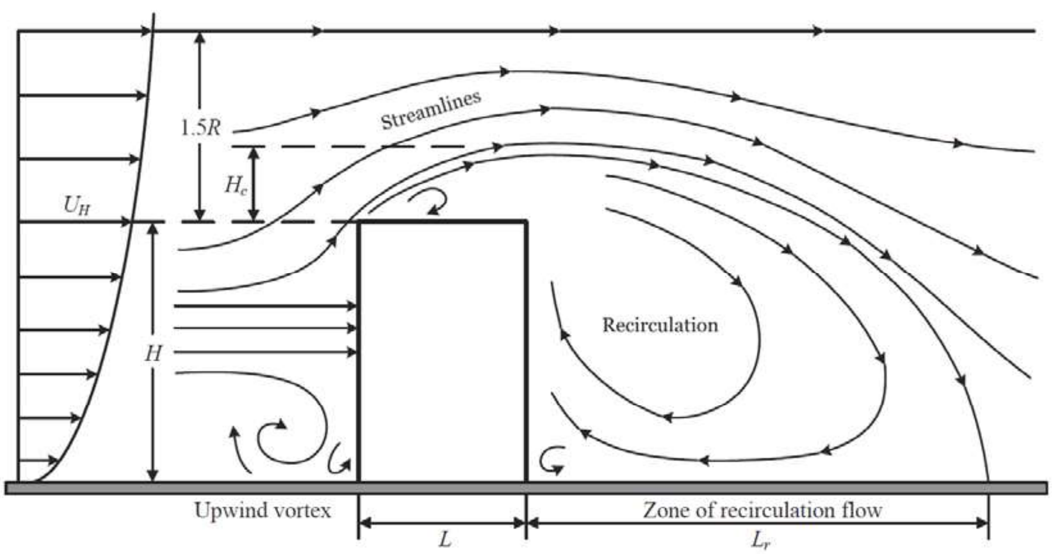
Computational Fluid Dynamics –
Mathematical simulations for predicting how a product or assembly reacts to real-world forces, vibration, heat, fluid flow, and other physical effects.





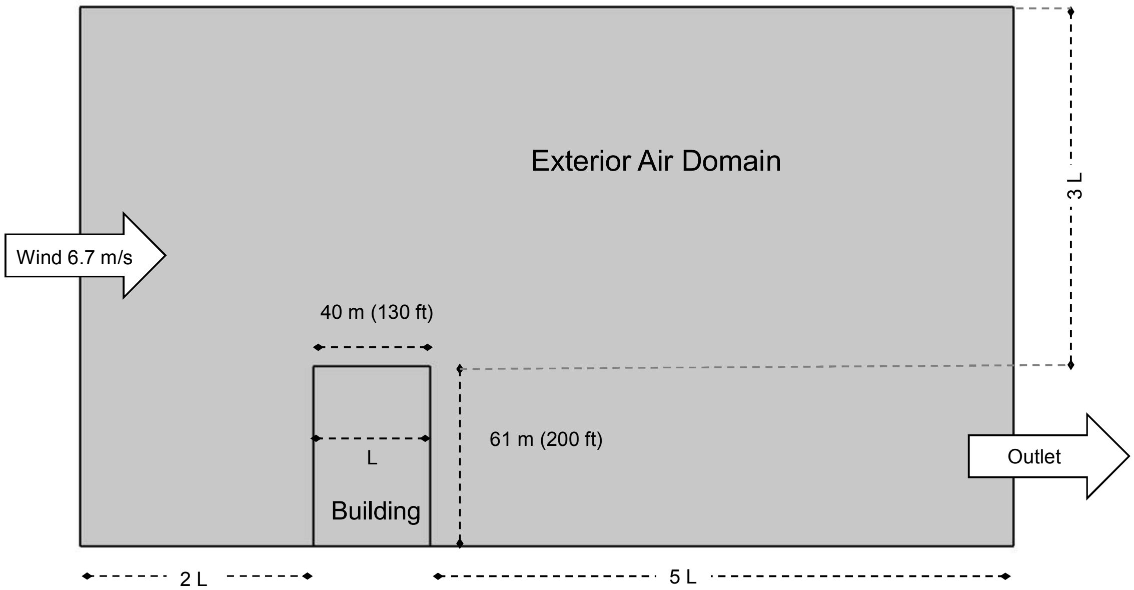


Let's Begin….Airflow Around Buildings

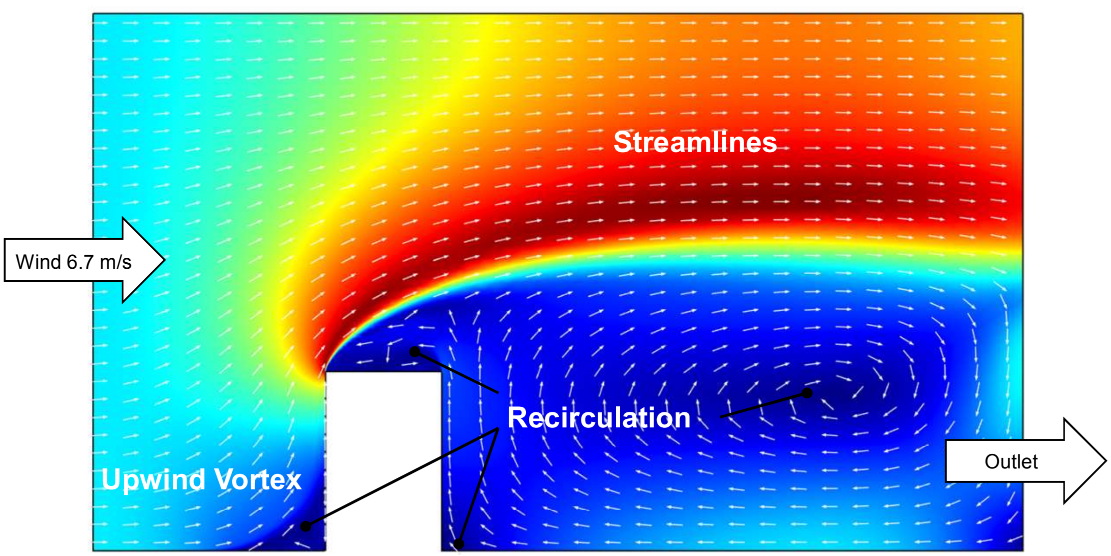


Modified from ASHRAE Handbook, 2014, Chapter 45

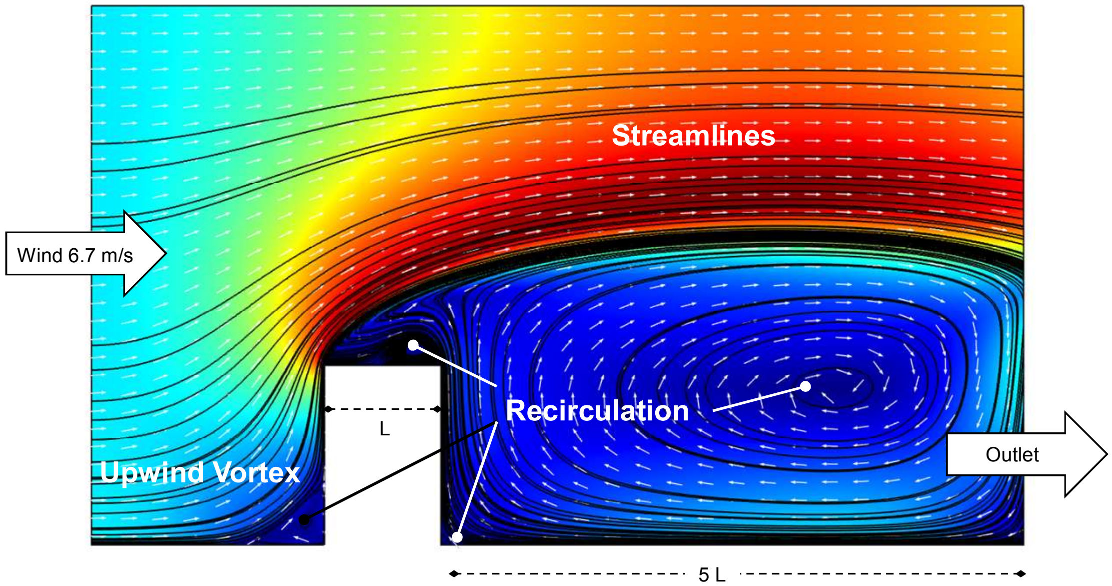
Airflow Around Buildings



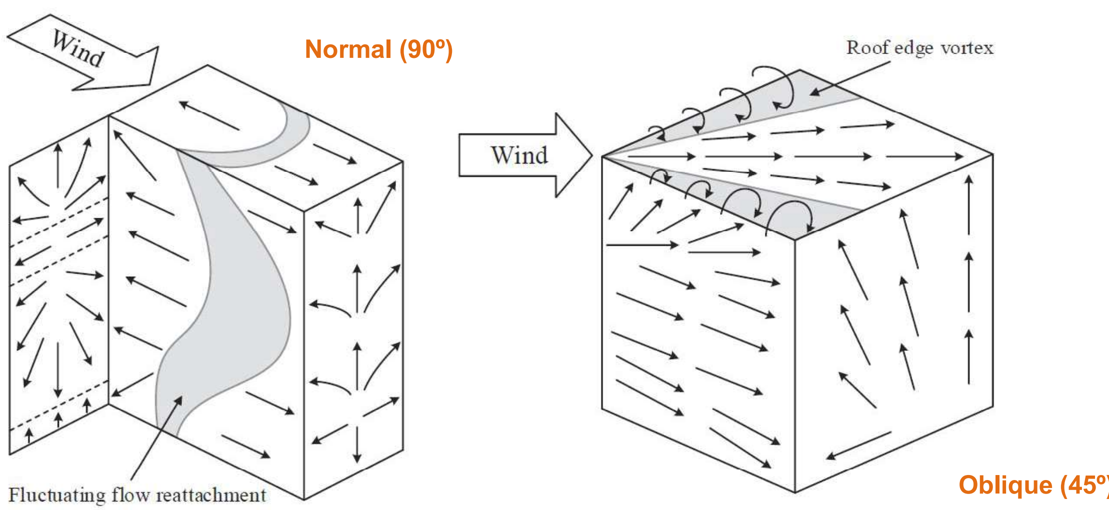
Airflow Around Buildings



Airflow Around Buildings



Surface Flow Patterns



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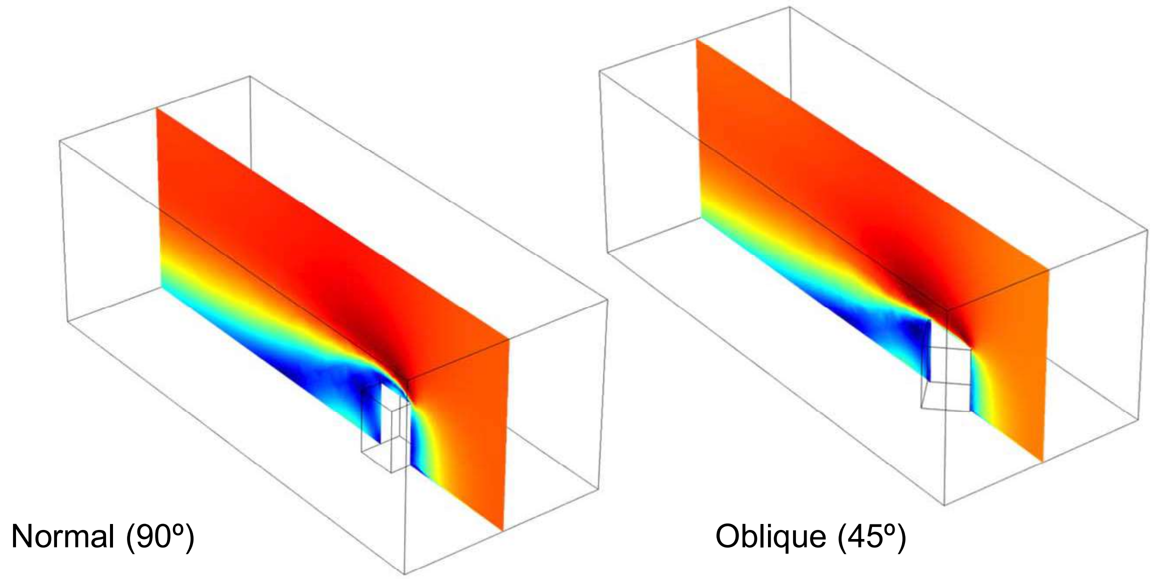
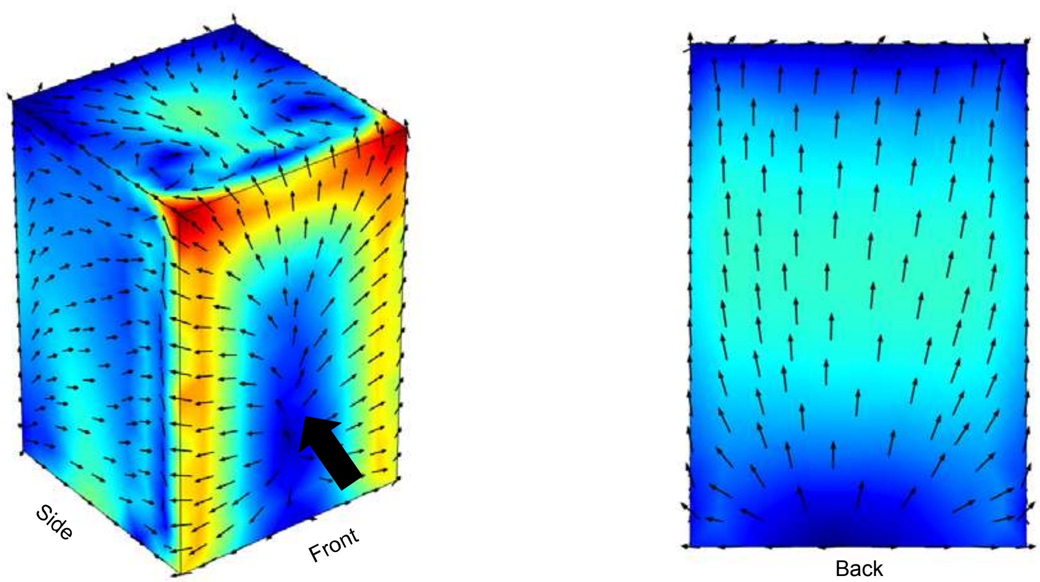
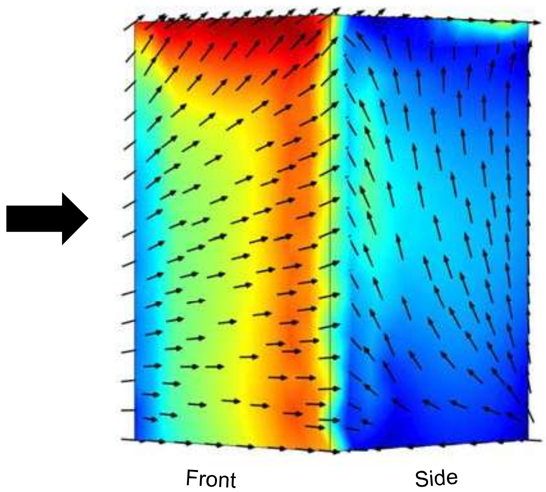
Airflow Around Buildings

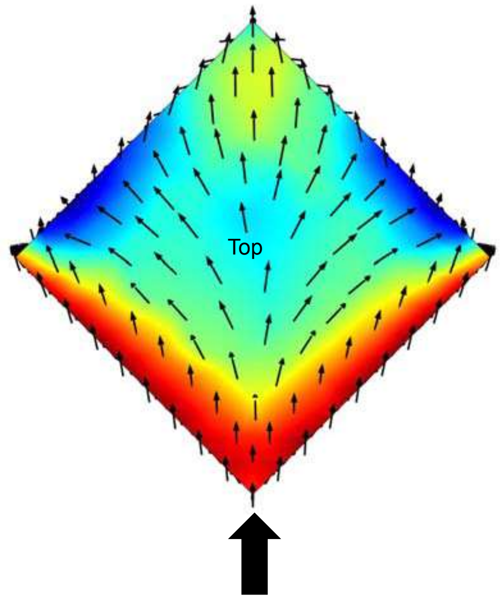


Surface Flow Patterns: Normal Flow (90º)



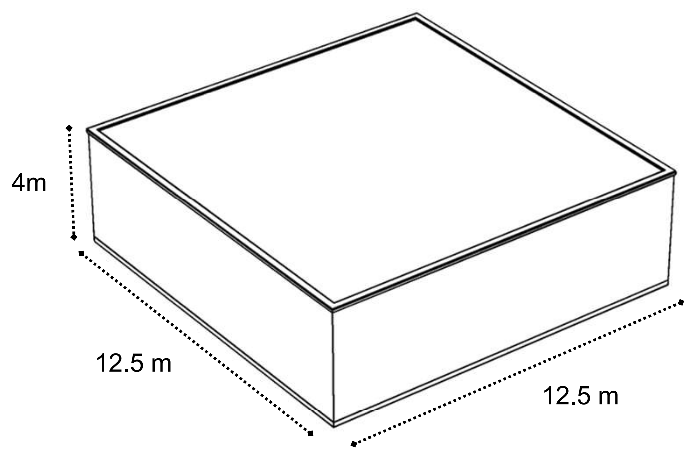
Surface Flow Patterns: Oblique Flow (45º)





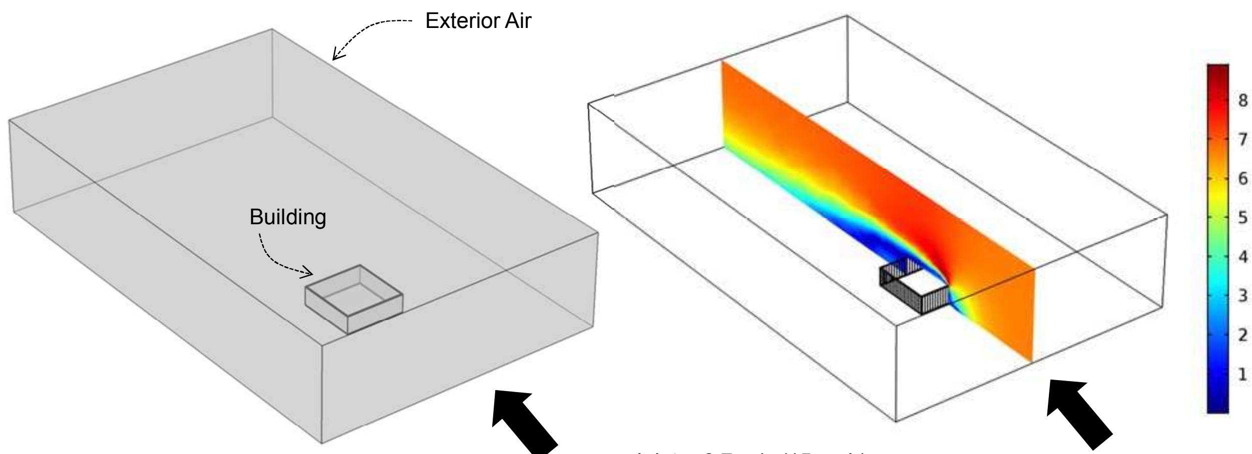
Airflow Around Buildings

Do low-rise buildings respond similarly?



