

Joseph Lstiburek, Ph.D., P.Eng, ASHRAE Fellow

Building Science

Adventures In Building Science

www.buildingscience.com

What is a Building?

A Building is an Environmental Separator

- Control heat flow
- Control airflow
- Control water vapor flow
- Control rain
- Control ground water
- Control light and solar radiation
- Control noise and vibrations
- Control contaminants, environmental hazards and odors
- Control insects, rodents and vermin
- Control fire
- Provide strength and rigidity
- Be durable
- Be aesthetically pleasing
- Be economical

Arrhenius Equation

For Every 10 Degree K Rise
Reaction Rate Doubles

$$k = Ae^{-E_a/(RT)}$$

Damage Functions

Water

Heat

Ultra-violet Radiation

2nd Law of Thermodynamics

Heat Flow Is From Warm To Cold

Moisture Flow Is From Warm To Cold

Moisture Flow Is From More To Less

Air Flow Is From A Higher Pressure to a
Lower Pressure

Gravity Acts Down

Thermodynamic Potential



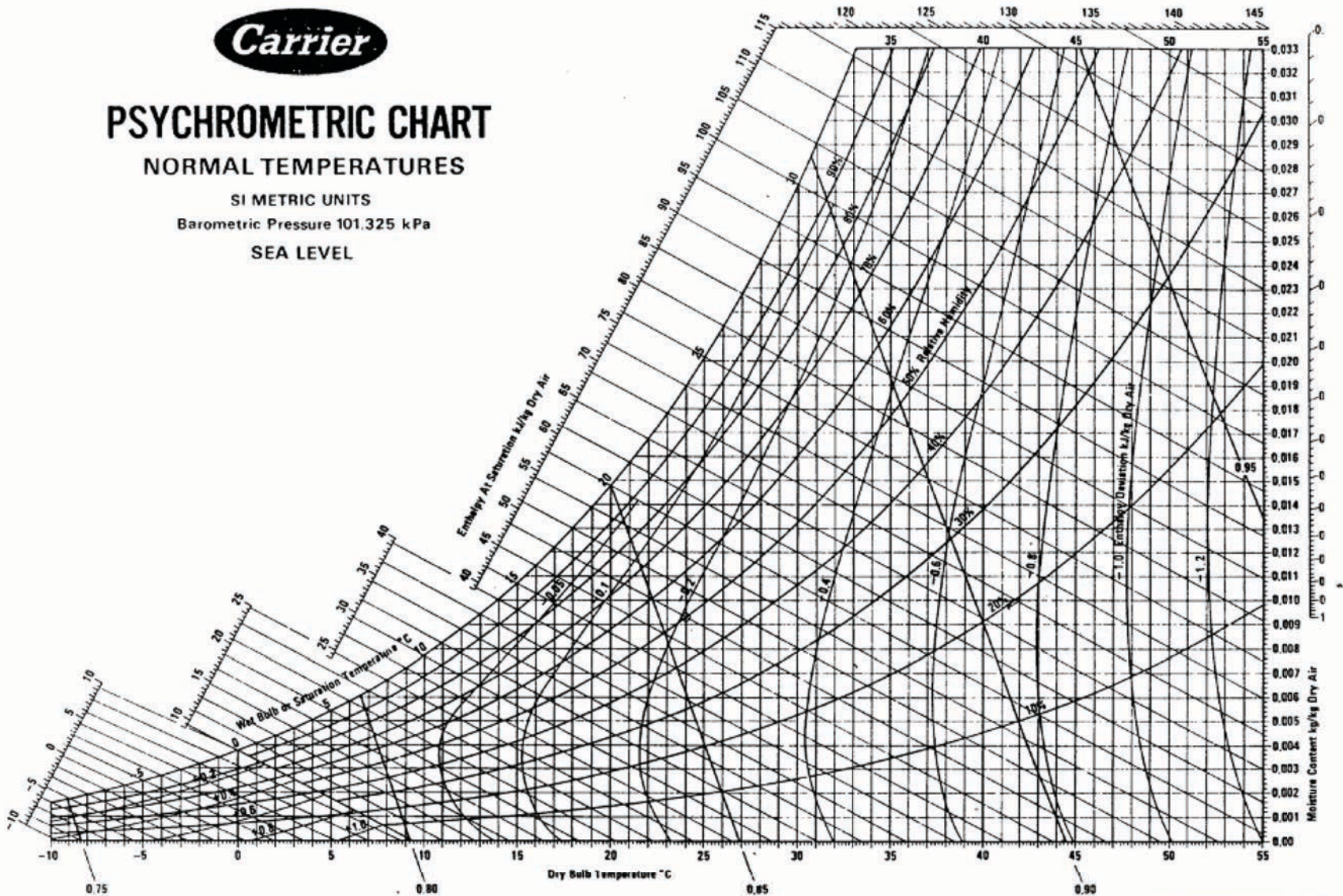
PSYCHROMETRIC CHART

NORMAL TEMPERATURES

SI METRIC UNITS

Barometric Pressure 101.325 kPa

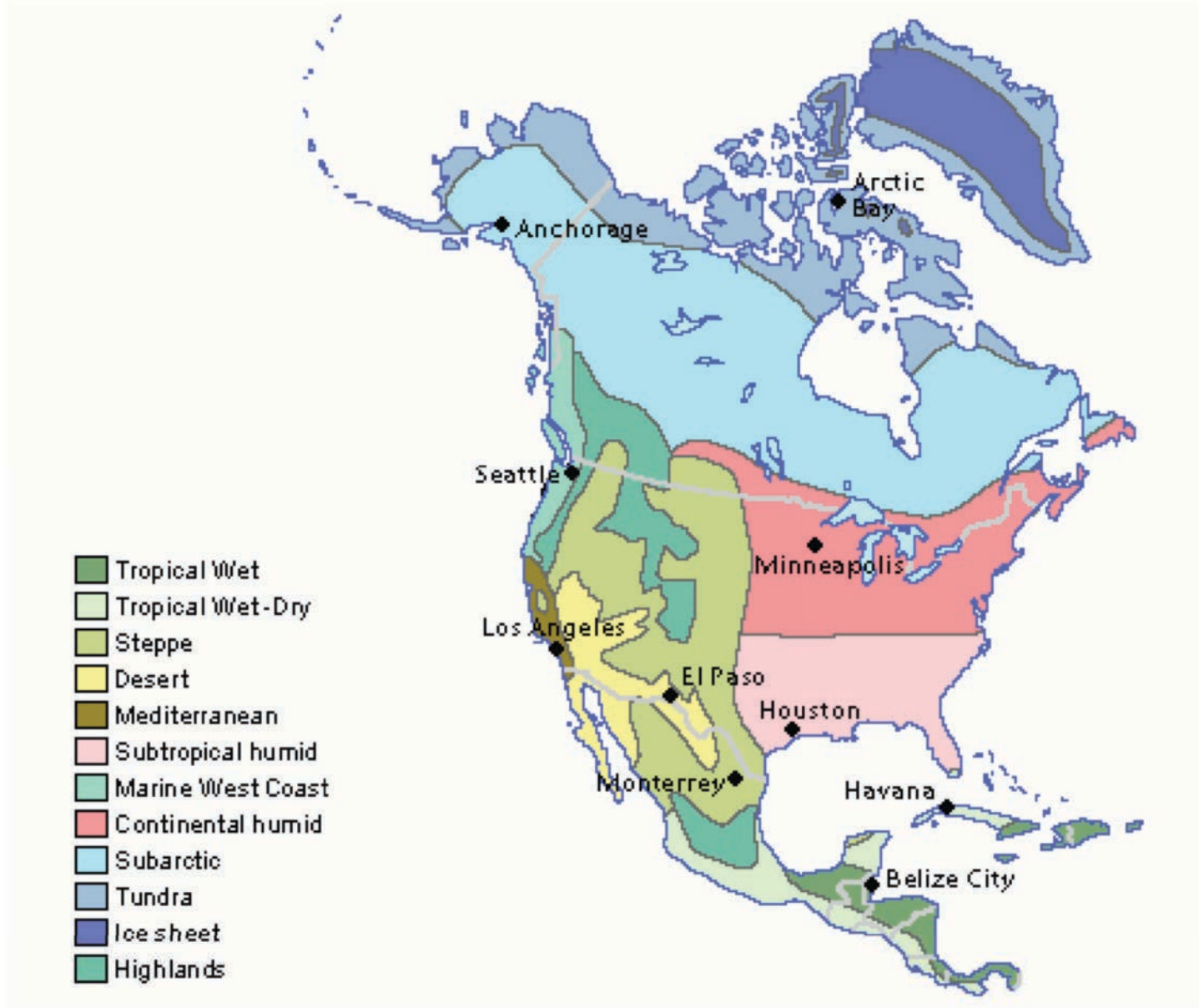
SEA LEVEL



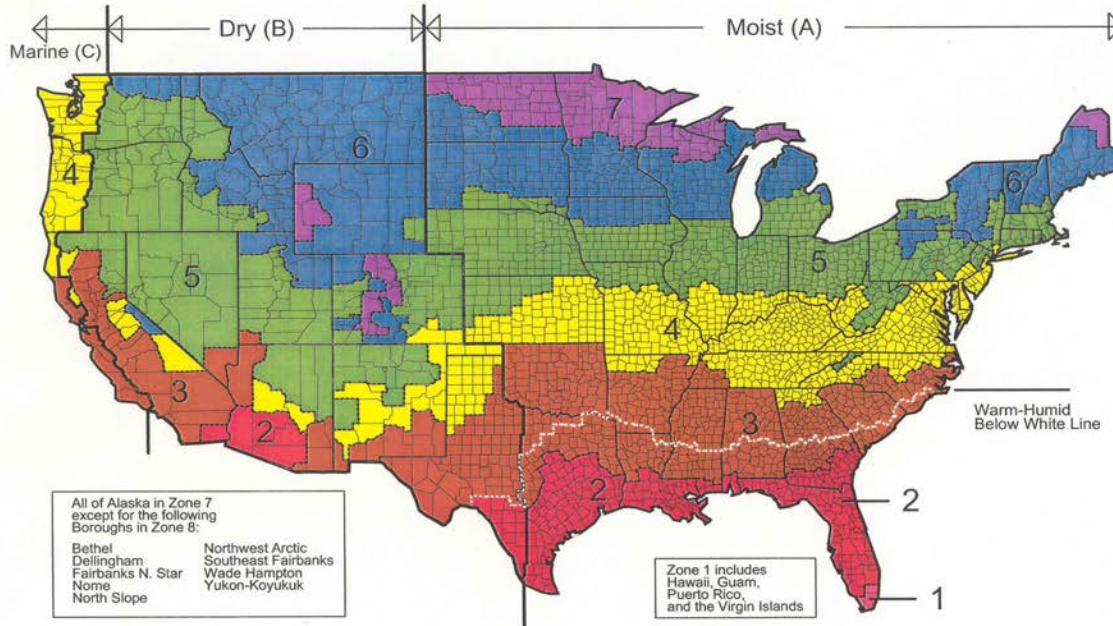
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice

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


Map of DOE's Proposed Climate Zones

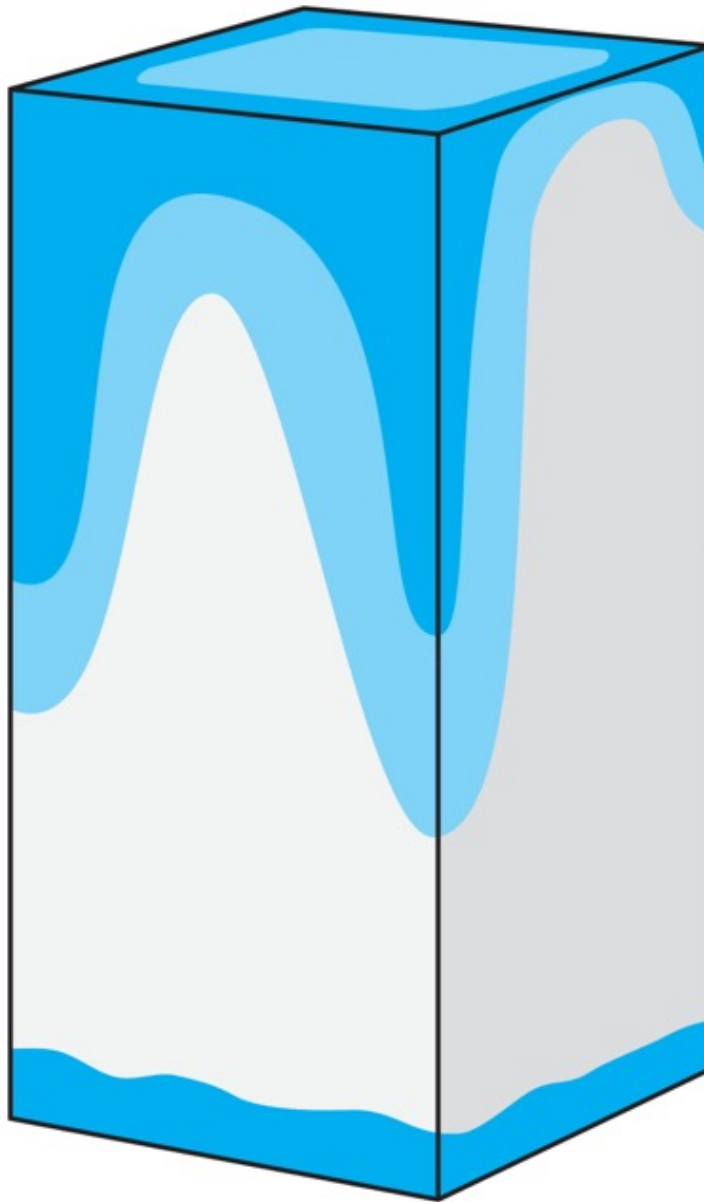


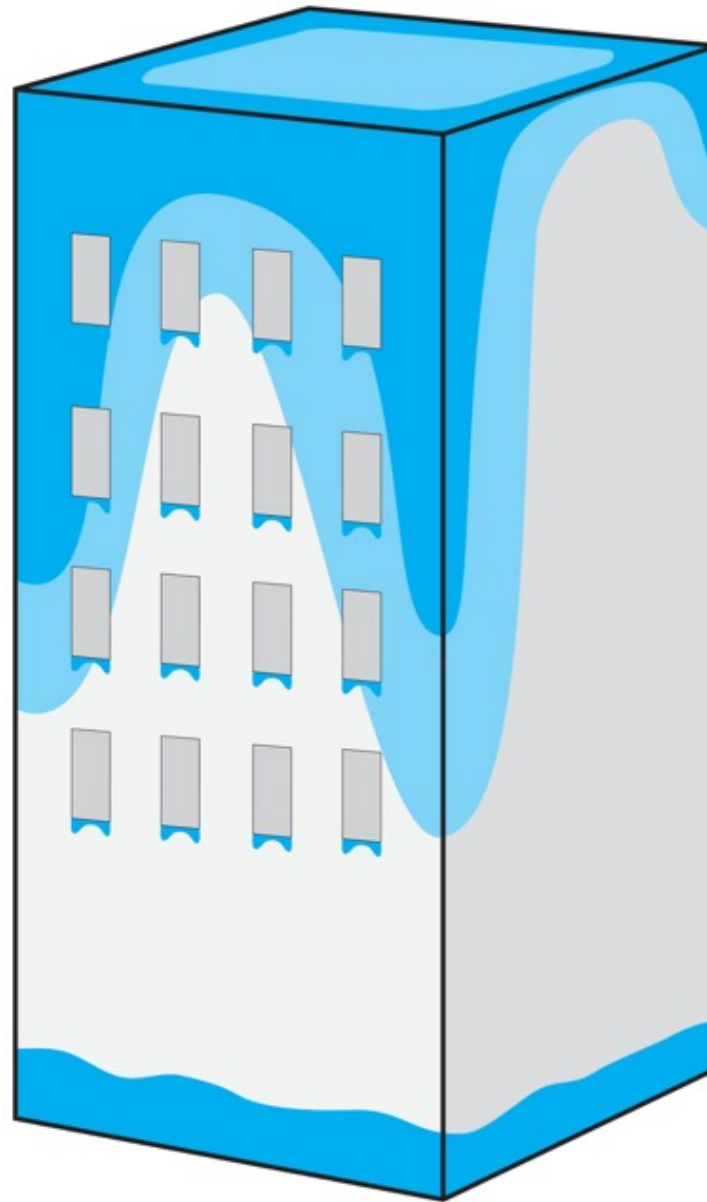
March 24, 2003



Exposure

- | | | |
|----------|---|-----------|
| Extreme |  | Over 60" |
| High |  | 40" - 60" |
| Moderate |  | 20" - 40" |
| Low |  | Under 20" |



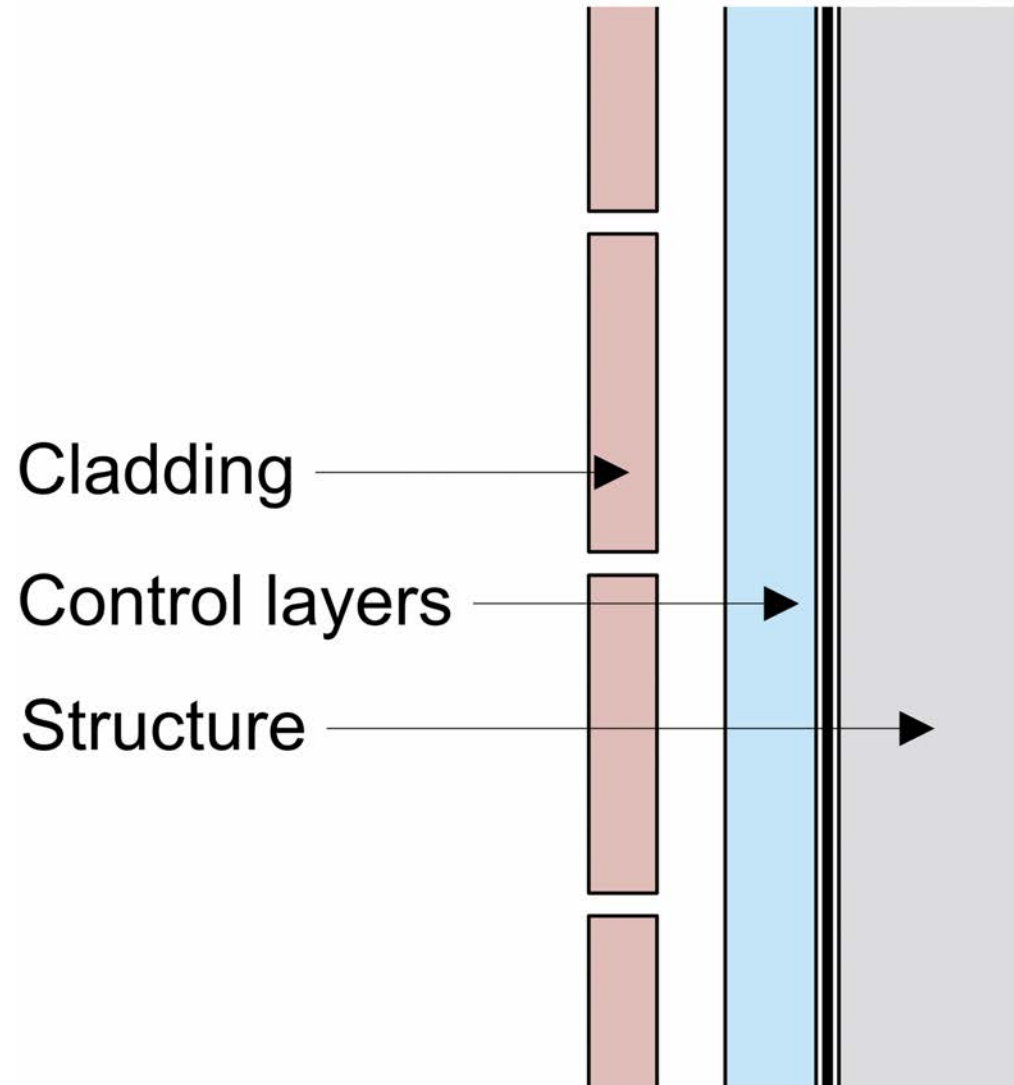


Water Control Layer

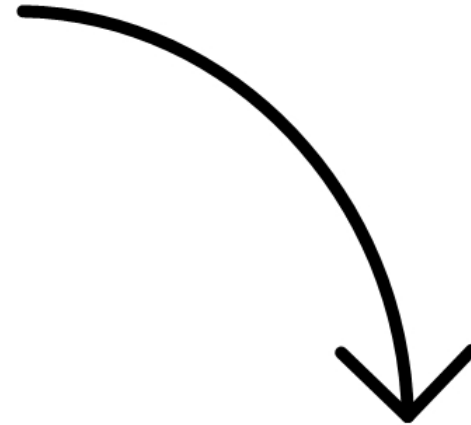
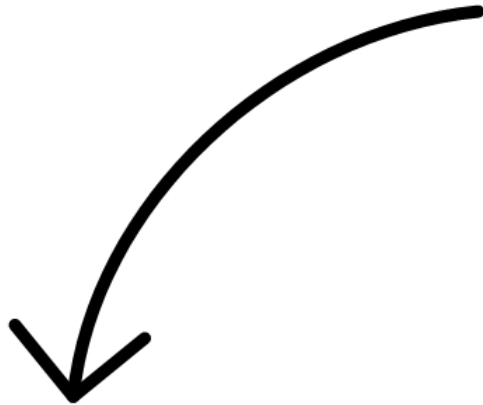
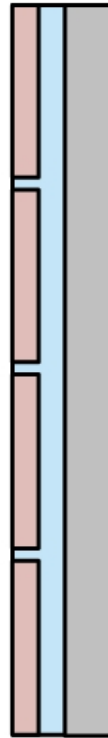
Air Control Layer