Conceptual Low-Rise Building

Airflow Around Buildings



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

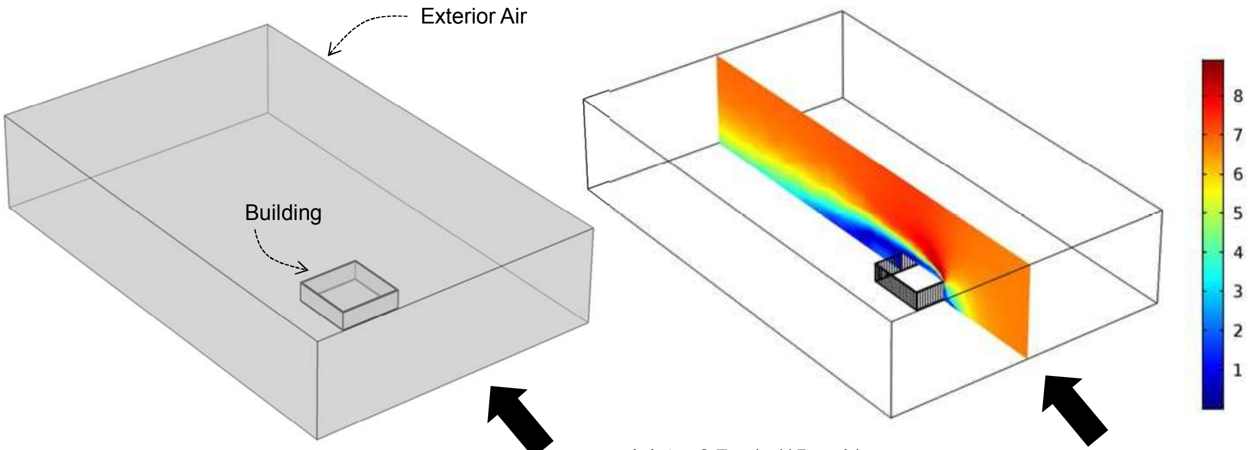
Airflow Around Buildings

6.7 m/s (15 mph) = ASHRAE Winter Design Condition

City	Climate Zone	Annual Average* Wind Speed m/s (mph)	Extreme Annual WS m/s (mph) ** 1%	2.5%	5%
Atlanta, GA	3C	4.1 (9.2)	9.8 (22.0)	8.6 (19.2)	7.7 (17.3)
Boston, MA	5A	5.7 (12.7)	12.0 (26.8)	10.8 (24.1)	9.3 (20.8)
Chicago, IL	5A	4.7 (10.5)	11.1 (24.8)	9.4 (21.1)	8.6 (19.2)
Dallas, TX	3B	4.9 (10.9)	11.7 (26.1)	10.6 (23.7)	9.2 (20.6)
Denver, CO	5B	4.4 (9.8)	11.9 (26.7)	10.4 (23.3)	8.7 (19.6)
Duluth, MN	7A	5.2 (11.6)	12.4 (27.7)	11.0 (24.5)	9.4 (21.0)
Kansas City, MO	4A	4.7 (10.6)	11.5 (25.8)	10.4 (23.2)	9.0 (20.1)
Minneapolis, MN	6A	4.8 (10.7)	11.1 (24.8)	9.8 (21.9)	8.7 (19.5)
New York, NY	4A	5.6 (12.5)	12.2 (27.3)	11.0 (24.7)	9.7 (21.7)
San Francisco, CA	3C	5.0 (11.2)	12.8 (28.6)	11.5 (25.8)	10.6 (23.7)
Seattle, WA	4C	4.1 (9.2)	9.0 (20.2)	8.1 (18.1)	7.3 (16.4)
Wichita, KS	4A	4.3 (9.6)	12.5 (28.0)	11.4 (25.4)	10.4 (23.2)
Wilmington, NC	3A	3.8 (8.5)	9.3 (20.7)	8.3 (18.5)	7.5 (16.8)

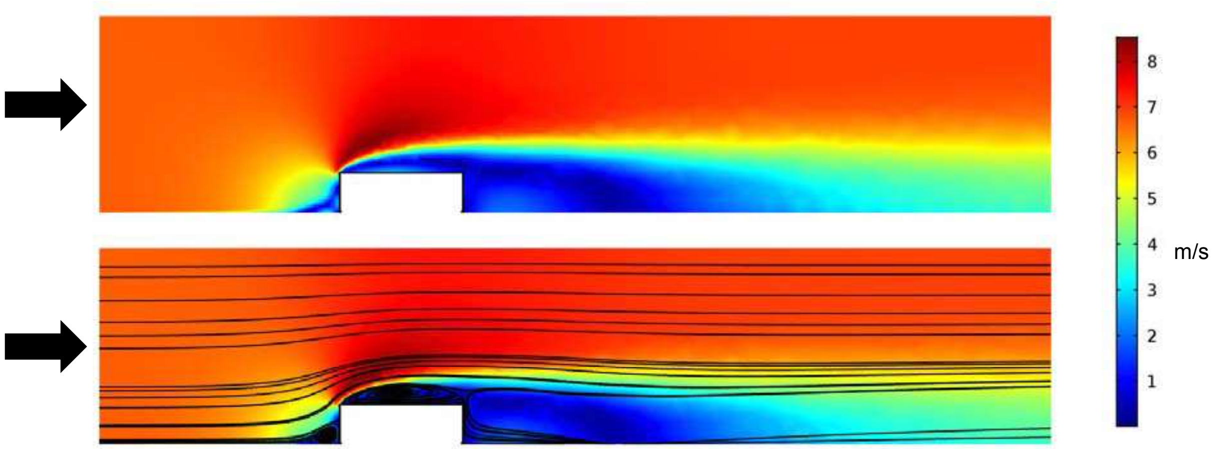
* NOAA Climatic Data
** ASHRAE Climatic Design (ASHRAE Handbook - Fundamentals)

Airflow Around Buildings

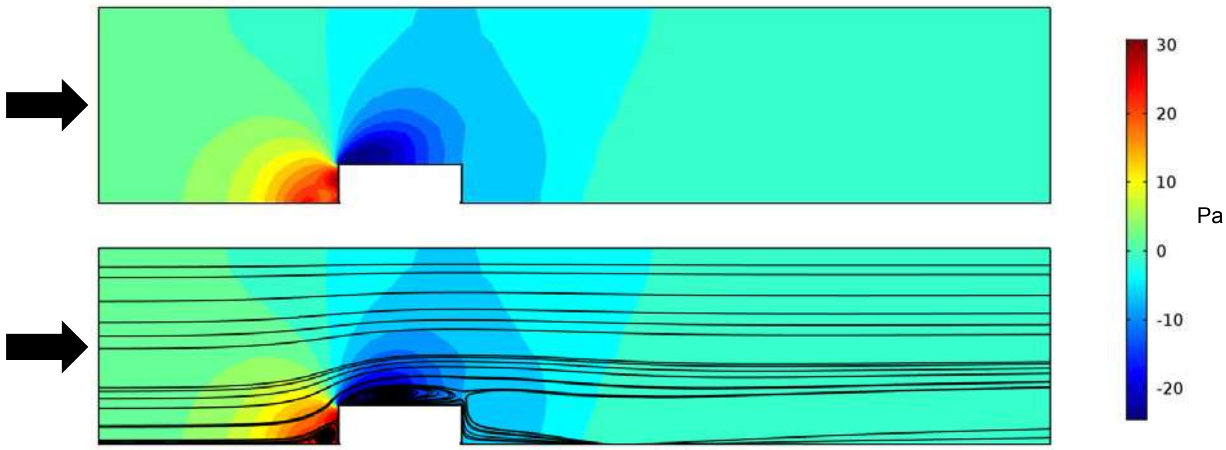


Inlet = 6.7 m/s (15 mph)
Winter Design Conditions ASHRAE Handbook

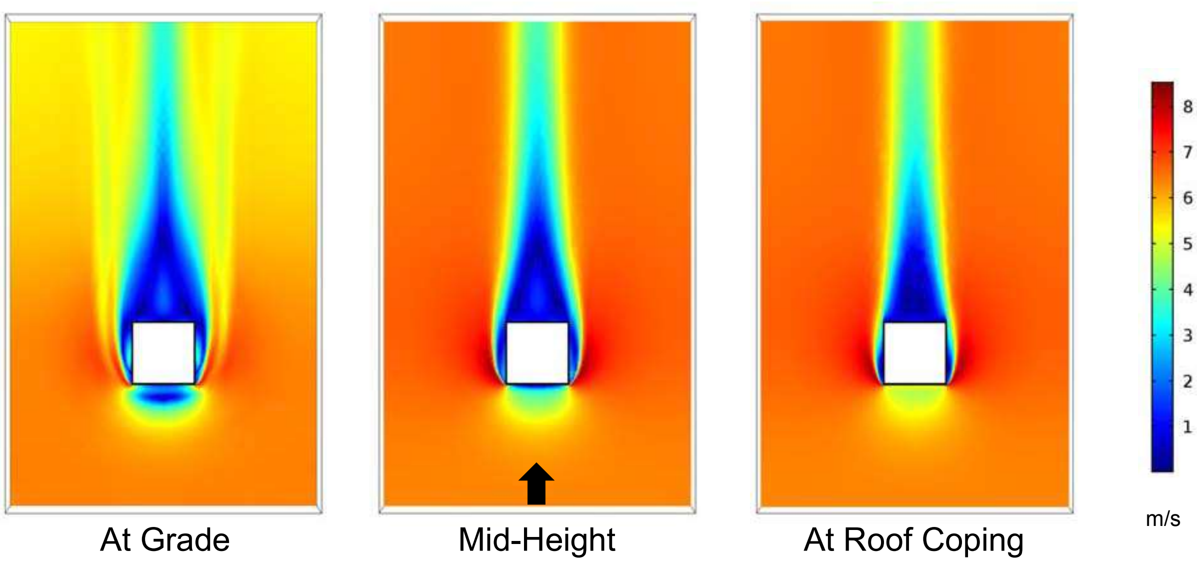
Airflow Around Buildings: Velocities



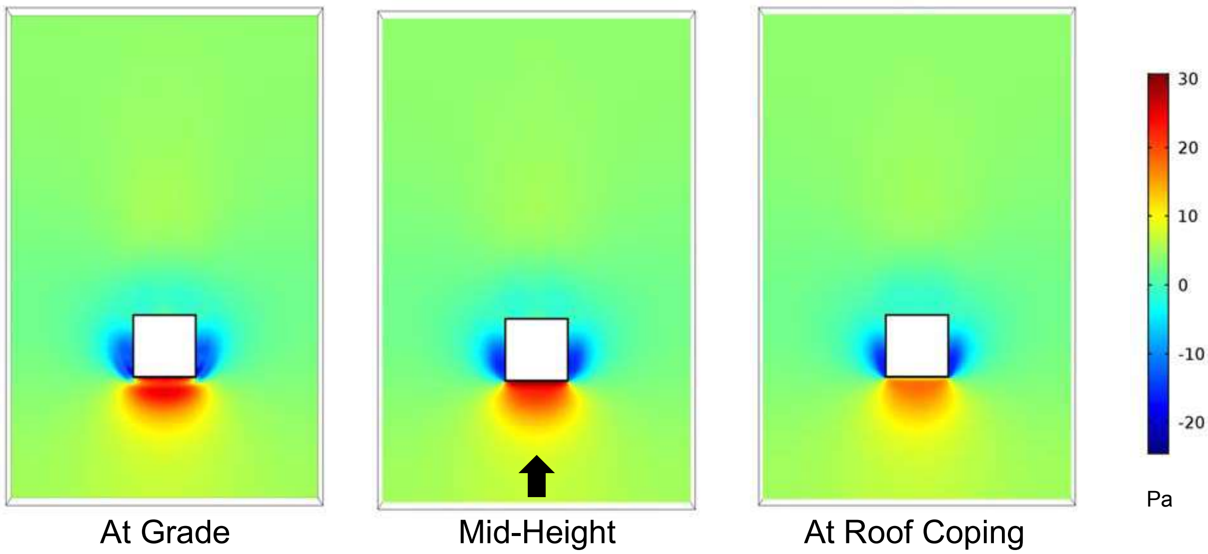
Airflow Around Buildings: Pressures



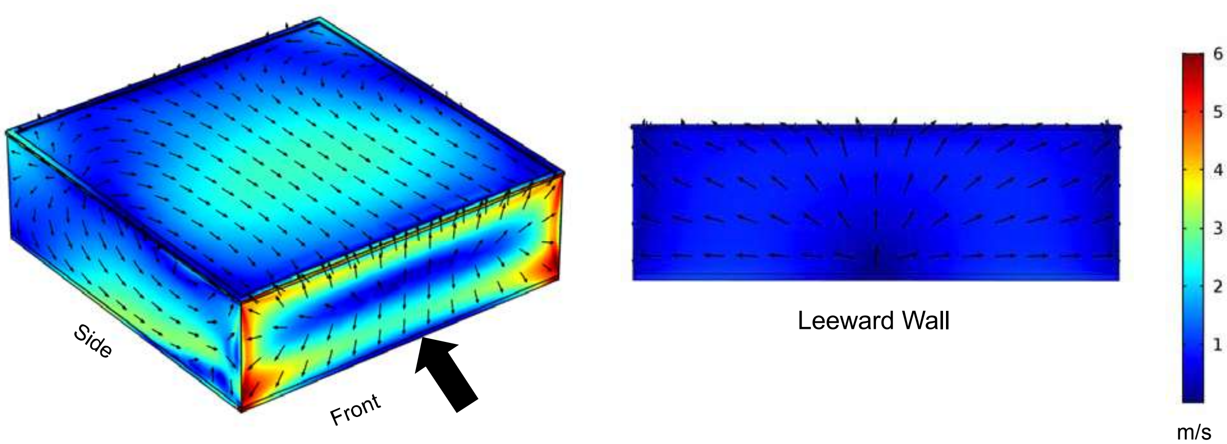
Airflow Around Buildings: Velocities



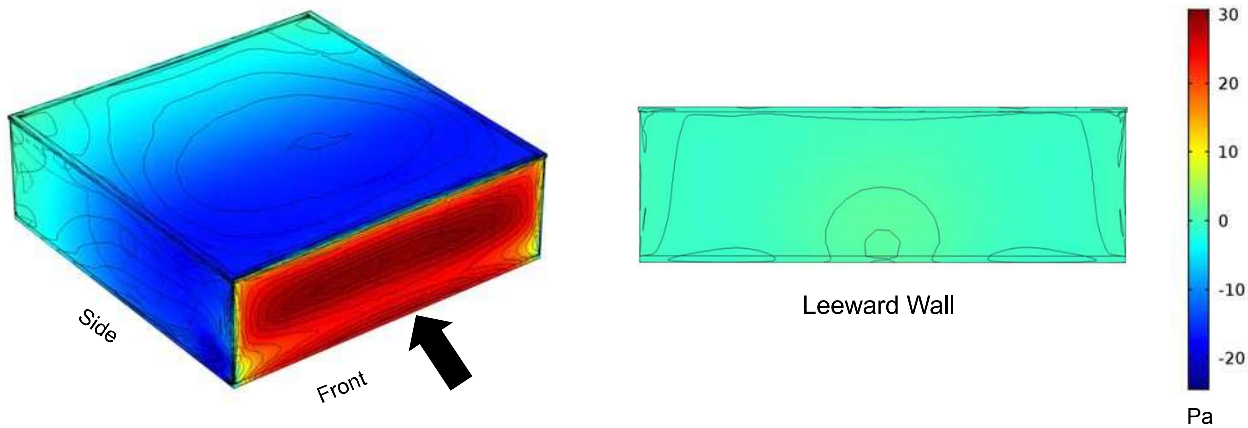
Airflow Around Buildings: Pressures



Surface Flow Patterns: Velocities



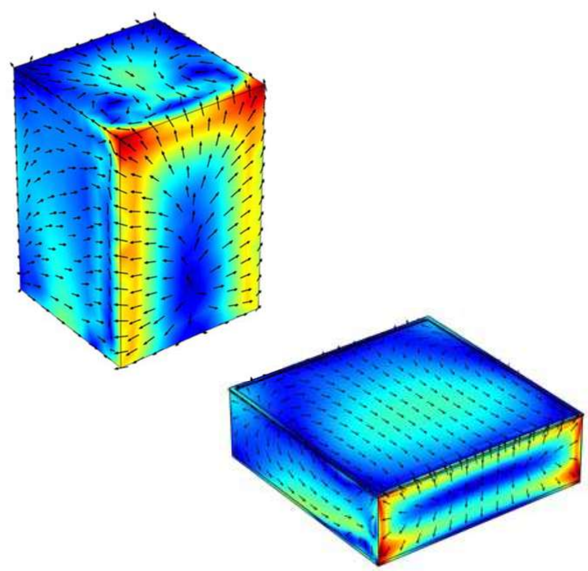
Surface Flow Patterns: Pressures



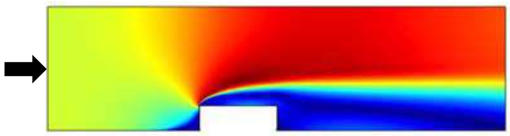
Building Airflows

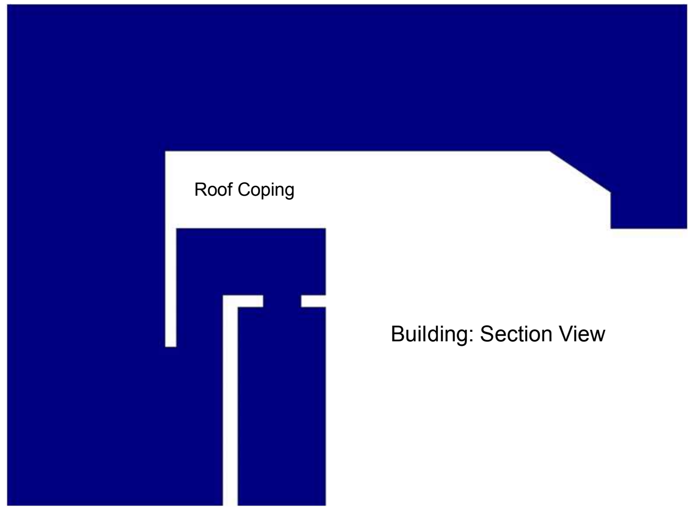
Key Considerations

- Benchmark flow patterns, velocities, pressures
- Demonstrate constraints of exterior surfaces and rainscreens
- Low-rise and high-rise buildings behave similarly with respect to general airflow patterns and surface pressures
- Complex geometries may have very different characteristics



Ventilation Openings





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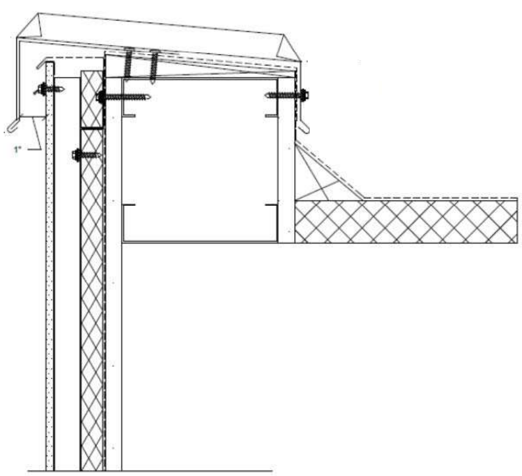
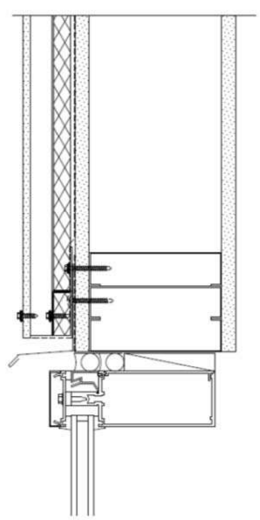
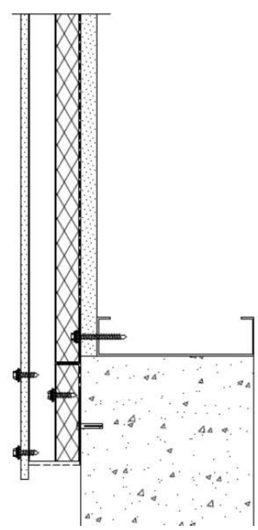
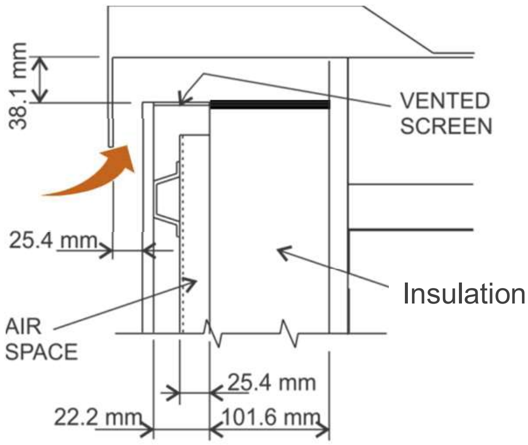
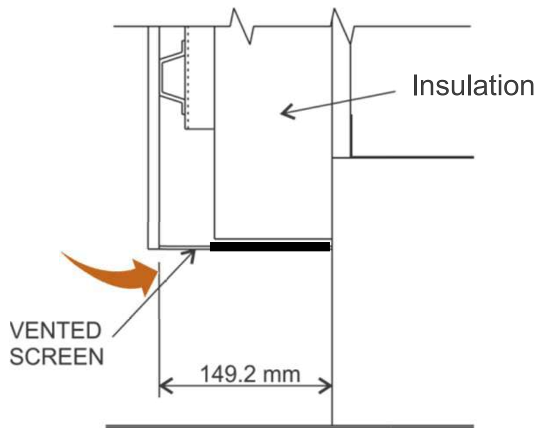




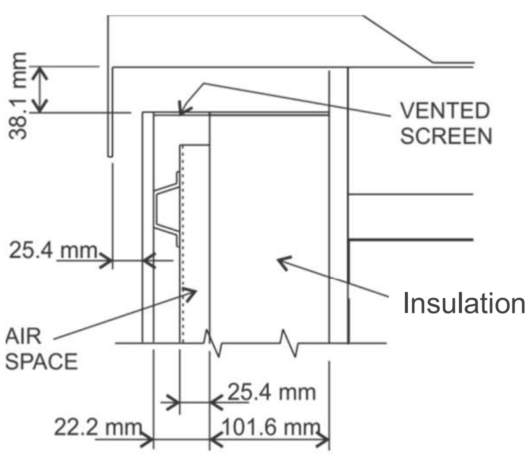


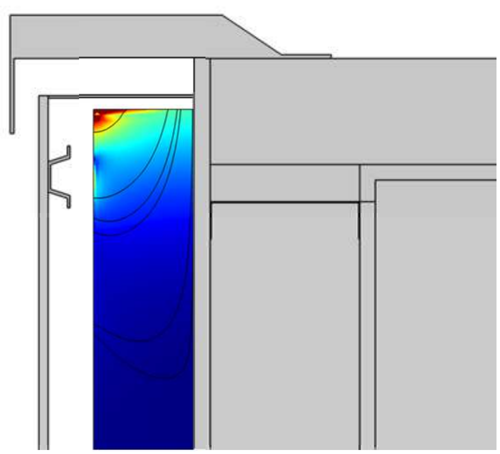
Considerations for Ventilation Openings



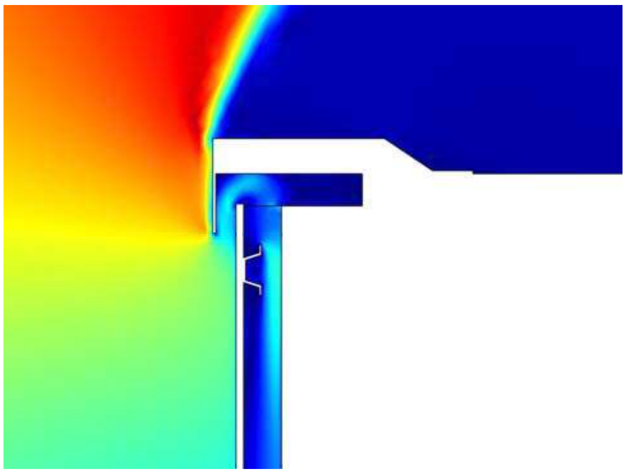


Considerations for Ventilation Openings

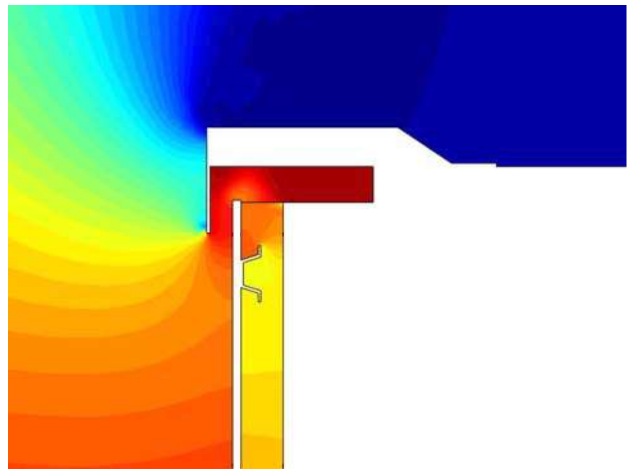




Considerations for Ventilation Openings



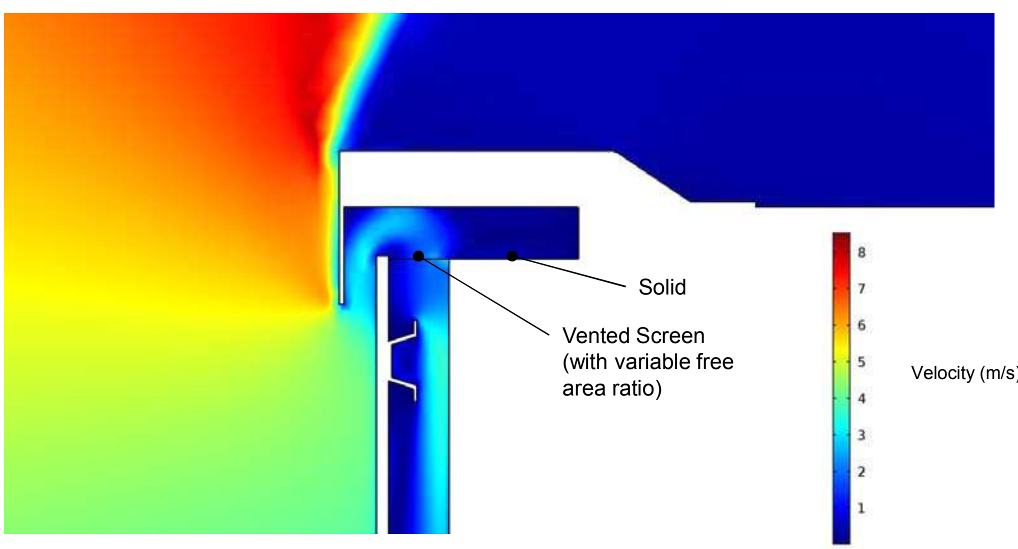
Velocity



Pressure

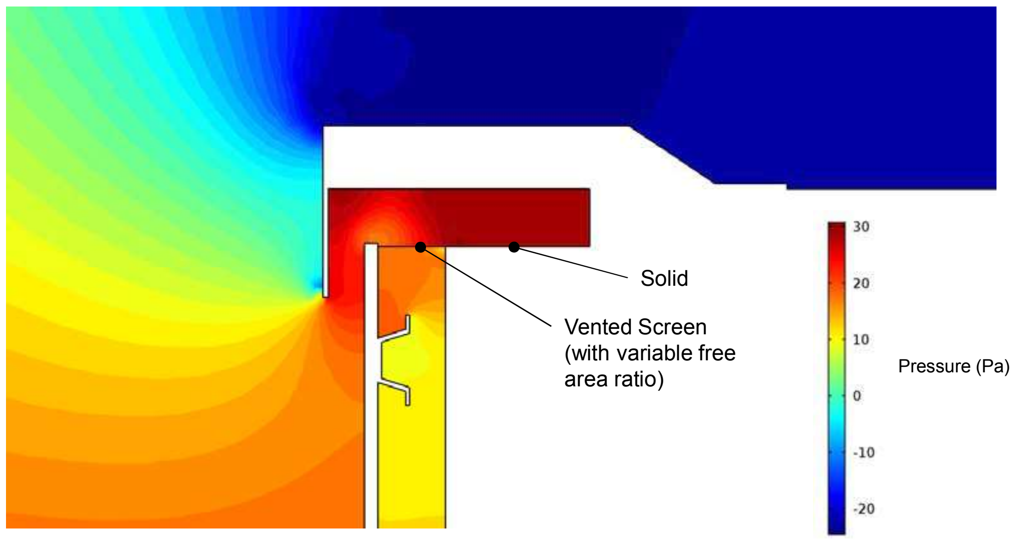
Considerations for Ventilation Openings

Velocity

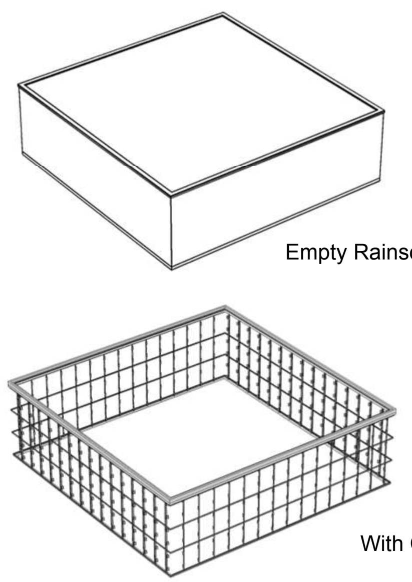


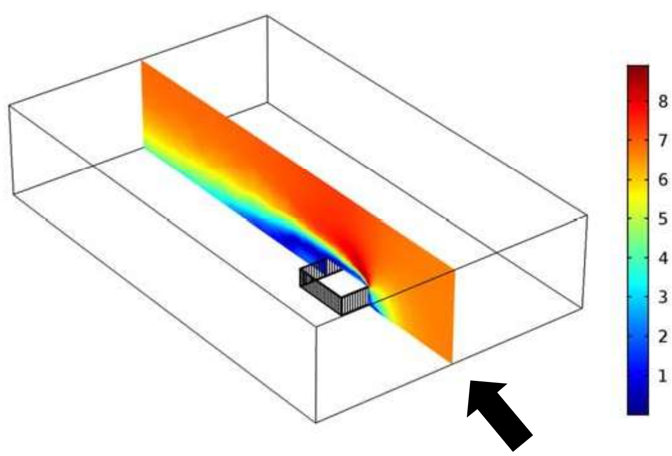
Considerations for Ventilation Openings

Pressure

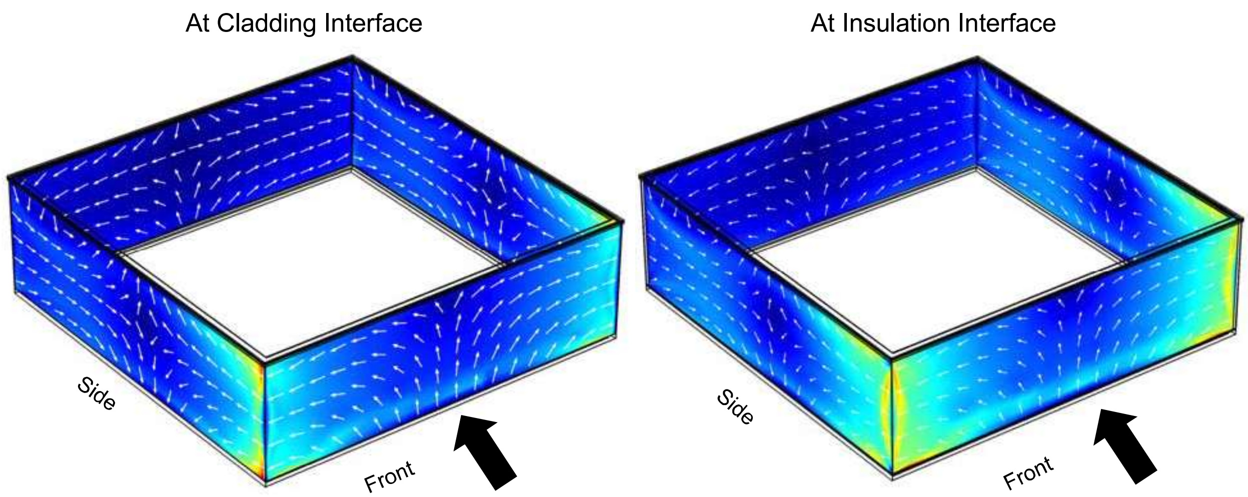


Rainscreen Airflow





Rainscreen Airflow: Empty Rainscreen Air Space



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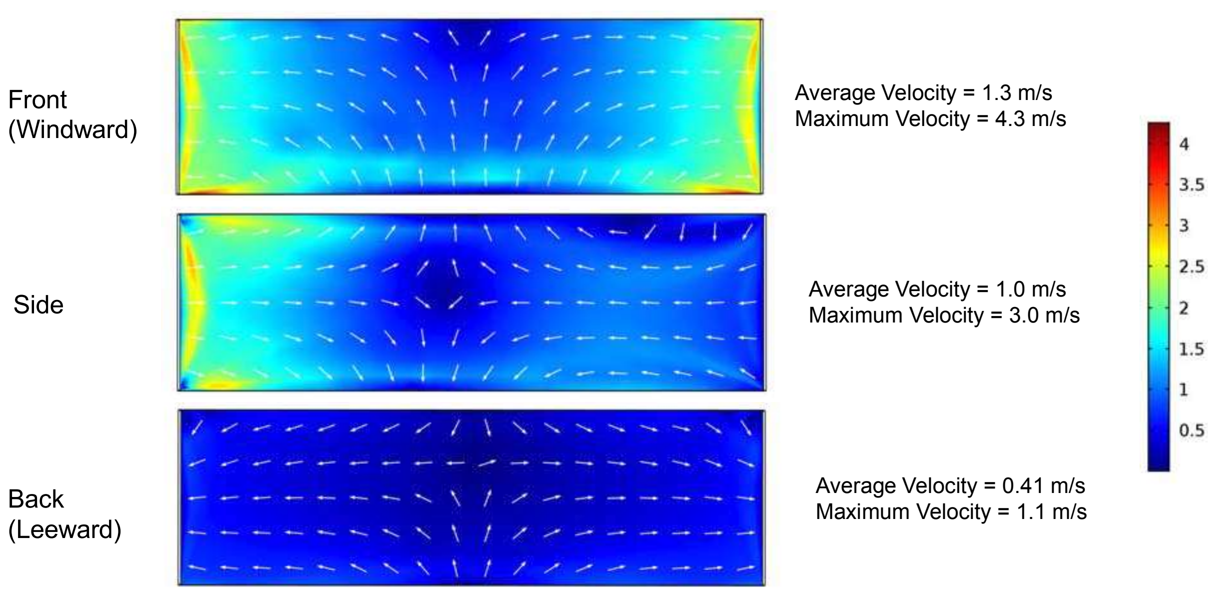
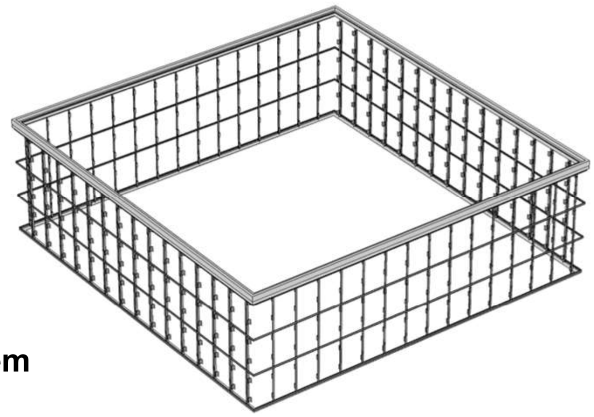


Rainscreen Airflow: Cladding Attachment System

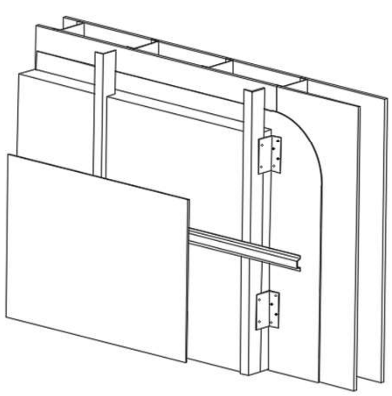
Conceptual Low-Rise Building

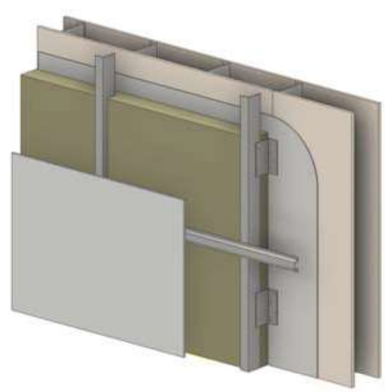


With Cladding
Attachment System

Rainscreen Airflow

Model Design: Detailed, Multi-Component Assembly

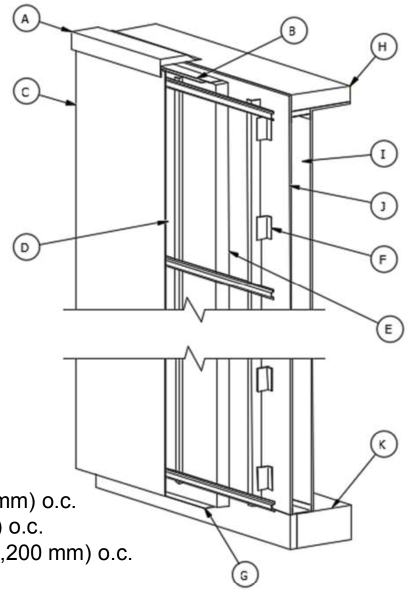




Rainscreen Airflow

Model Design

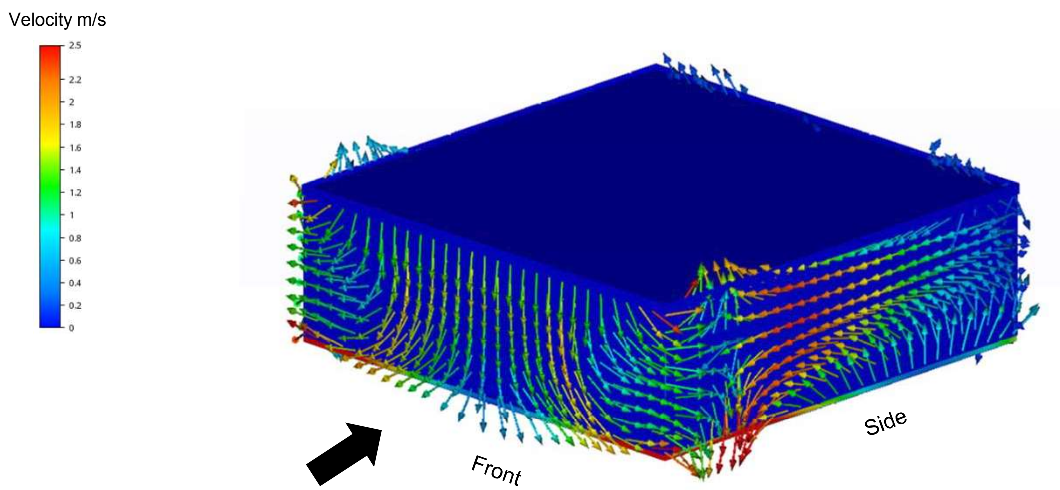
A Coping
B Air screen (top)
C Cladding (HD Fiber Cement)
D Rainscreen air space (1-7/8”) (~50 mm)
E Mineral wool (4”) (100 mm)
F Cladding support system
G Air screen (bottom)
H Roof insulation (XPS)
I Interior gypsum (5/8”)
J Gypsum sheathing (5/8”)
K Concrete floor slab



- Vertical Girts: 32” (~800 mm) o.c.
- Brackets: 26.2” (660 mm) o.c.
- Hat Channels: 4 at 47” (1,200 mm) o.c.

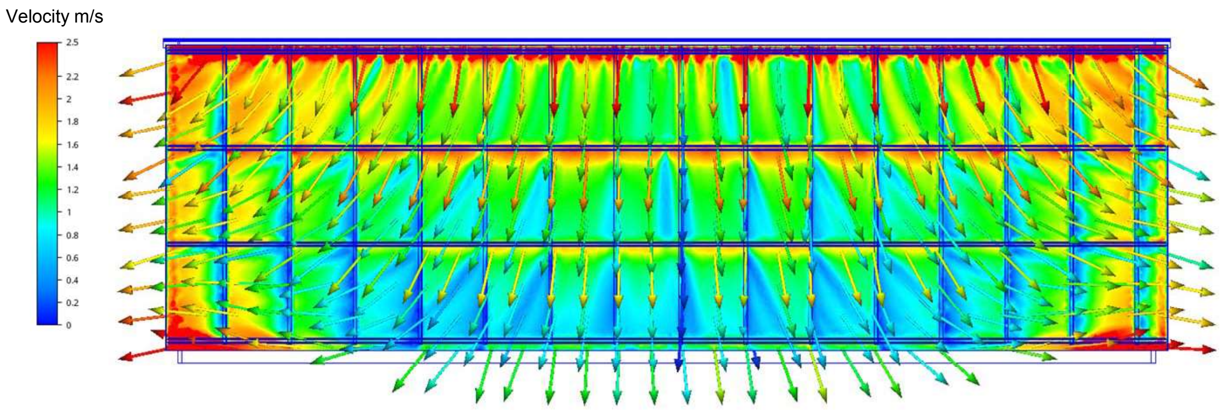
Rainscreen Airflow: Cladding Attachment System

Air Velocities within the Rainscreen Cavity



Rainscreen Airflow: Cladding Attachment System

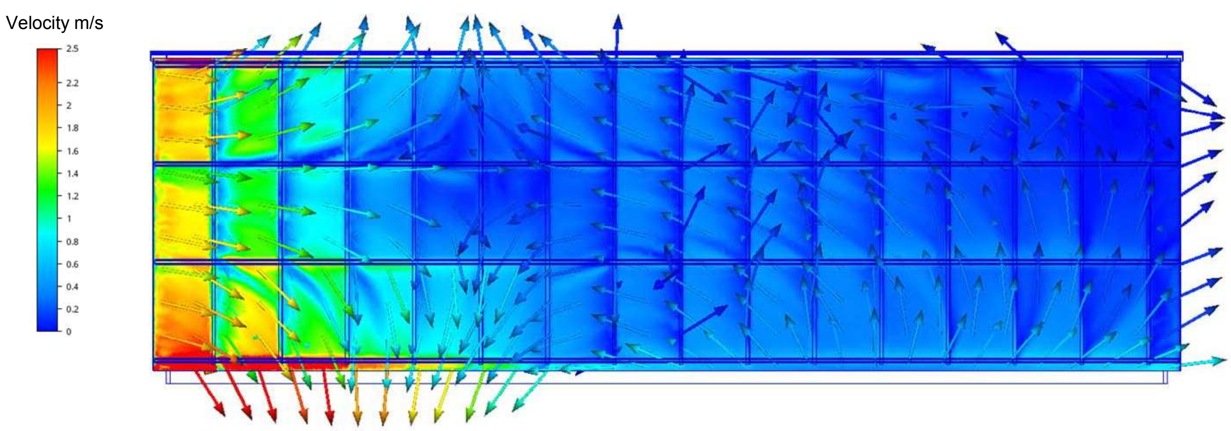
Windward Wall



Rainscreen Velocities: 0.1 to >3 m/s (0.328 to 9.8 ft/s)

Rainscreen Airflow: Cladding Attachment System

Side Wall



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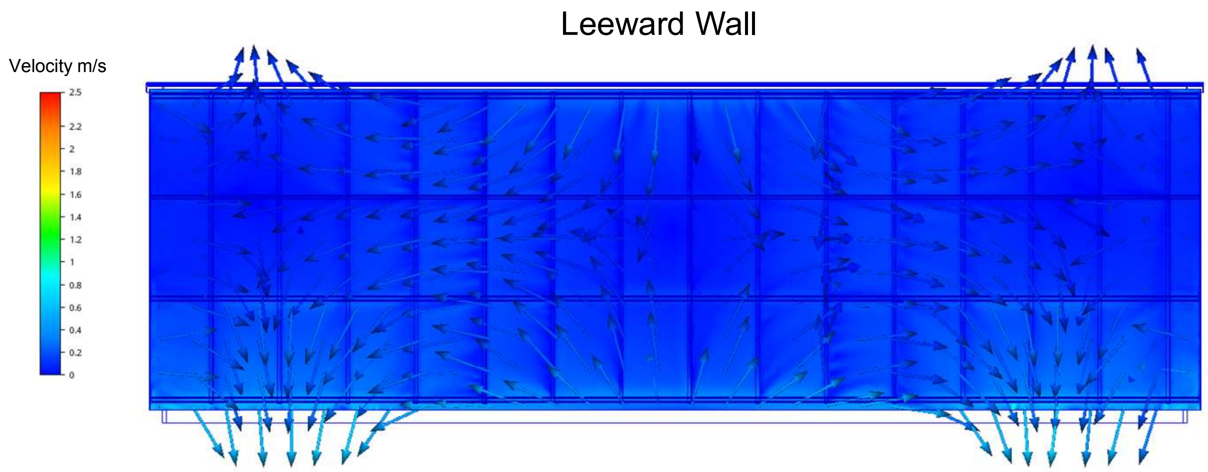
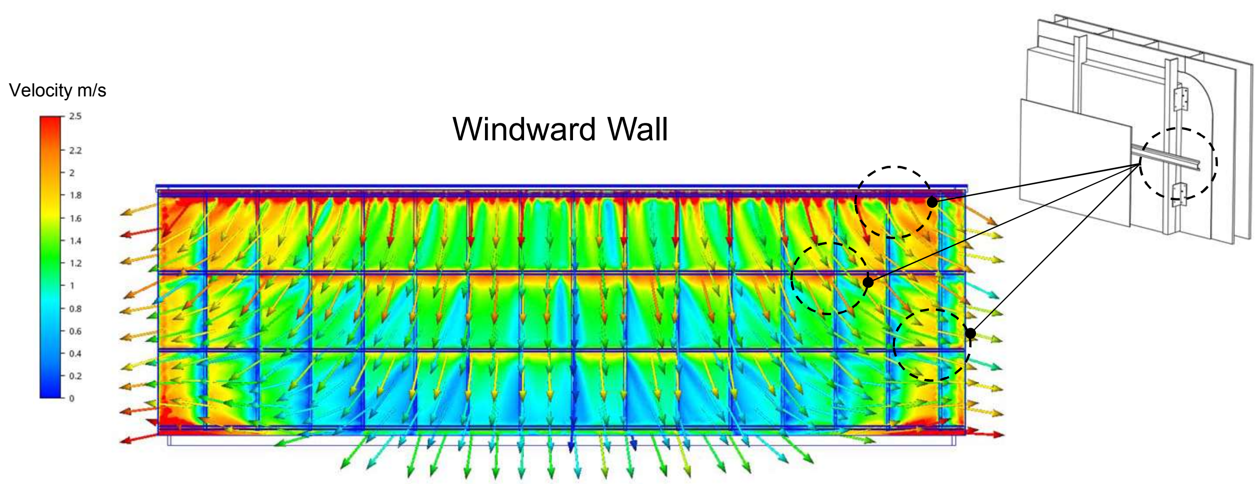
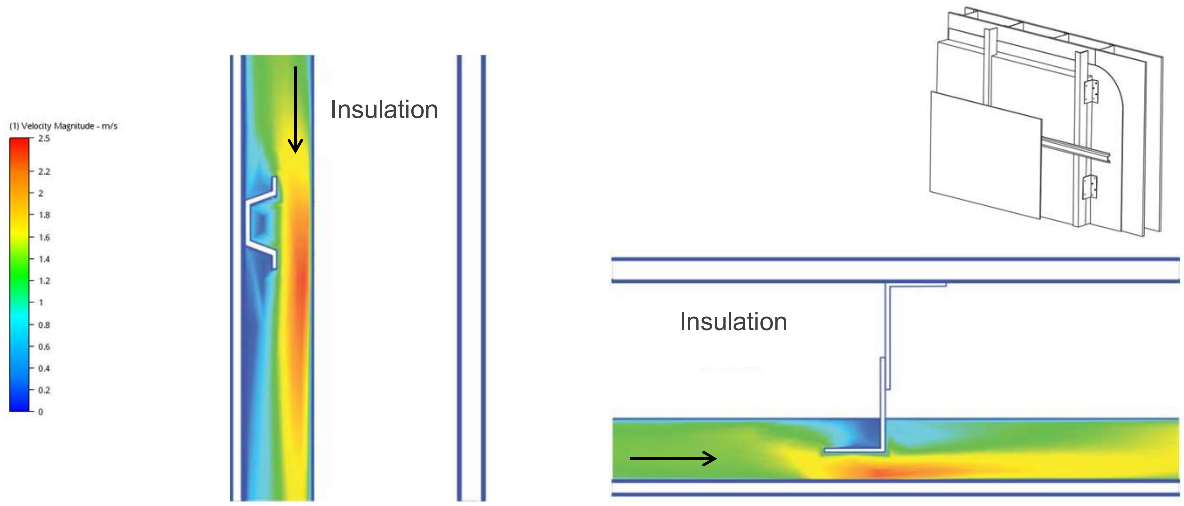
Rainscreen Airflow: Cladding Attachment System