Vapor Control Layer

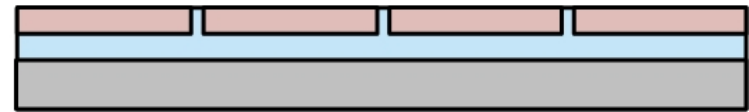
Thermal Control Layer



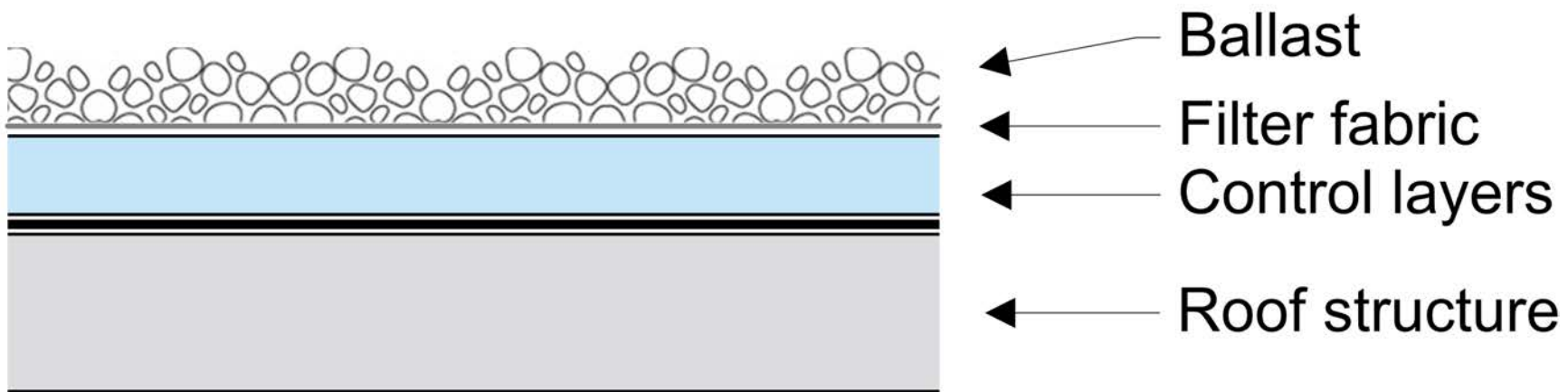
Wall

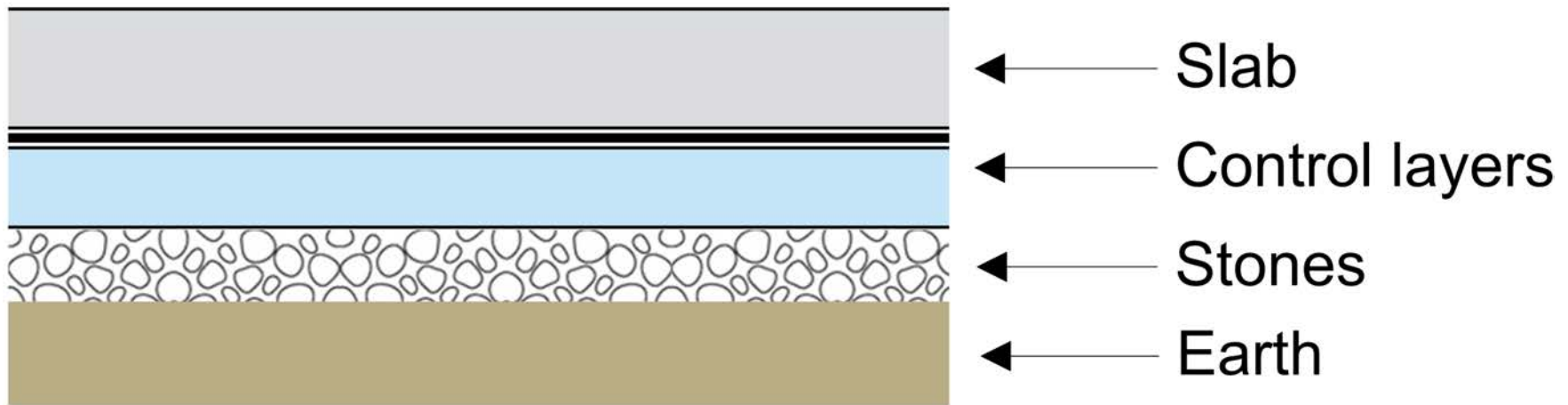