Rainscreen Airflow: Cladding Attachment System



Rainscreen Airflow: Cladding Attachment System

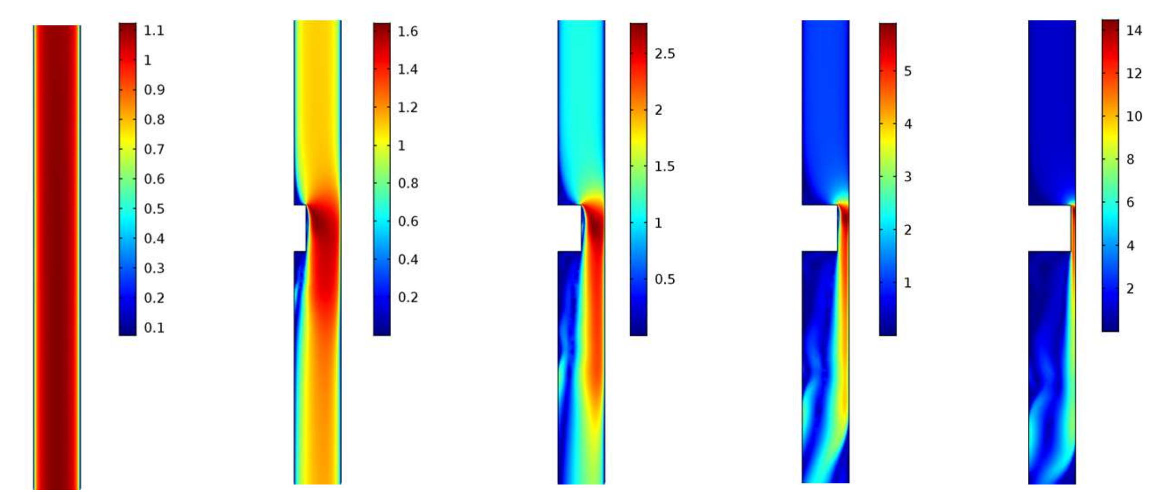


Section View

Plan View

The Effects of Simple Constrictions: 1 m/s inlet

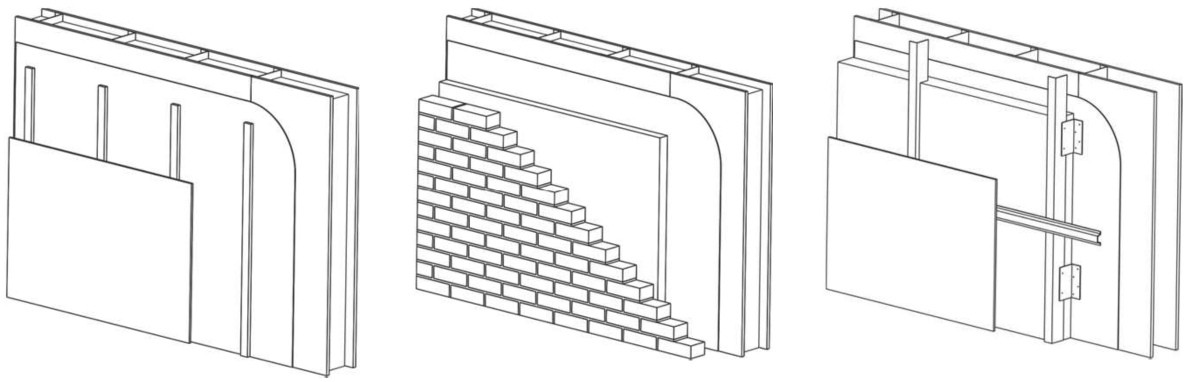
0% Occluded | 25% Occluded | 50% Occluded | 75% Occluded | 90% Occluded



U_{max} = 1.1 | U_{max} = 1.6 | U_{max} = 2.7 | U_{max} = 5.9 | U_{max} = 14.5

Rainscreen Airflow

A B C



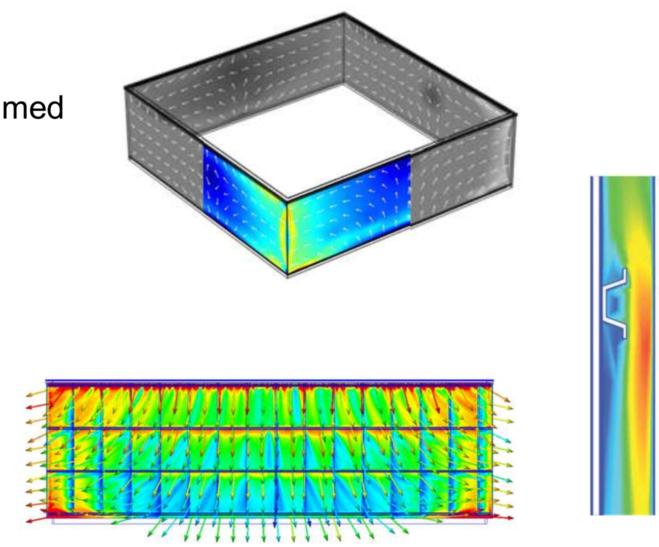
Smaller ventilation openings
Slightly-ventilated air layer
Simpler, planar airflow paths

Larger ventilation openings
Well-ventilated air layer
Complex 3D airflow paths

Rainscreen Airflows

Key Considerations:

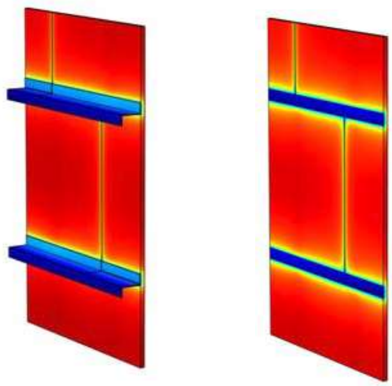
- Velocities are higher than assumed
- Multi-directional flows
- Corner regions: increased air velocities & greater turbulence
- Rainscreen geometries greatly influence flow patterns and intensities
- Ramifications for heat transfer

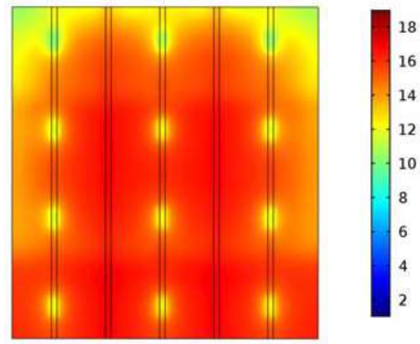


Convective Heat Loss

Conductive Processes

Convective Processes

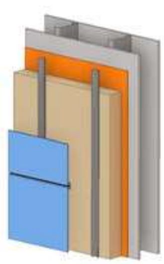




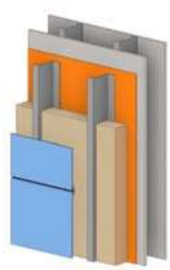
(Thermal Bridging)

(Wind-Washing)

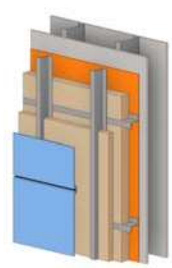
Thermal Bridging



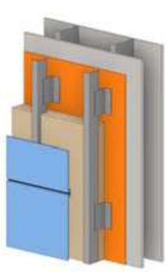
Hat Channels



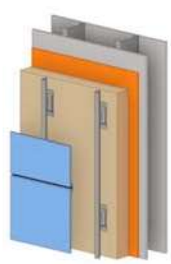
Vertical Girts



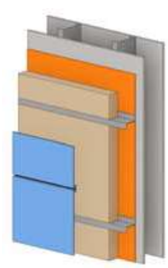
Double Girts



Brackets & Rails

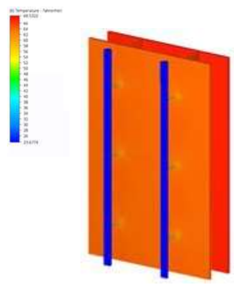


Exterior CI Bracket System



Horizontal Girts

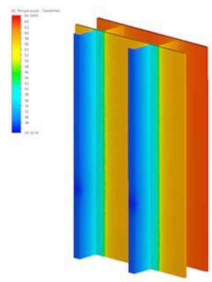
Thermal Bridging



Hat Channels

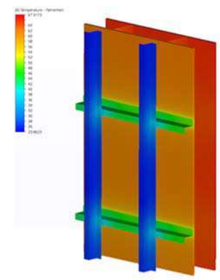
↓10.3%

(with fasteners)



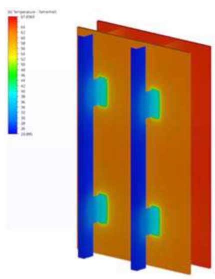
Vertical Girts

↓ 63%



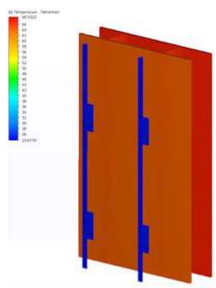
Double Girts

↓ 41%



Brackets & Rails

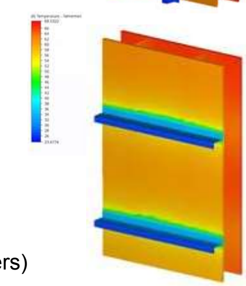
↓ 38%



Exterior CI Bracket System

↓ 16.2%

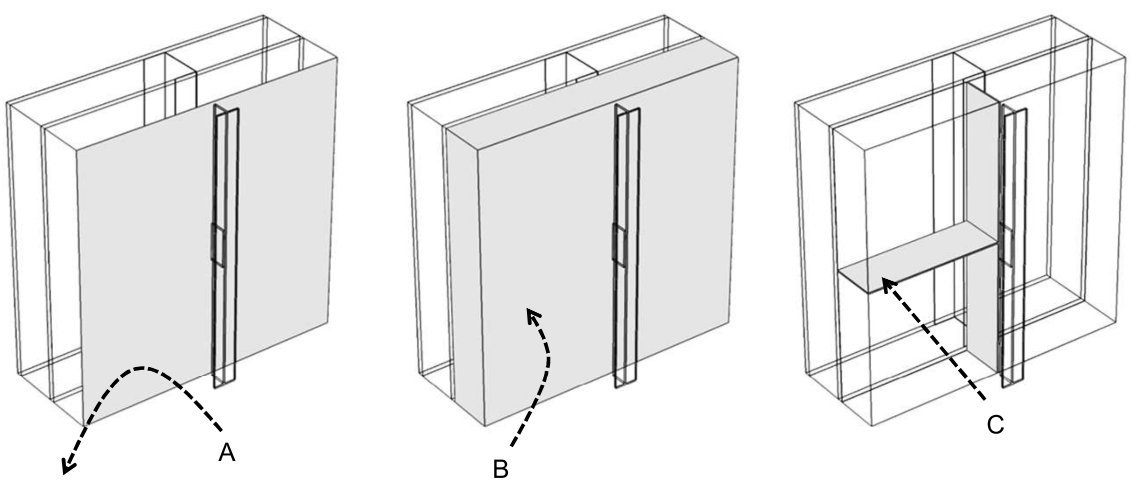
(with fasteners)



Horizontal Girts

↓ 51.9%

Convective Mechanisms: 'Wind-Washing'

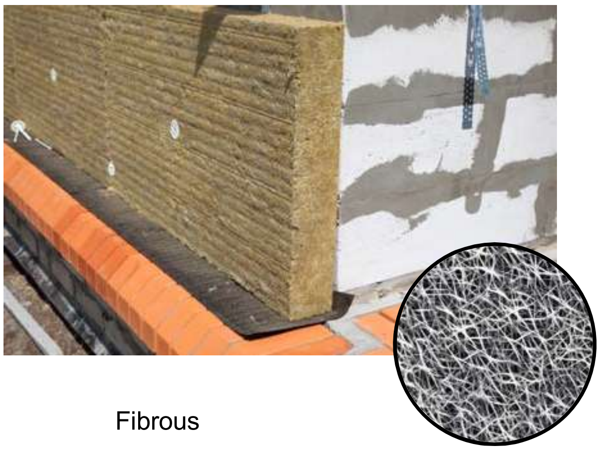


A) Surface Convection

B) Open Pore Volume

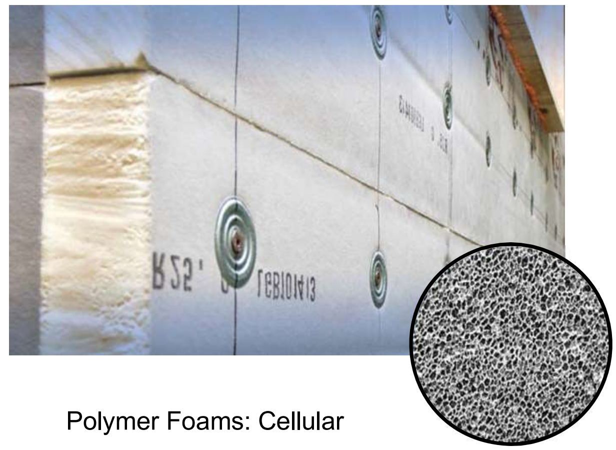
C) Gaps

Convective Mechanisms & Insulation Types



Fibrous

Air Permeability: varies based on density

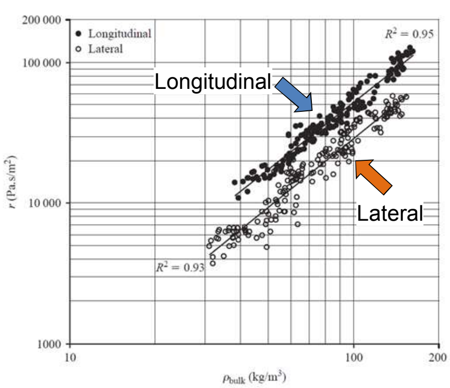


Polymer Foams: Cellular

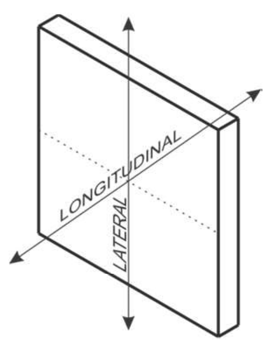
Air Permeability: impermeable at expected pressures

Properties of Fibrous Insulation

Mineral Wool & Air Resistance



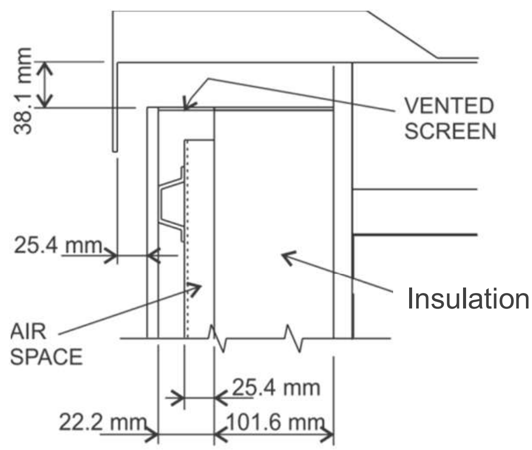
Hopkins C. 2007. Sound Insulation.
Published by Elsevier Ltd. ISBN: 978-0-7506-6526-1. 648 p:79-82.

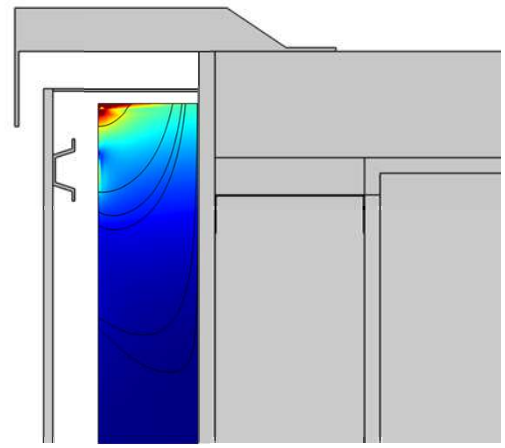


Influenced by . . .

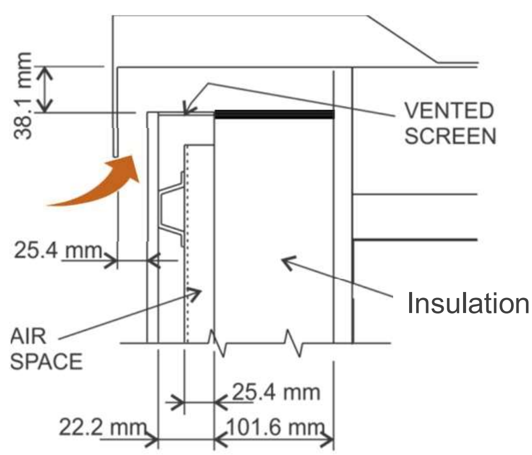
- Density
- Fiber orientation
  - Lateral perm: 50% higher
- Matrix composition
- Fiber size
- Fiber inhomogeneity
- Pressure
  - ISO 9053 / EN 29063: 0.2 Pa
  - 30% higher at 5 – 10 Pa

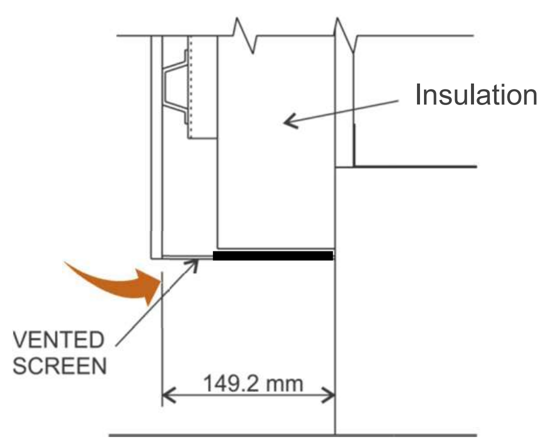
Considerations for Ventilation Openings



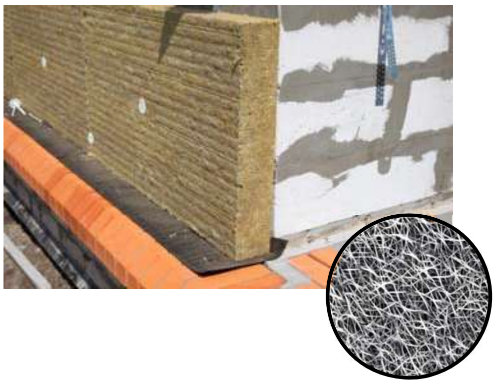


Considerations for Ventilation Openings





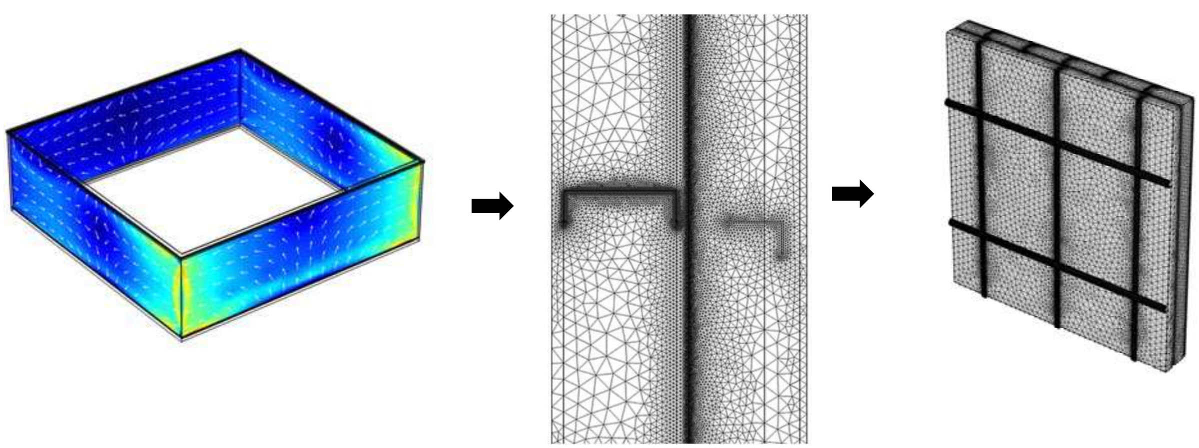
Convective Heat Loss



Permeability (m²)	Permeability (m³/Pa·m·s)	Resistivity (Pa·s/m²)	Density (kg/m³)	Density (lb/ft³)
2.0×10^{-10}	11.1×10^{-6}	90,000	160	10
4.0×10^{-10}	22.2×10^{-6}	45,000	90	5.6
6.0×10^{-10}	33.3×10^{-6}	30,000	80	5.0
8.0×10^{-10}	44.4×10^{-6}	22,500	70	4.4
1.0×10^{-9}	55.5×10^{-6}	18,000	50	3.2
1.5×10^{-9}	83.3×10^{-6}	12,000	40	2.5
2.0×10^{-9}	111×10^{-6}	9,000	30	1.9

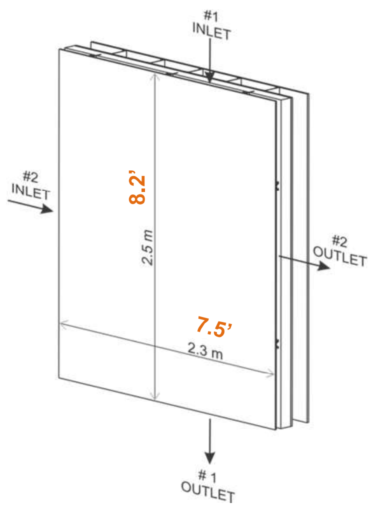
Convective Heat Loss

From Whole Building to Wall Assembly



Meshing

Convective Heat Loss



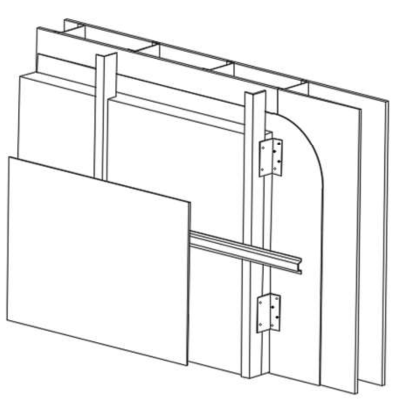
Exterior Temperature
-5°C (23°F)

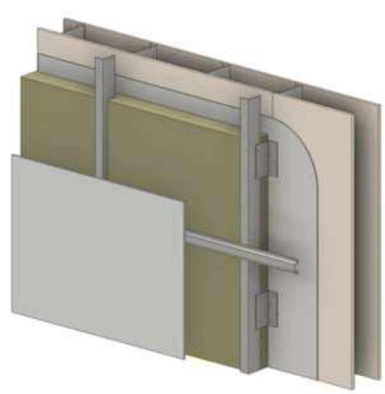
Winter design conditions are representative of most of North America

Interior Temperature
21°C (69.8°F)

Study Design

Detailed, Multi-Component Assembly

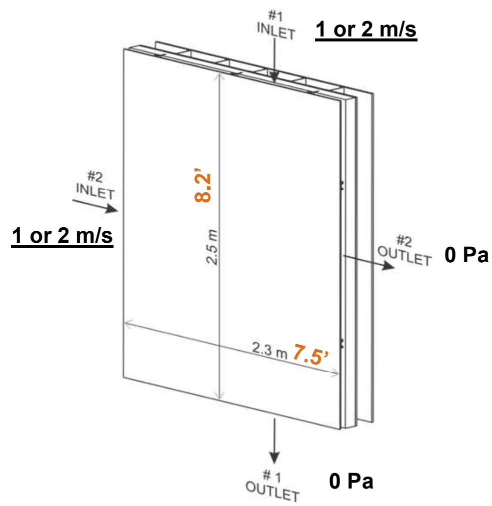




Convective Heat Loss

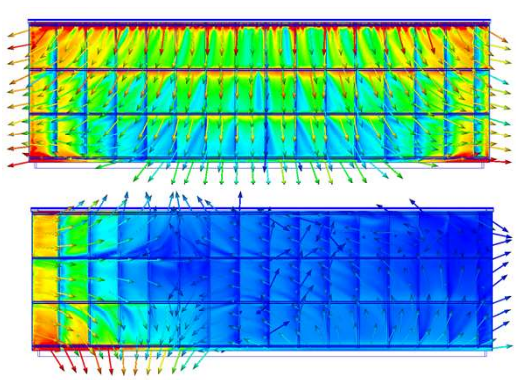
Study Design

Permeability (m²)	Permeability (m³/Pa·m·s)	Resistivity (Pa·s/m²)	Density (kg/m³)	Density (lb/ft³)
2.0×10^{-10}	11.1×10^{-6}	90,000	160	10
4.0×10^{-10}	22.2×10^{-6}	45,000	90	5.6
6.0×10^{-10}	33.3×10^{-6}	30,000	80	5.0
8.0×10^{-10}	44.4×10^{-6}	22,500	70	4.4
1.0×10^{-9}	55.5×10^{-6}	18,000	50	3.2
1.5×10^{-9}	83.3×10^{-6}	12,000	40	2.5
2.0×10^{-9}	111×10^{-6}	9,000	30	1.9

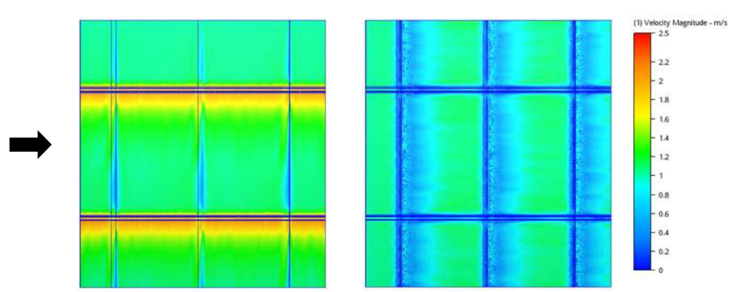


Convective Heat Loss

A unidirectional inlet results in simple flow regimes



Whole Building

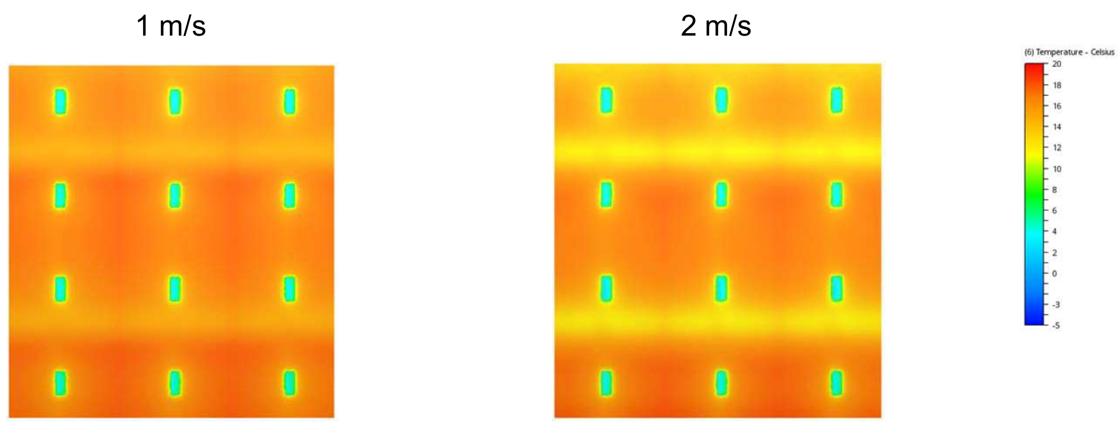


Vertical Flows

Horizontal Flows

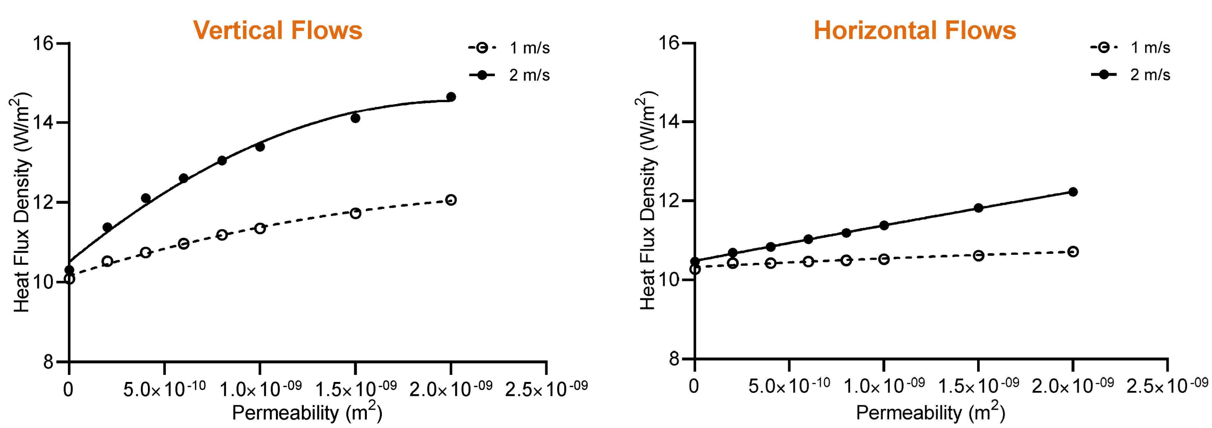
Convective Heat Loss

Temperature at Exterior Surfaces of Sheathing: Vertical Flow

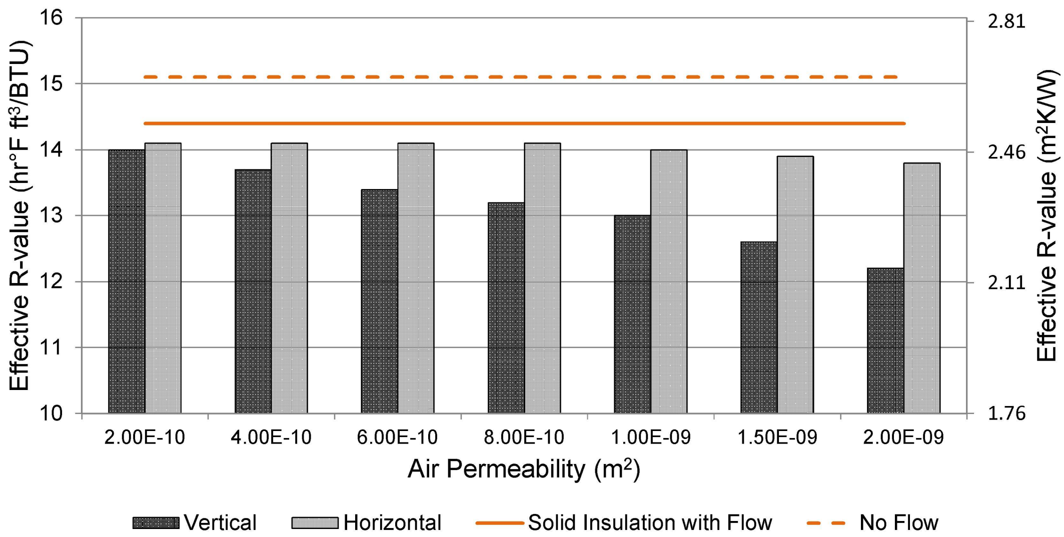


Convective Heat Loss

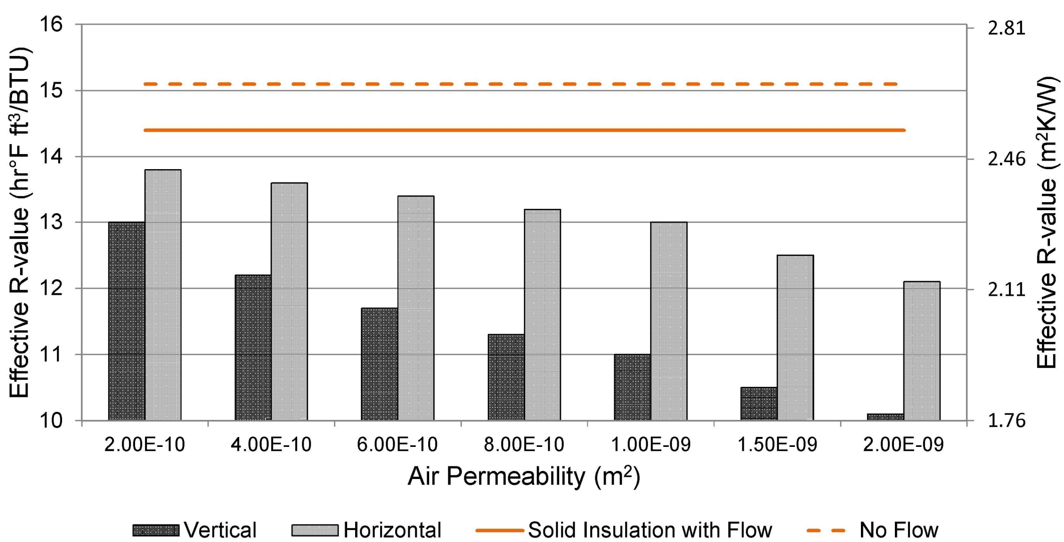
Heat Flux in Response to Vertical & Horizontal Flows



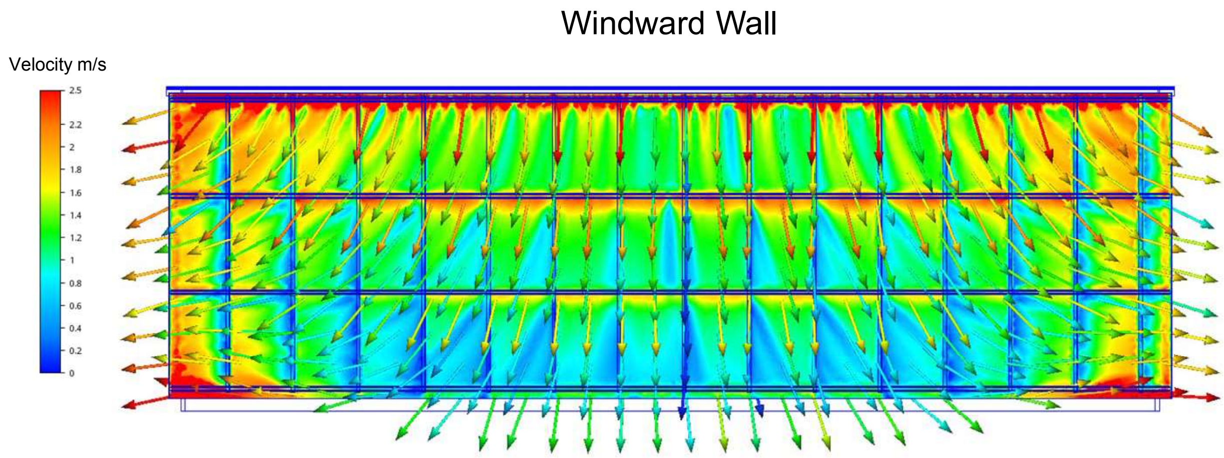
Effective R Values: 1 m/s



Effective R Values: 2 m/s

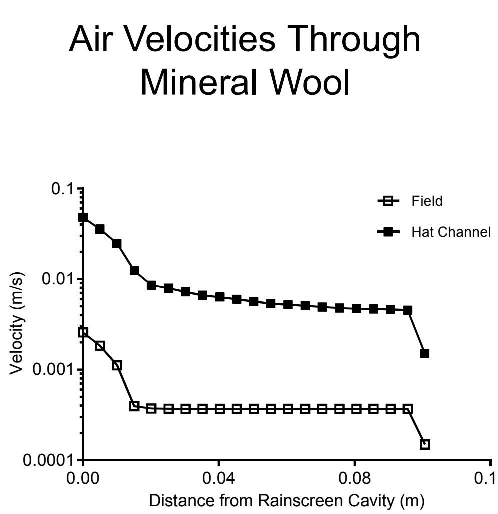


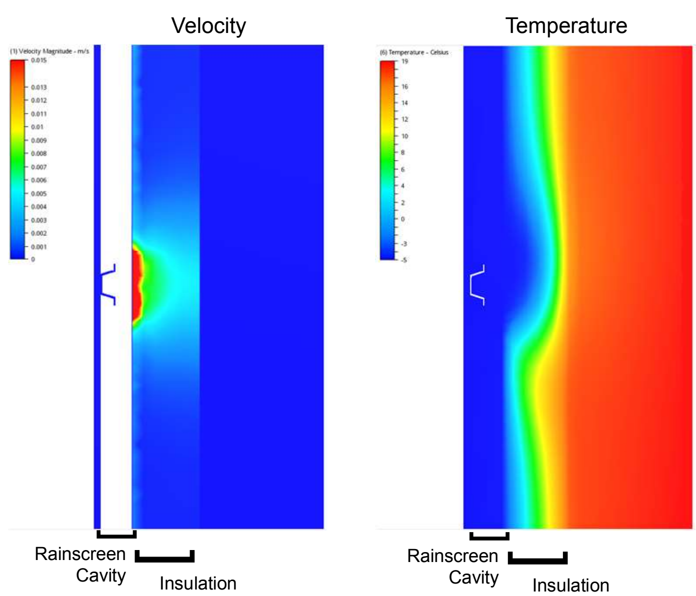
Rainscreen Airflows



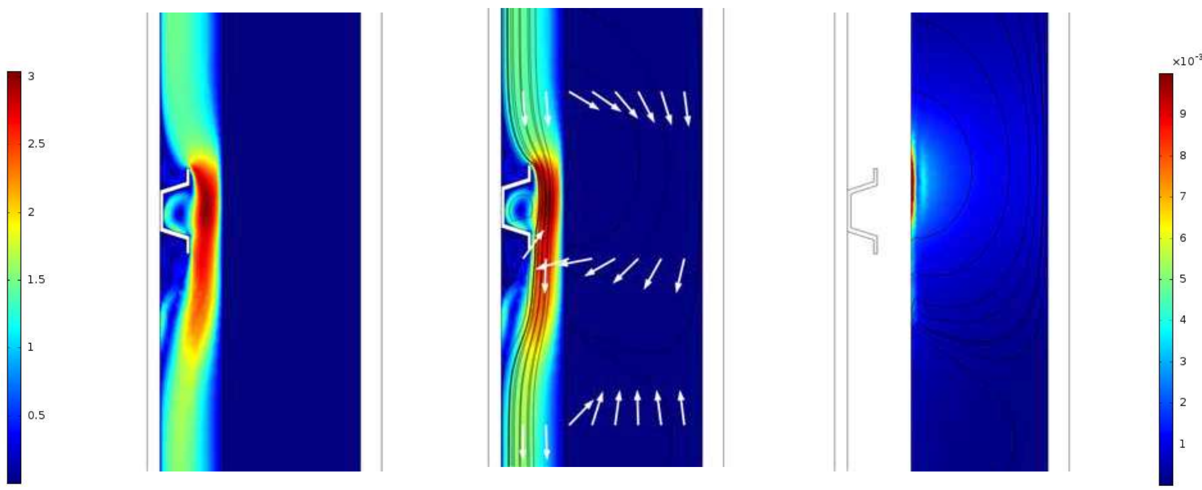
Rainscreen Velocities: 0.1 to >3 m/s (0.328 to 9.8 ft/s)

Convective Heat Loss



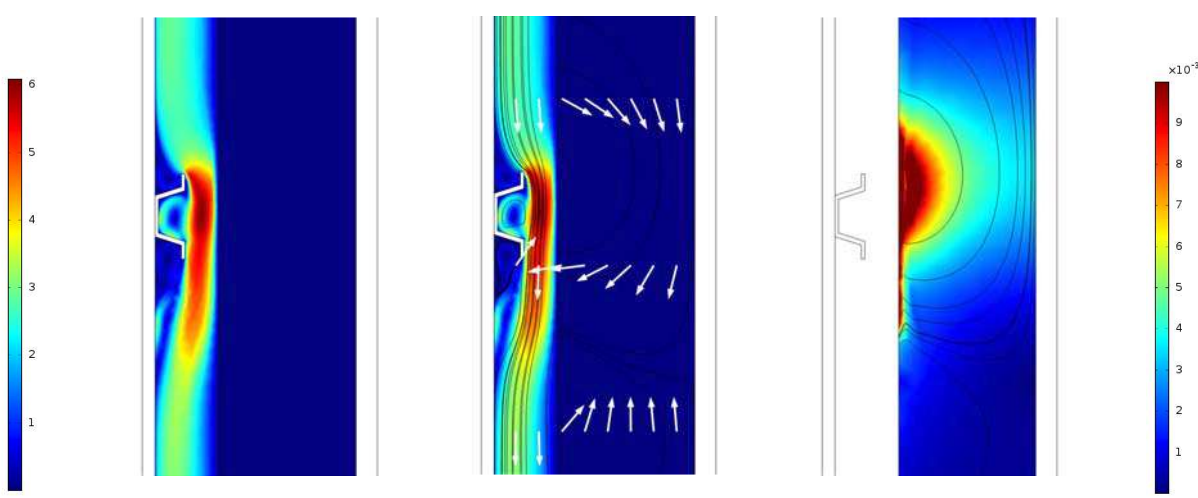


Open Pore Transport: Vertical Flow at 1 m/s



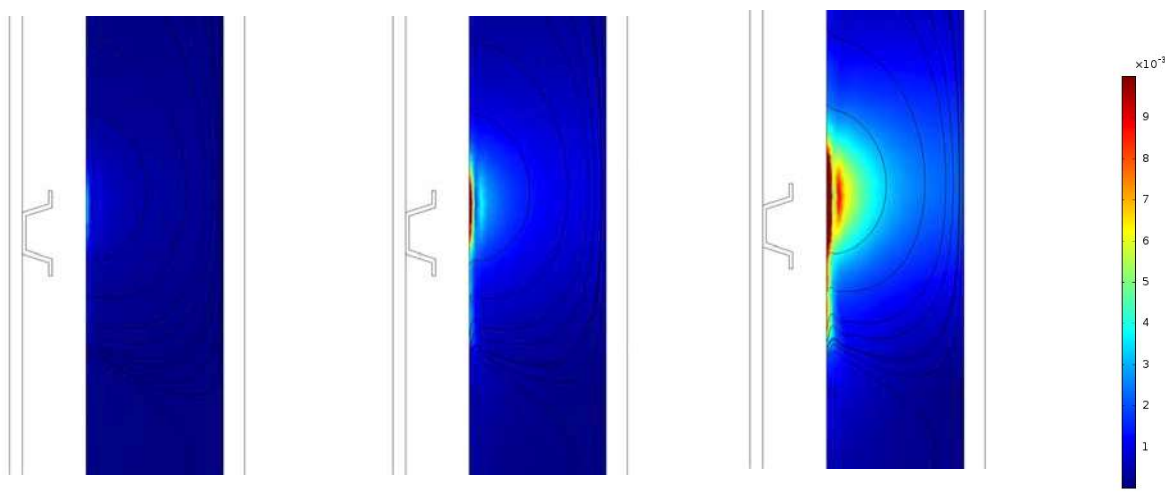
$8x10^{-10}$ m^2 (Density ~70 kg/m^3)