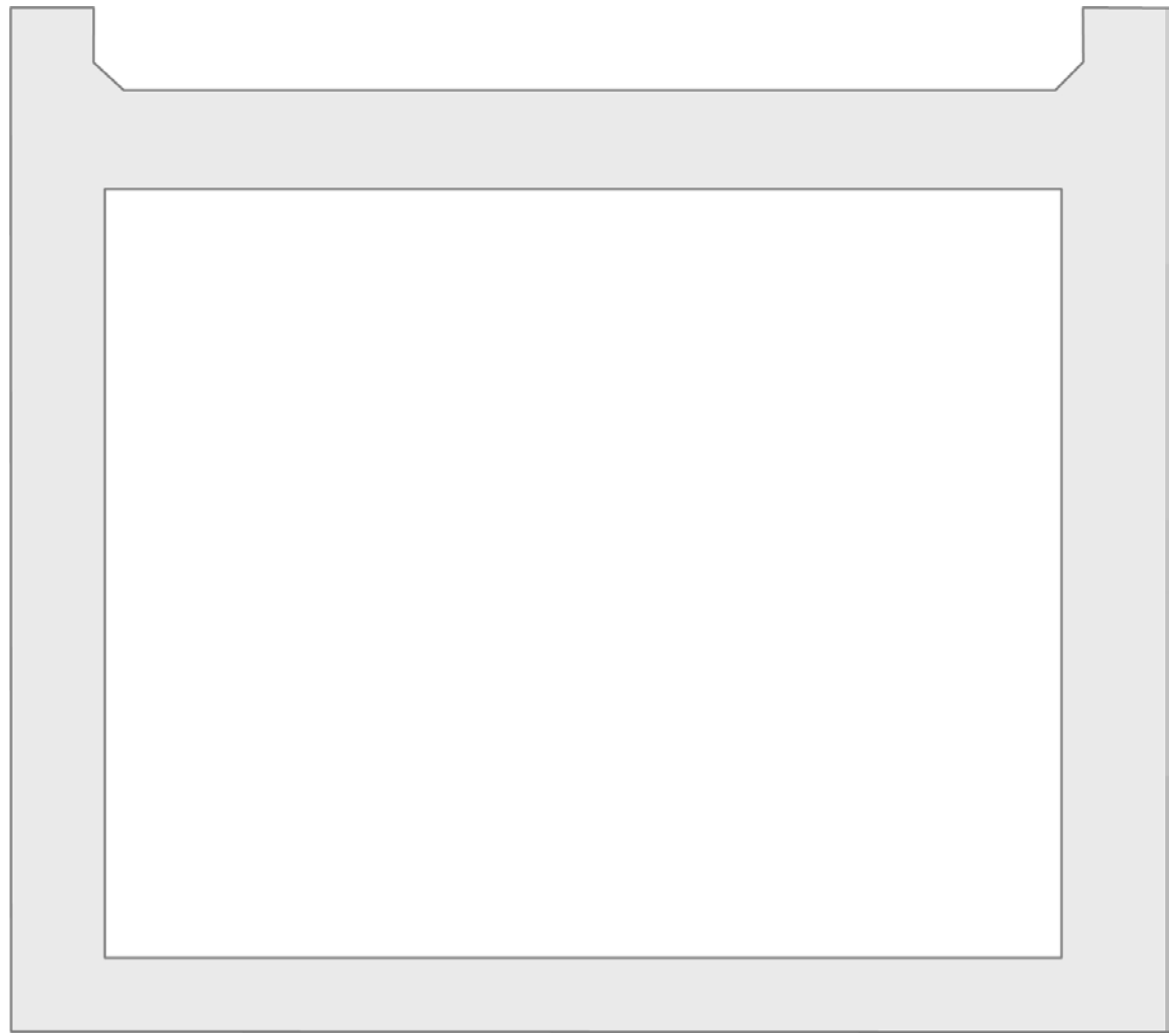
Slab