Open Pore Transport: Vertical Flow at 2 m/s



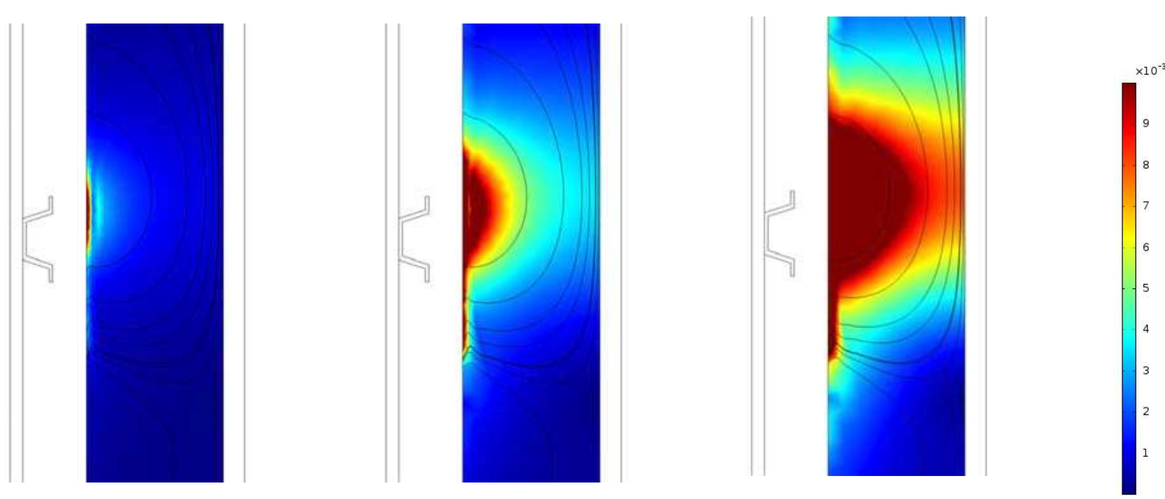
$8x10^{-10}$ m^2 (Density ~70 kg/m^3)

Open Pore Transport: Vertical Flow at 1 m/s



$2x10^{-10}$ m^2 (Density ~160 kg/m^3) | $8x10^{-10}$ m^2 (Density ~70 kg/m^3) | $2x10^{-9}$ m^2 (Density ~30 kg/m^3)

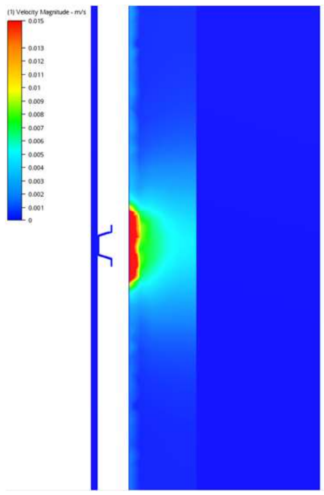
Open Pore Transport: Vertical Flow at 2 m/s



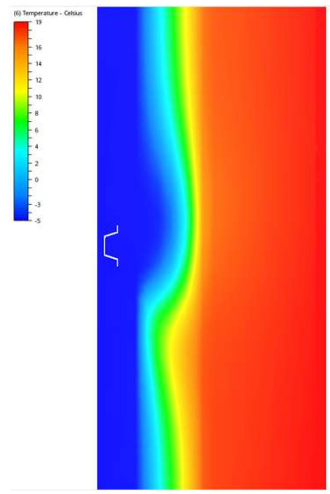
$2x10^{-10}$ m^2 (Density ~160 kg/m^3) | $8x10^{-10}$ m^2 (Density ~70 kg/m^3) | $2x10^{-9}$ m^2 (Density ~30 kg/m^3)

Convective Heat Loss

Velocity

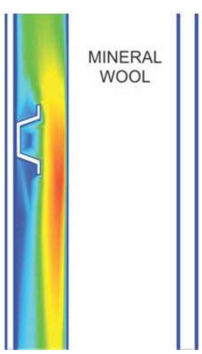


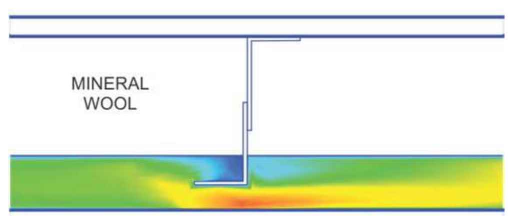
Temperature



Hat Channel Assembly

Reduction in Effective R-Value



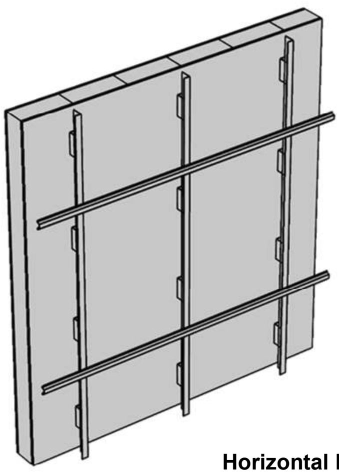


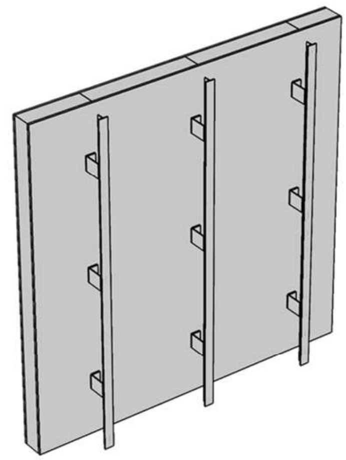
Vertical
↓ 7% to 33% (compared to no-flow condition)

Horizontal
↓ 7% to 19% (compared to no-flow condition)

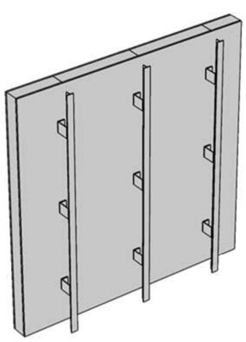
(Reduction due to thermal bridging = ↓ 27%)

Comparing Cladding Attachment Systems



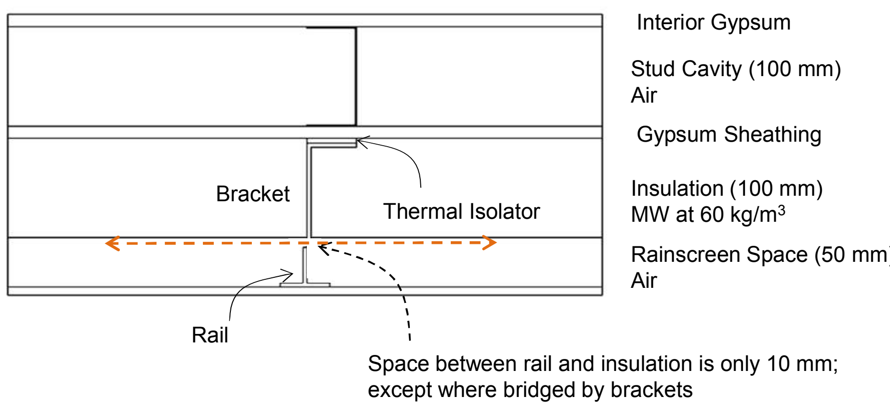


Vertical Rail Assembly



Rails at every stud
(600 mm oc)

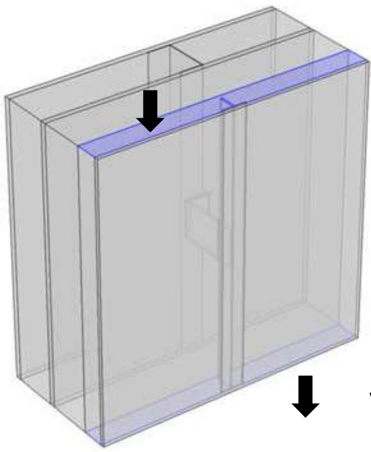
Brackets at 600 mm oc



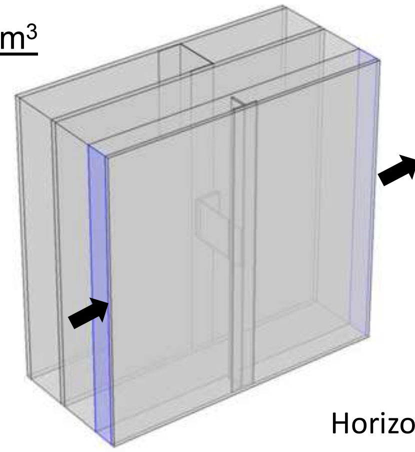
Vertical Rail Assembly

Inlet Fows: 0.1, 0.5, 1, 1.5, and 2.0 m/s

Density = 60 kg/m^3

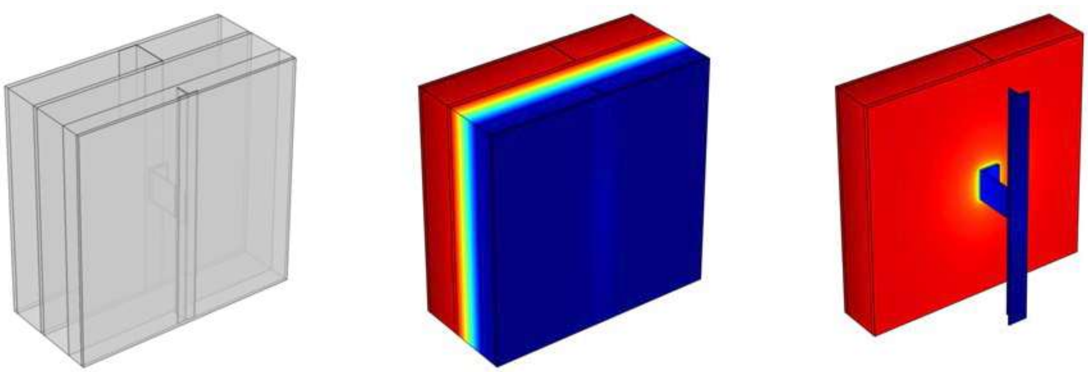


Vertical



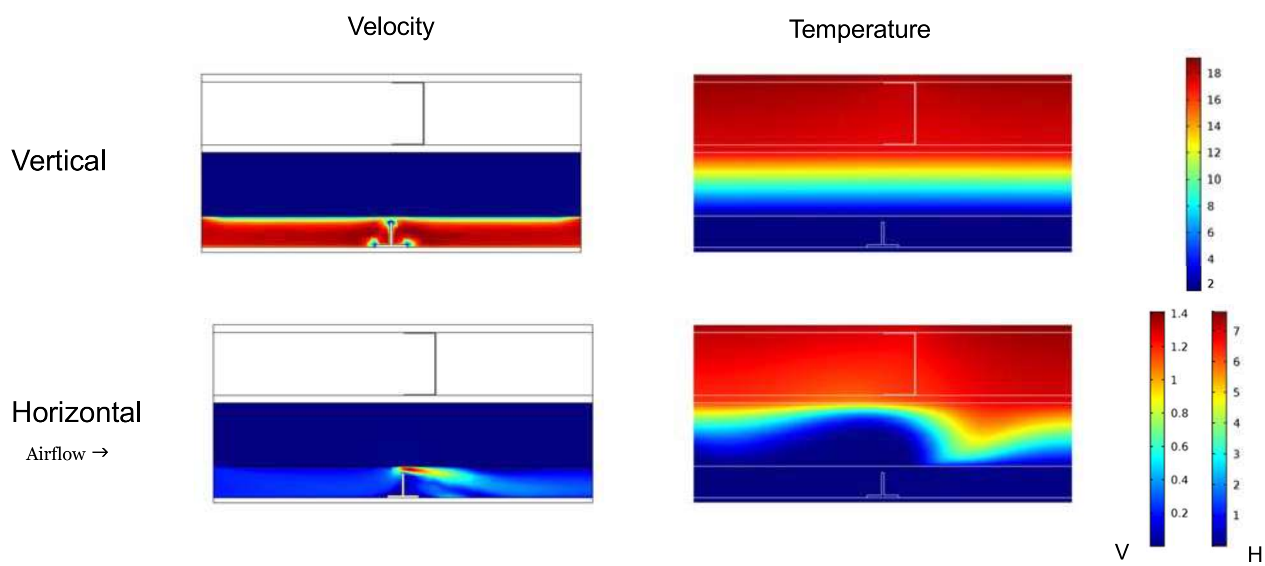
Horizontal

Vertical Rail Assembly

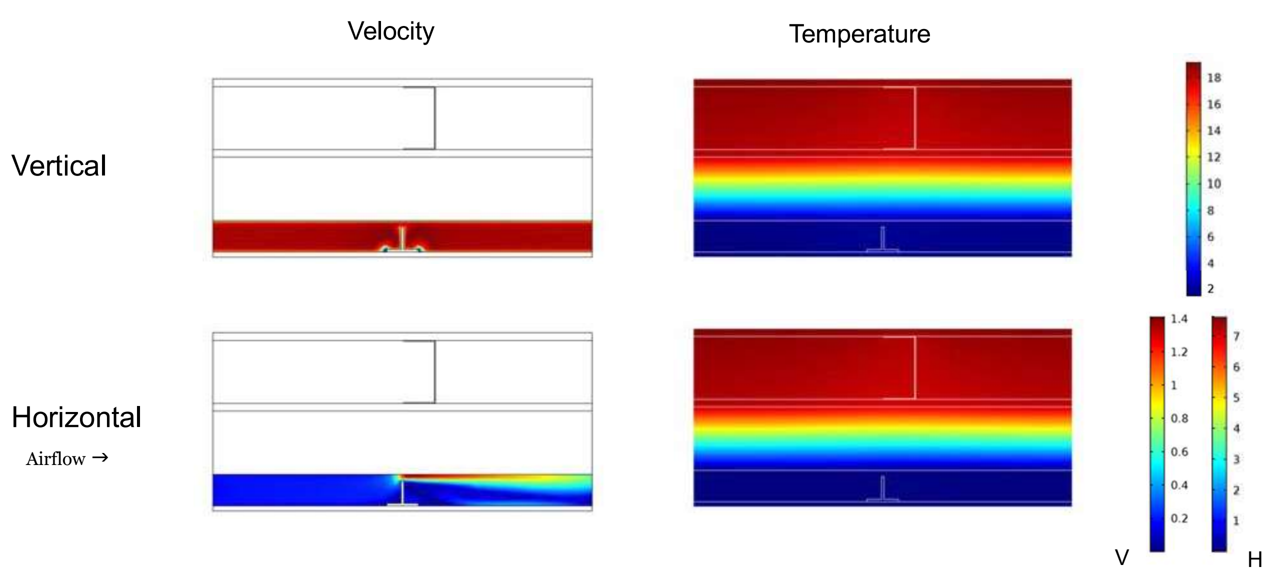


Effective R-Value with Thermal Bridging Components = 14.6 (2.56 RSI)
(↓ 27% reduction)

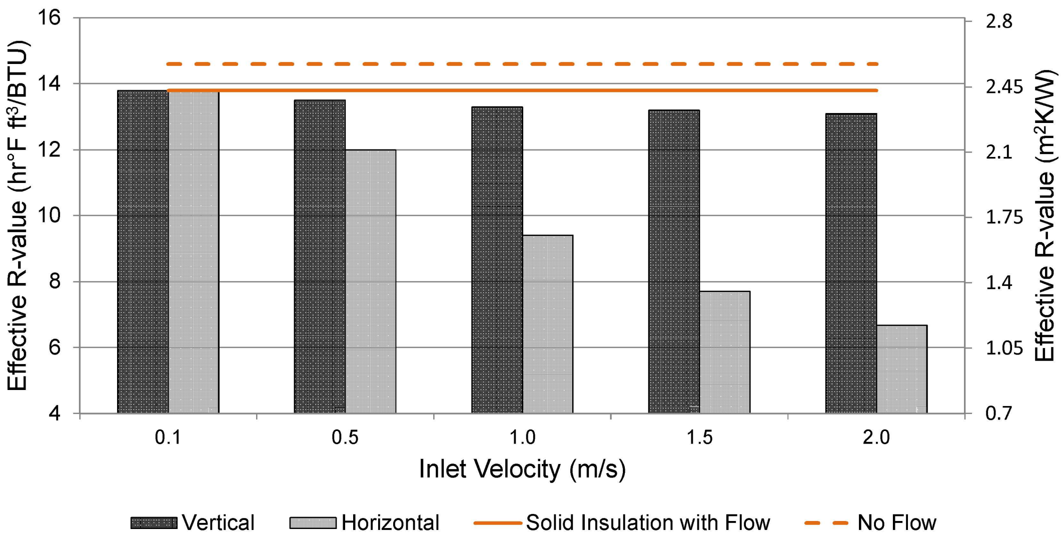
Vertical Rail Assembly: Mineral Wool



Vertical Rail Assembly: Solid Insulation

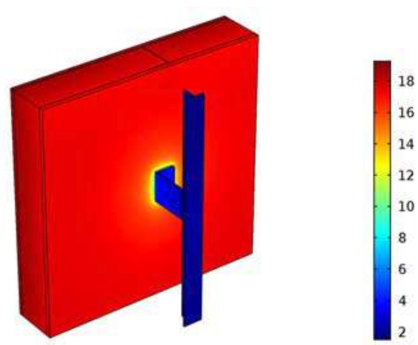


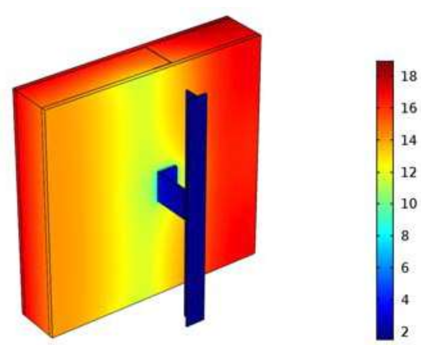
Effective R-Values: Fibrous Insulation



Vertical Rail Assembly

Reduction in Effective R-Value



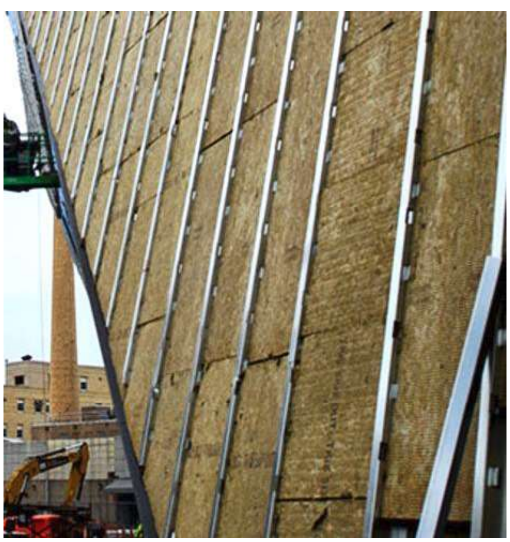


Vertical
↓ 5% to 10% (compared to no-flow condition)

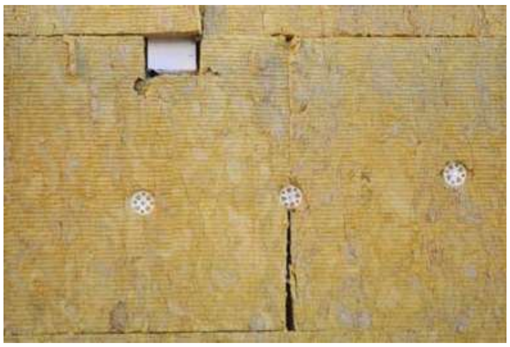
Horizontal
↓ 5% to 54% (compared to no-flow condition)

Insulation Gaps

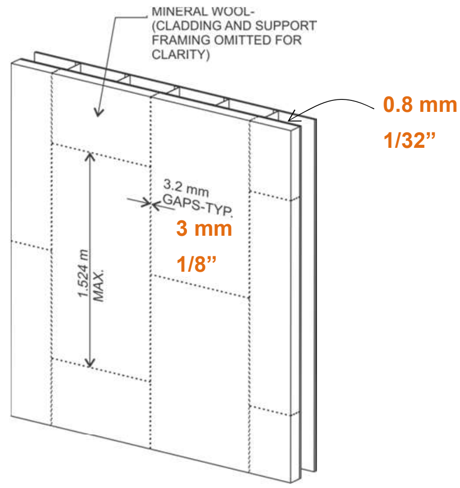

Case Study: Insulation Gaps



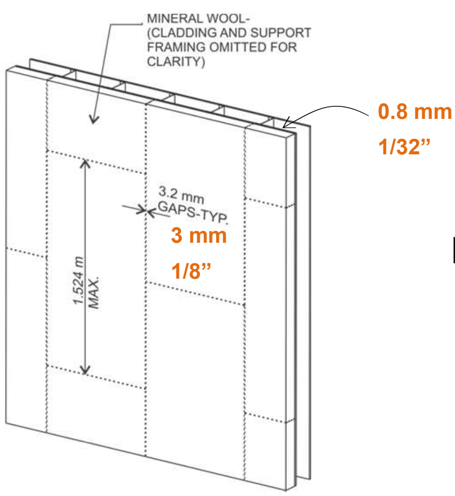

Insulation Gaps: Study Design

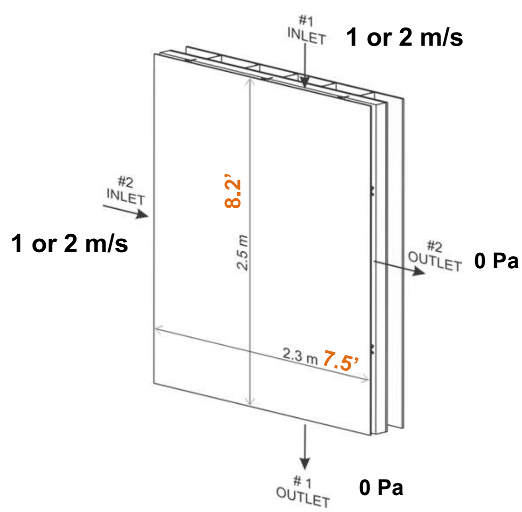


Hat channel model with MW air permeability of 1.0 x 10^{-9} (density of ~50 kg/m^3)



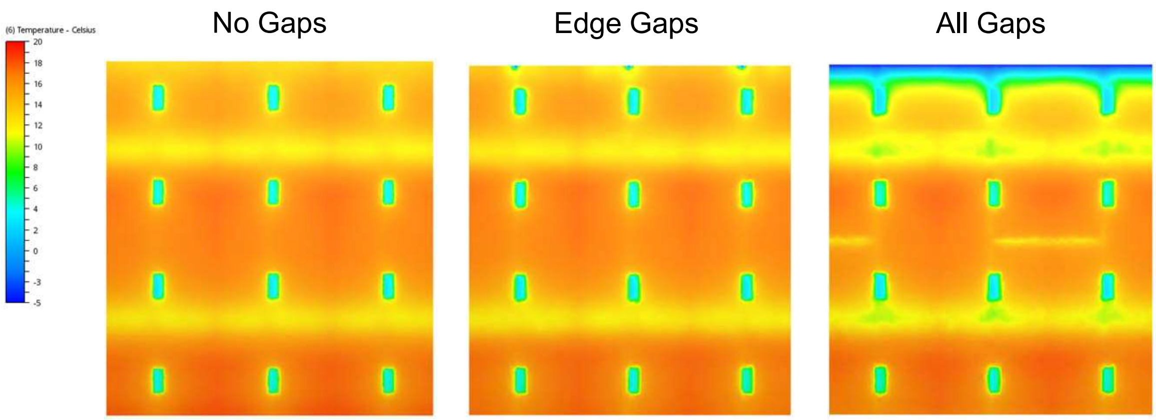
Insulation Gaps: Study Design





Insulation Gaps

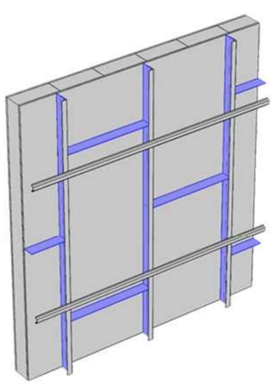
Thermal Conditions at Exterior Surfaces of Wall Sheathing: 2 m/s



Vertical flows at 2 m/s

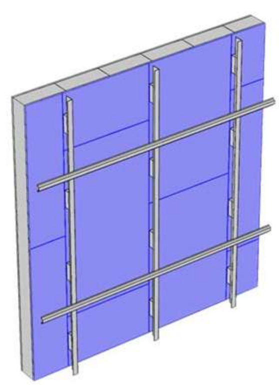
Hat Channel Assembly

Reduction in Effective R-Value



No Gaps
↓ 7% to 14%
(for the same density)

Gaps: Solid Insulation
↓ 11% to 46%



Edge Gaps
↓ 12% to 30% (compared to no-flow condition)

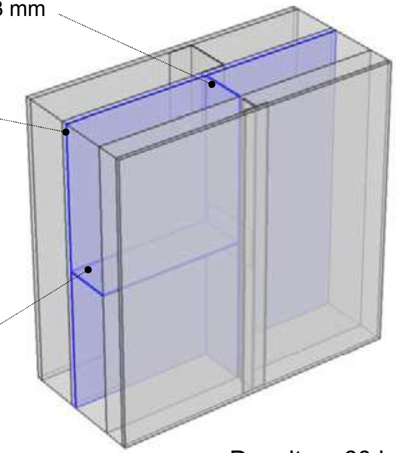
Edge & Back Gaps
↓ 24% to 42% (compared to no-flow condition)

Vertical Rail Assembly

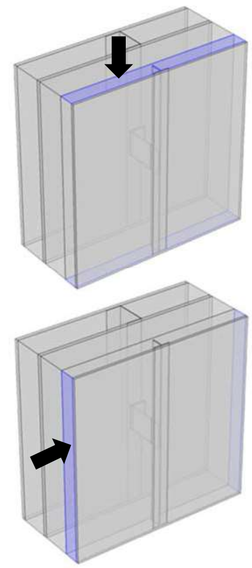
Vertical Edge Gap:
Gap Width = 3 mm

Back Gap:
Gap Width = 0.8 mm

Horizontal Edge Gap:
Gap Width = 3 mm



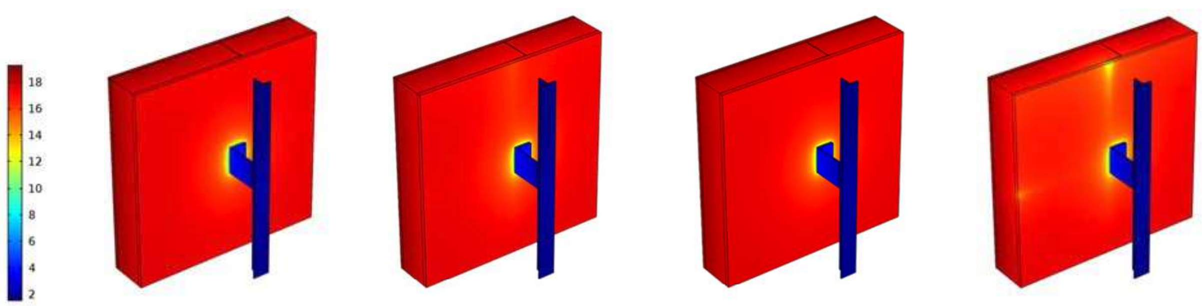
Density = 60 kg/m^3



Inlet Flows
1 m/s

Vertical Rail Assembly

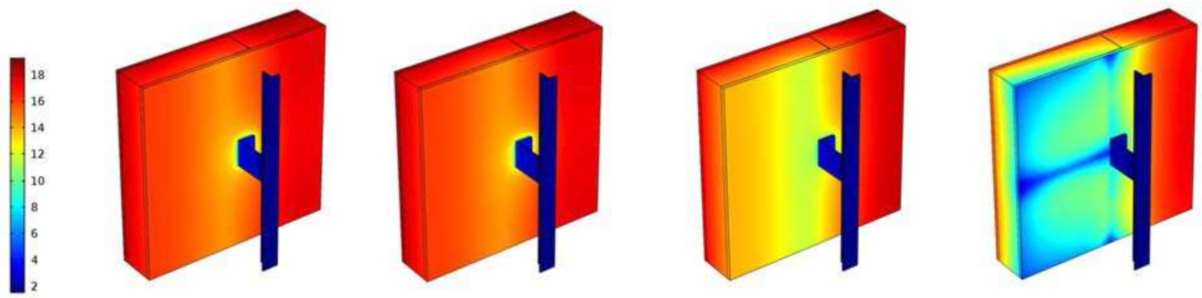
Vertical Flows at 1 m/s



No Gaps | Edge Gaps | Back Gaps | Combined Gaps

Vertical Rail Assembly

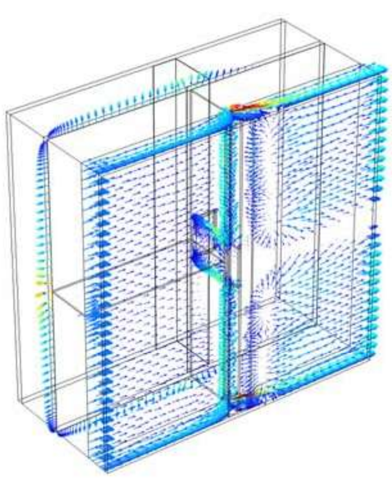
Horizontal Flows at 1 m/s

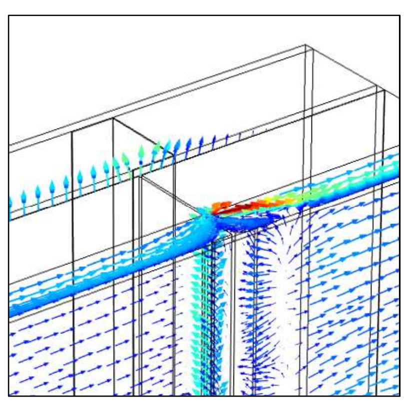


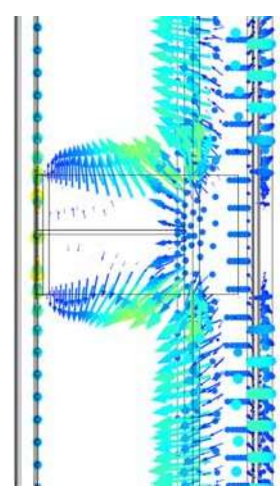
No Gaps | Edge Gaps | Back Gaps | Combined Gaps

Vertical Rail Assembly

Gap Flow

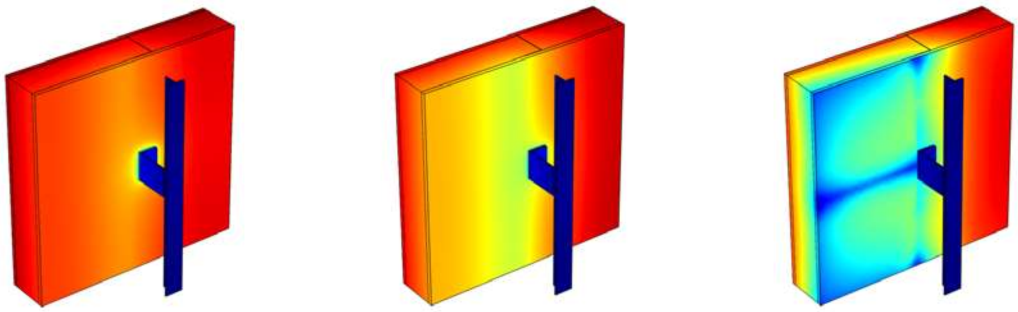






Vertical Rail Assembly

Reduction in Effective R-Value



Edge Gaps
↓ 11% to 39%
(compared to no-flow condition)

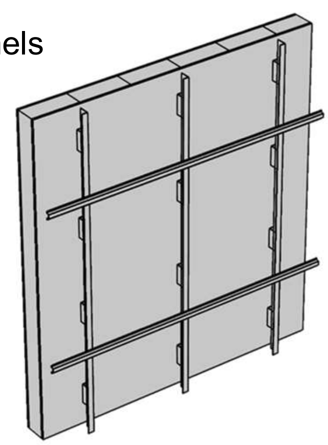
Back Gap
↓ 9% to 52%
(compared to no-flow condition)

Combined Gaps
↓ 20% to 69%
(compared to no-flow condition)

* No Gaps = ↓ 8% to 36% at 1 m/s

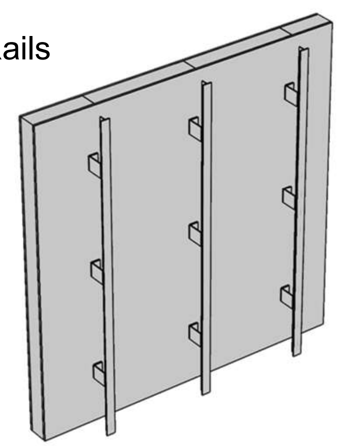
Insulation Gaps: Comparing Assemblies

Hat Channels



1 m/s: ↓12% to 28%
2 m/s: ↓14% to 42%

Vertical Rails



1 m/s: ↓ 9% to 69%
2 m/s: not simulated

Wind Washing & Convective Heat Loss

Mechanism	Effective R Value	Primary Factors	Types of Insulation Affected

Prior Research: Hot/Cold Plate Studies

Van Straaten R, Trainor T. 2014. Effects of wind washing on Roxul mineral wool sheathing in low-rise residential buildings. Building Science Laboratories.

Density = 70 kg/m^3

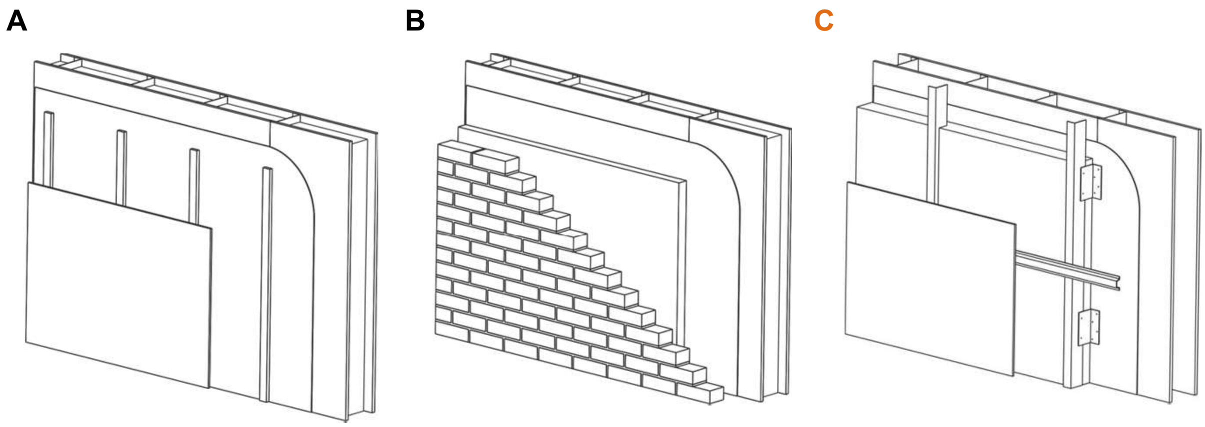
0.1 m/s (Low Wind) — 1 m/s (High Wind)

ROXUL™ CAVITYROCK® MD Thickness	No Wind		Low Wind		High Wind	
	U-Value W/m2 °C	R-Value hr ft^2 °F/Btu	U-Value W/m2 °C	R-Value hr ft^2 °F/Btu	U-Value W/m2 °C	R-value hr ft^2 °F/Btu
32 mm (1.25”)	1.35	4.2	1.35	4.2	1.49	3.8
51 mm (2”)	0.68	8.4	0.68	8.4	0.69	8.2
76 mm (3”)	0.45	12.6	0.45	12.6	0.46	12.4

1.6% Reduction in R-Value

Our Studies: 1.4% Reduction in R-Value for the same density of insulation (4”)

Rainscreen Airflow

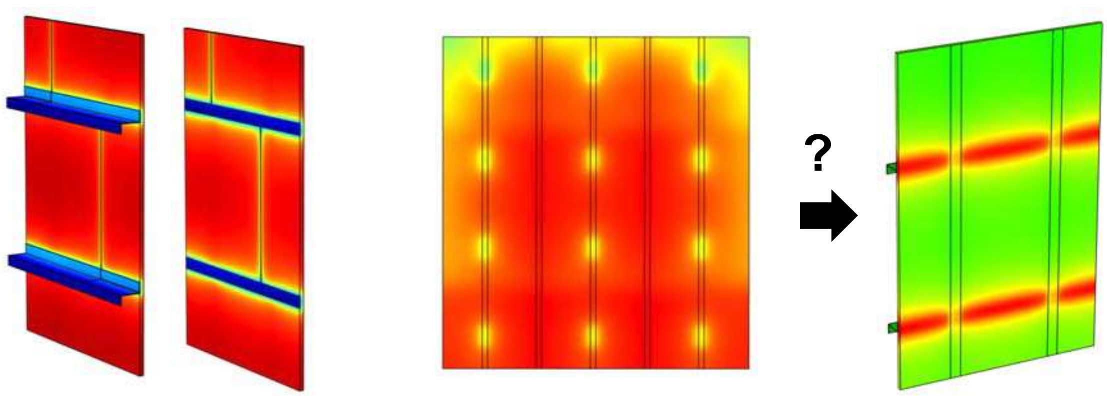


Smaller ventilation openings
Slightly-ventilated air layer
Simpler, planar airflow paths

Larger ventilation openings
Well-ventilated air layer
Complex 3D airflow paths

What are the effects on moisture transport?

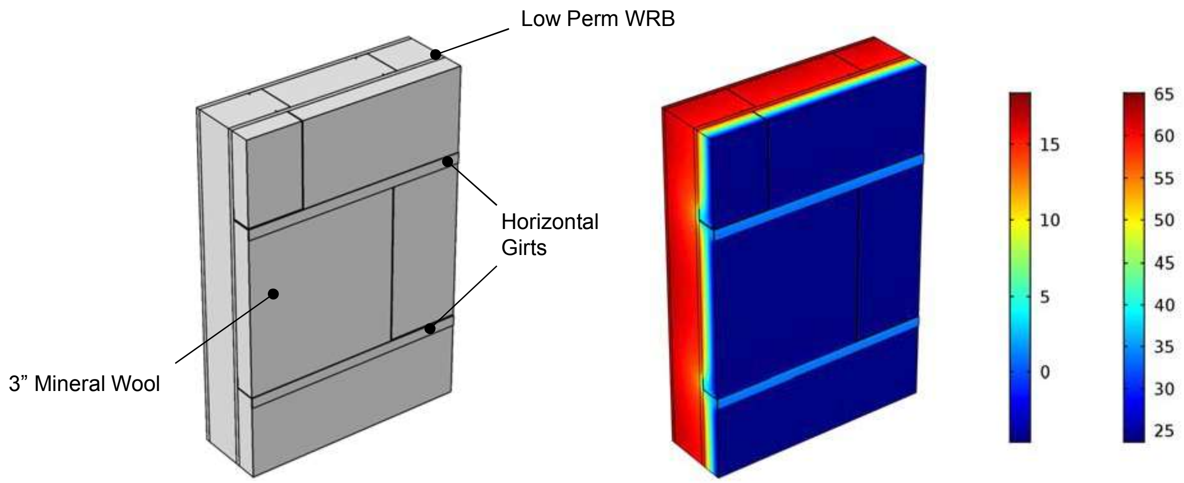
Conductive Processes | Convective Processes | Moisture Transport



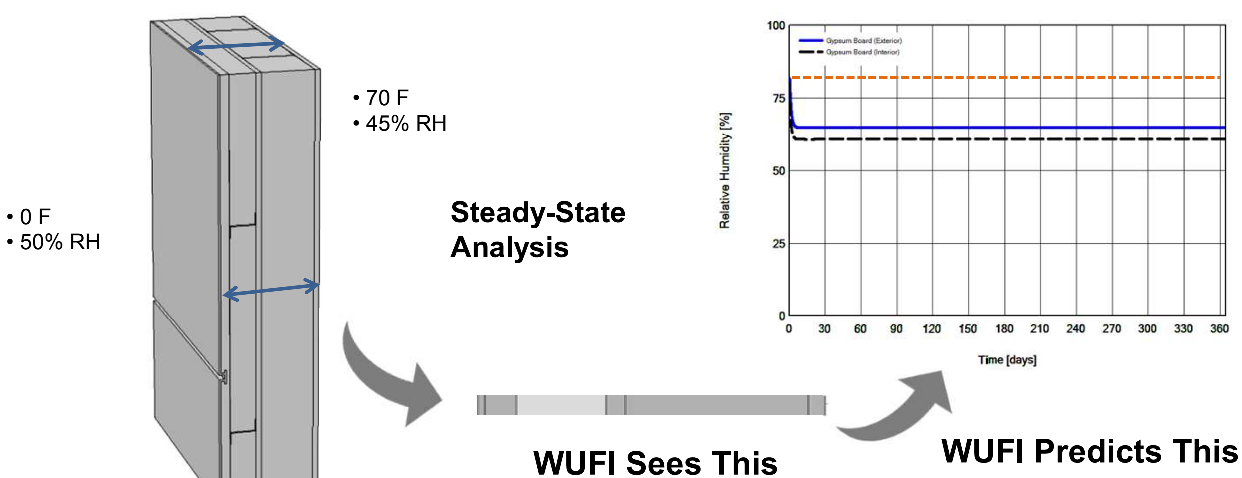
R-values: ↓~10 - 60%

R-values: ↓~10 - 70%

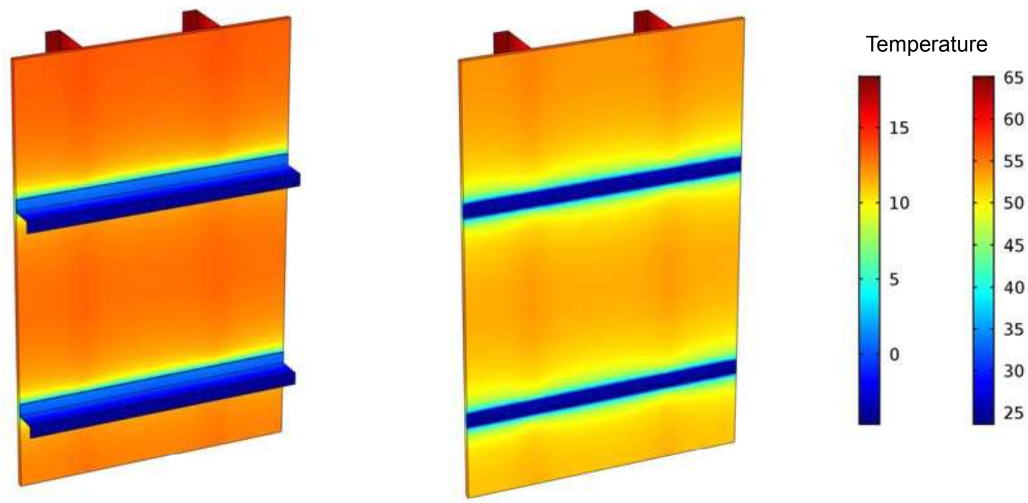
Moisture Transport: Effects of Thermal Bridging



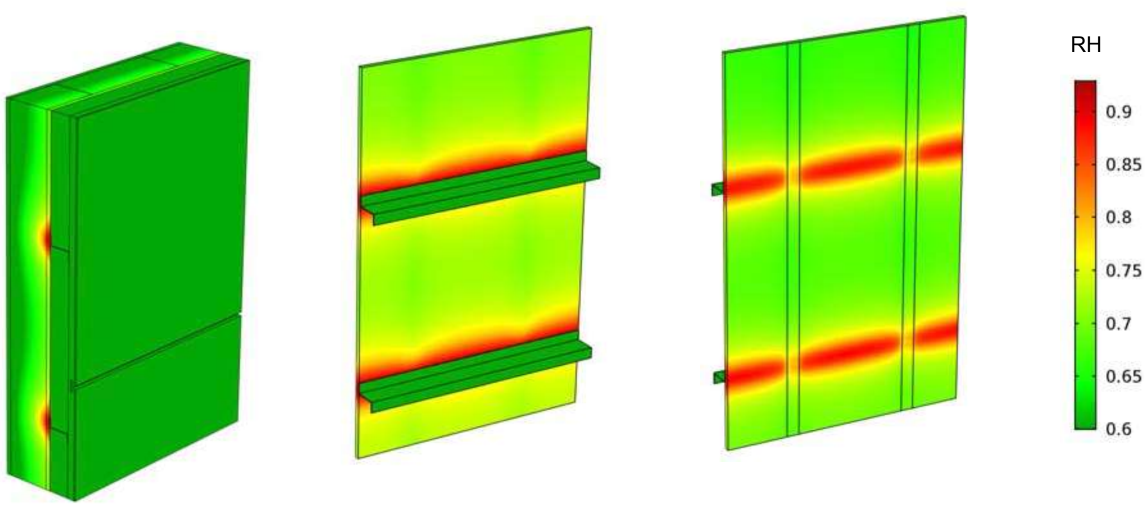
Moisture Transport: Effects of Thermal Bridging



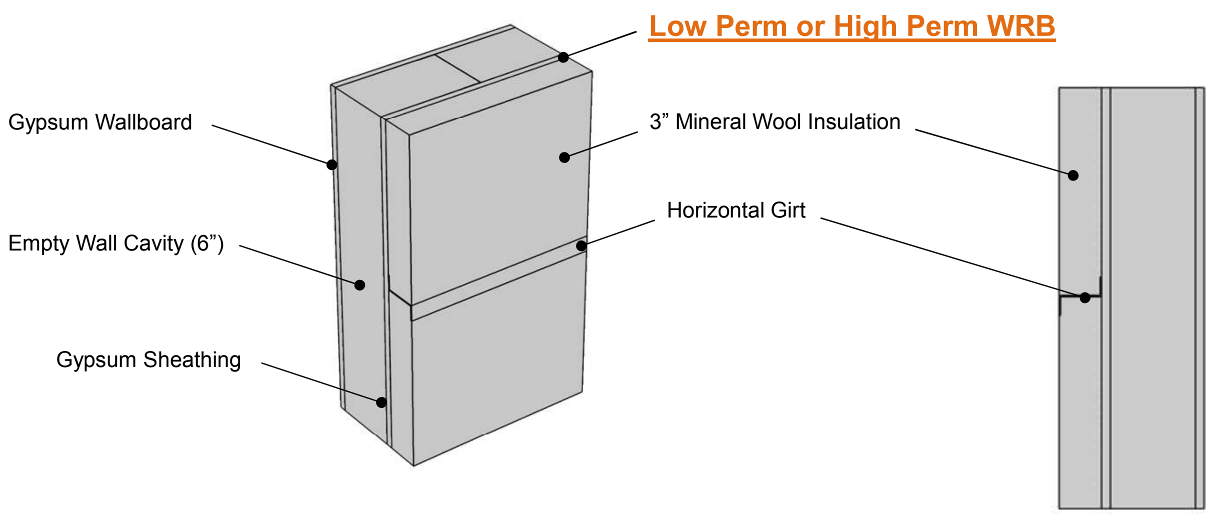
Moisture Transport: Effects of Thermal Bridging



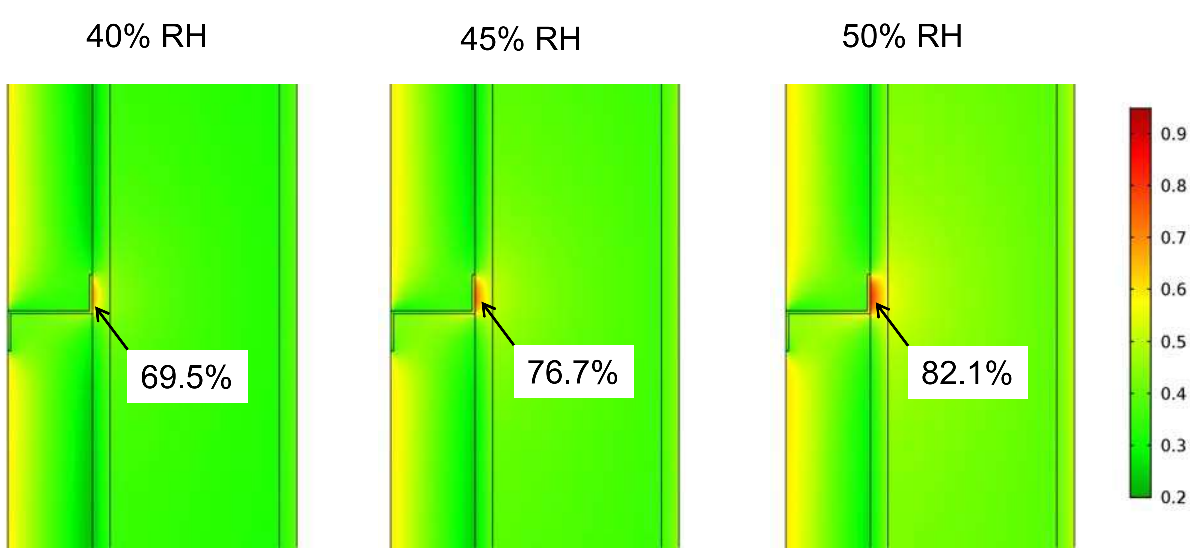
Moisture Transport: Effects of Thermal Bridging



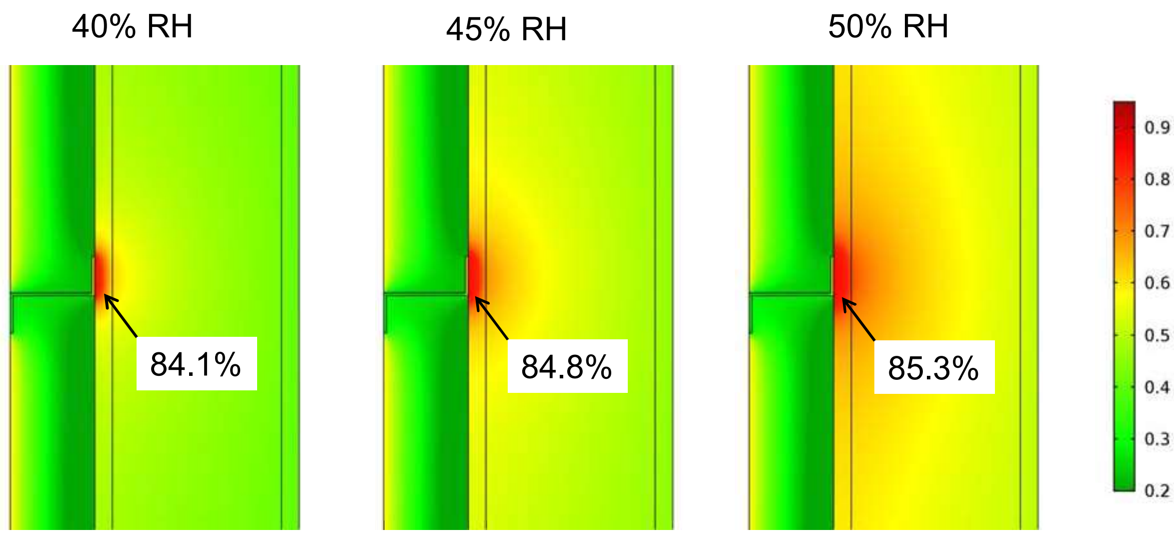
Moisture Transport: Effects of Thermal Bridging



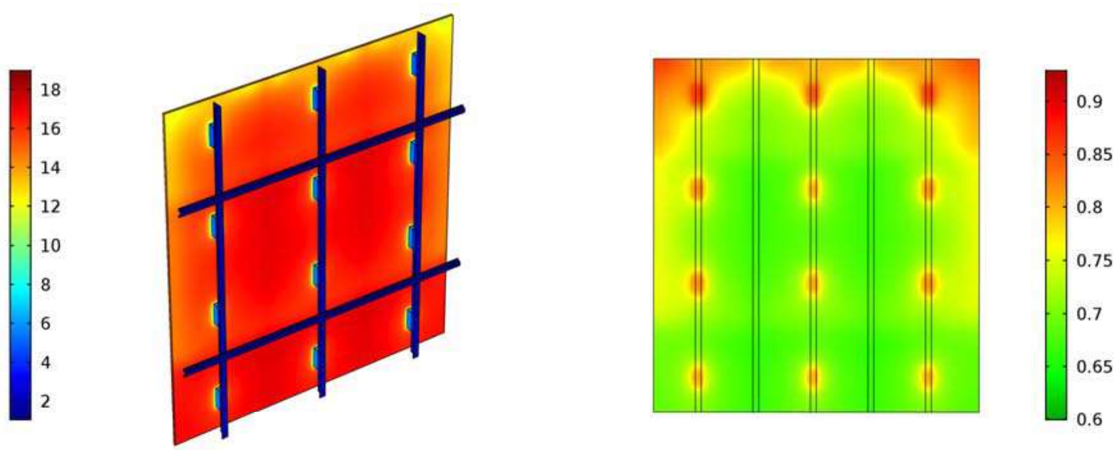
Moisture Transport: High-Perm WRB



Moisture Transport: Low-Perm WRB

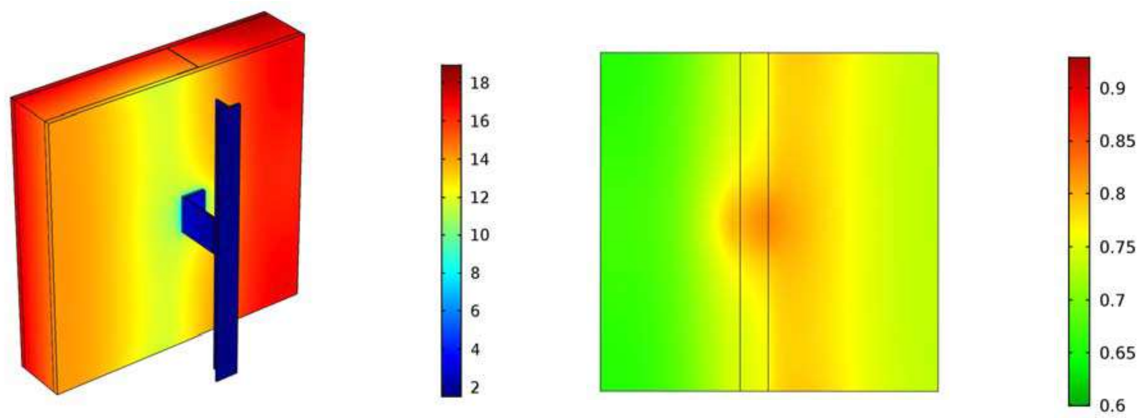


Moisture Transport: Effects of Convection



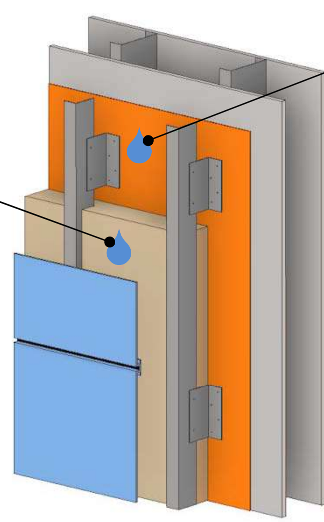
Hat Channel Assembly: Gaps

Moisture Transport: Effects of Convection



Vertical Rail Assembly: Horizontal Flow

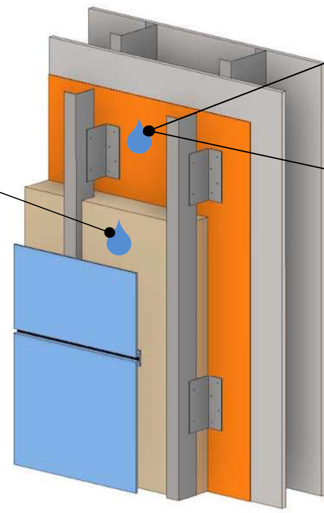
Moisture Transport: Drainage Efficiency



Moisture Transport: Drainage Efficiency

Drainage Plane #1

"Rainscreen Cavity Plane"



Drainage Plane #2

"AB / WRB Plane"

1%

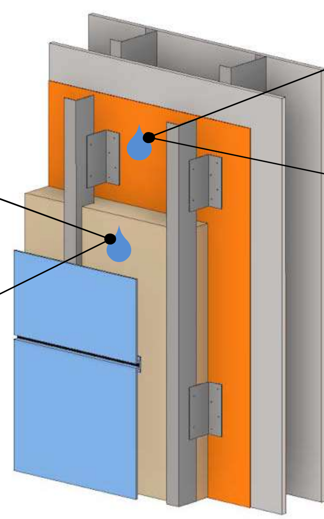
Moisture Transport: Drainage Efficiency

Drainage Plane #1

"Rainscreen Cavity Plane"

Problems
Not at AB / WRB plane,

Not continuous with typical wall flashings



Drainage Plane #2

"AB / WRB Plane"

Problems
Low drainage efficiency

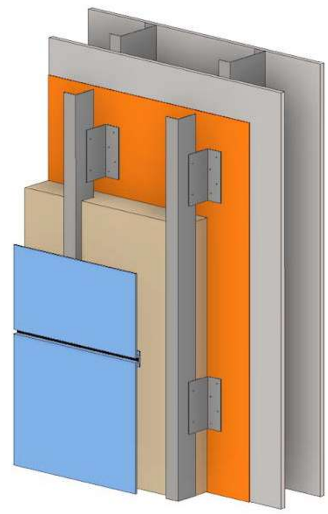
Low drying potential

Air gaps create thermal bypasses

Potential Problems → Solutions

Design Considerations

1. Building Shape & Orientation
2. Rainscreen Geometry
3. Cladding Attachment Spacing
4. Location of Gaps Relative to Cladding Attachment
5. Ventilation Openings
6. Insulation Type: Density / Air Permeability
7. Insulation Fastening
8. Gap Treatment
9. Drainage Efficiency
10. Type of Water-Resistive Barrier



Solutions

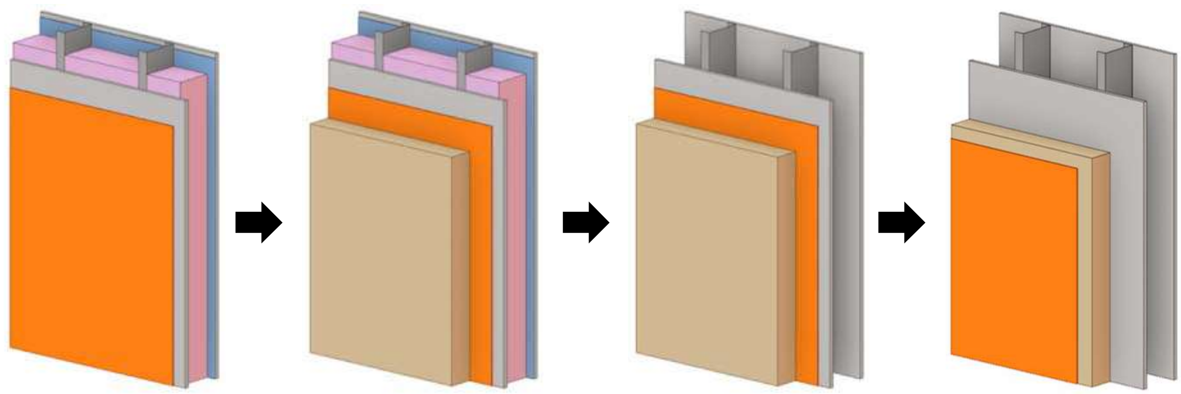
The Building Enclosure Core *Cladding-centric perspective → performance-centric perspective*

1 Simplicity
2 Adaptability
3 Performance

Moisture Resilience
- Independent of cladding type
- Accommodates high moisture loading
- High drying capacity
- Redundant safeguards
- Considers human errors
- Considers reasonable climate extremes
- High constructability

Air Management & Thermal Efficiency
- Emphasizes exterior CI
- Improves air management
- Minimizes thermal bridging
- Minimizes convective heat loss
- Achieves high R-values
- Adaptable to all climates
- High constructability

Solutions: Evolution of the Modern Wall

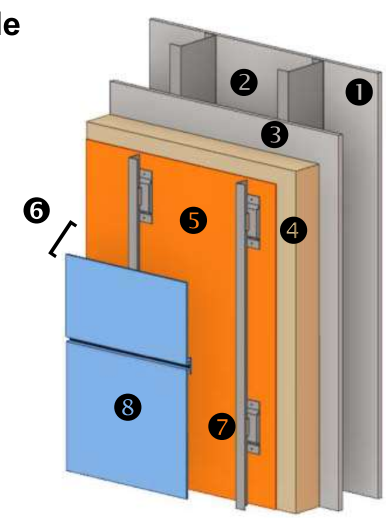


- Vapor Barrier - Thermal Bridging	- Vapor Barrier - Dual Drainage Plane - Thermal Bridging	- Dual Drainage Plane - Thermal Bridging / Gaps - Convective Heat Loss	- Thermal Bridging / Gaps - Convective Heat Loss - Material Properties

Strategies for Higher Performing Walls

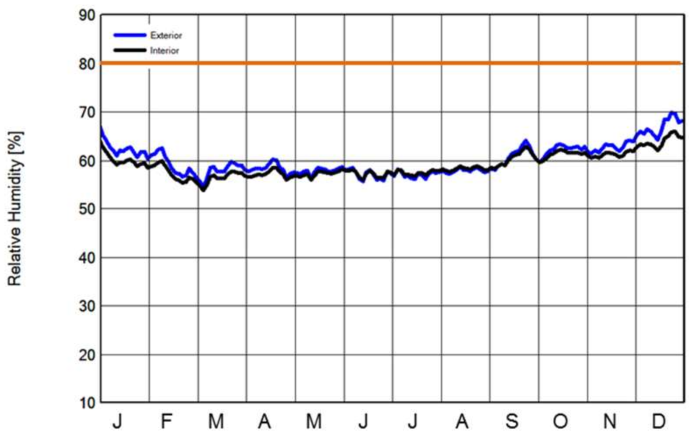
The Building Enclosure Core: An Example

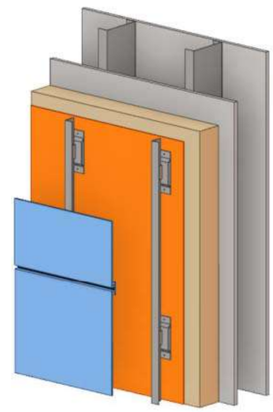
1. Interior Wall Panel
2. Empty Study Cavity
3. Gypsum Glass-Faced Sheathing
4. Polyiso: 2" to 3.5" (glass-faced)
5. Type II WRB – Exterior (ASTM E2556)
   * alternatively, omit WRB
6. Ventilated Rainscreen
7. Cladding Attachment - variable
8. Cladding



Strategies for Higher Performing Walls

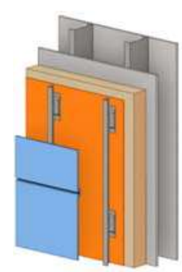
The Building Enclosure Core: An Example





Strategies for Higher Performing Walls

The Building Enclosure Core: An Example



Simplicity

- Omits interior vapor retarders
- Omits cavity insulation
- Omits sheathing, where possible
- Omits redundant WRB
- Omits WRB, where possible

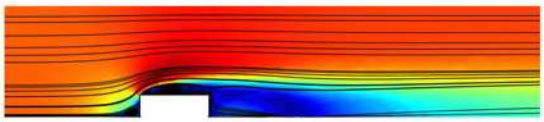
Adaptability

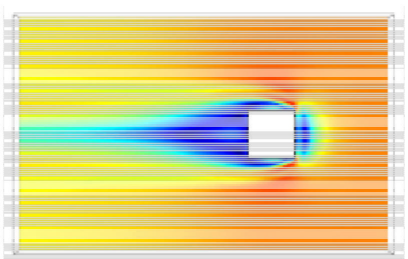
- Easily adaptable to all climate zones
- Readily adaptable to high energy performance
- Adaptable to all cladding types

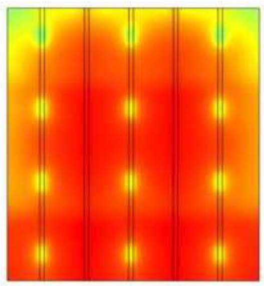
Performance

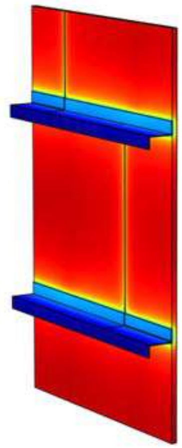
- Relies on exterior CI = simplifies moisture management
- Minimizes thermal bridging
- Weds drain plane to rainscreen cavity
- Vapor-permeable WRB: bidirectional drying
- Achieves air infiltration requirements

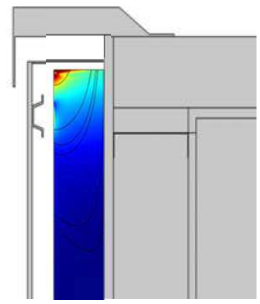
Closing Remarks











Thank You.

Insulated Rainscreens:
The Need to Rethink Conventional Design

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