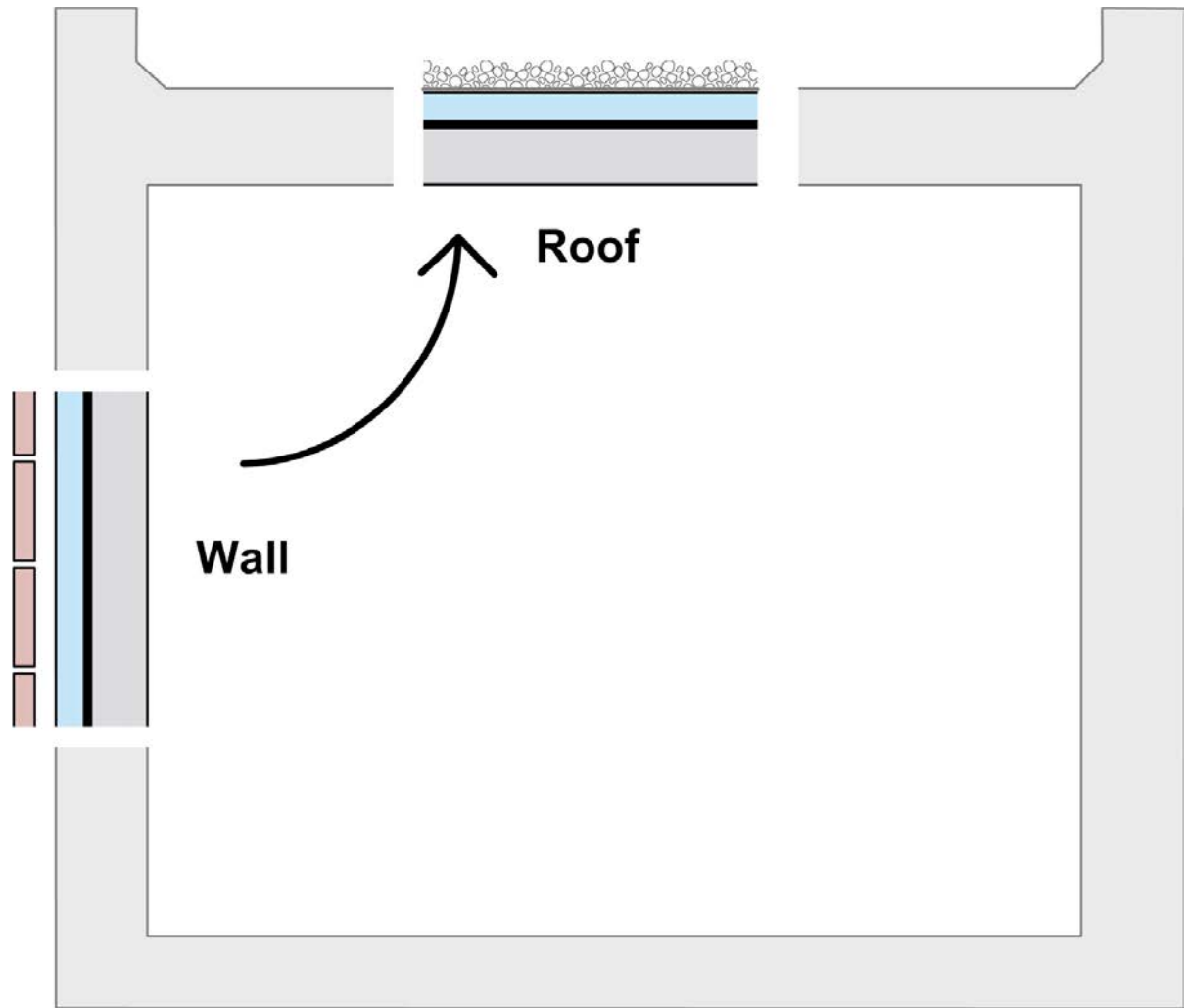
Roof

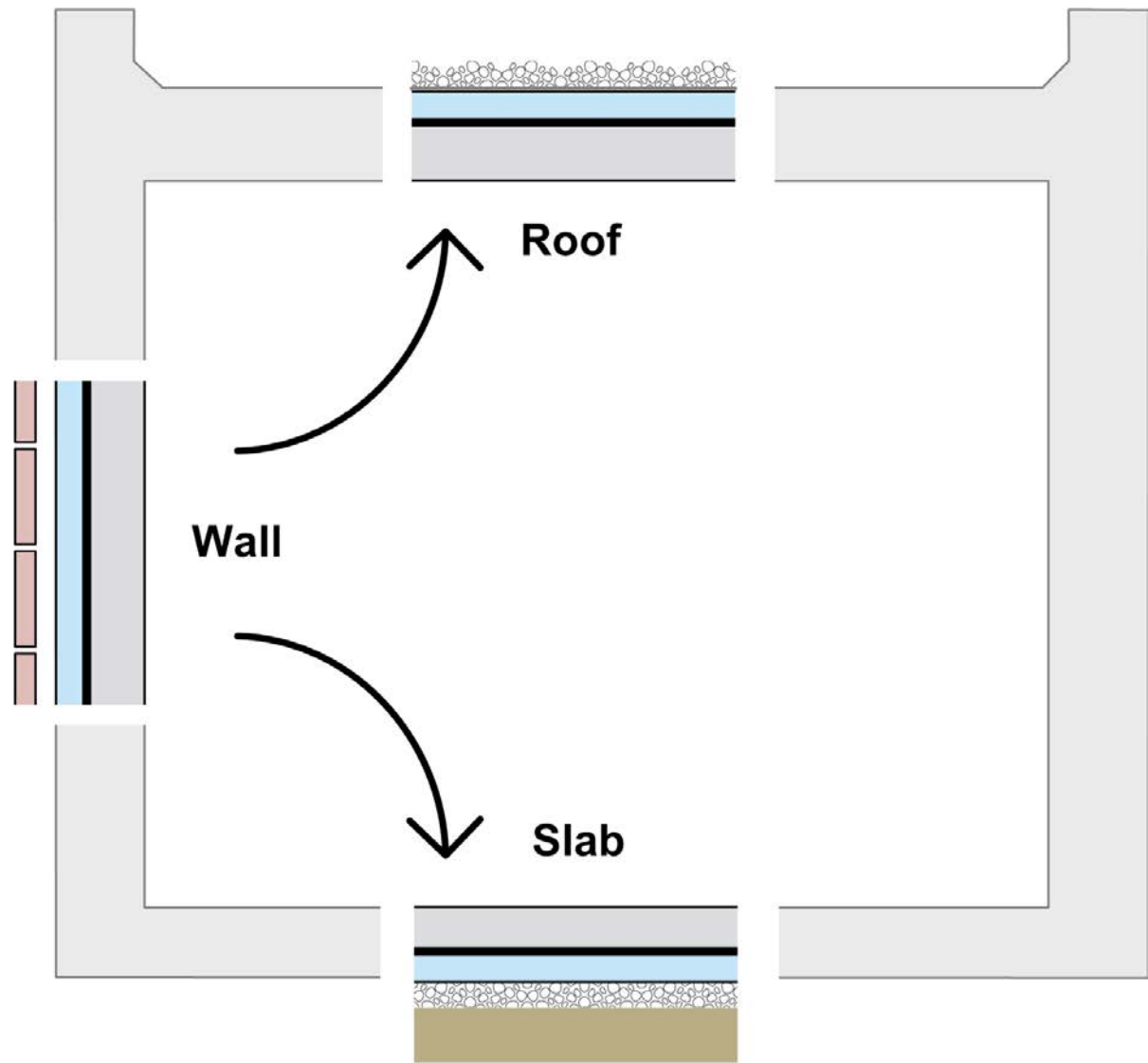


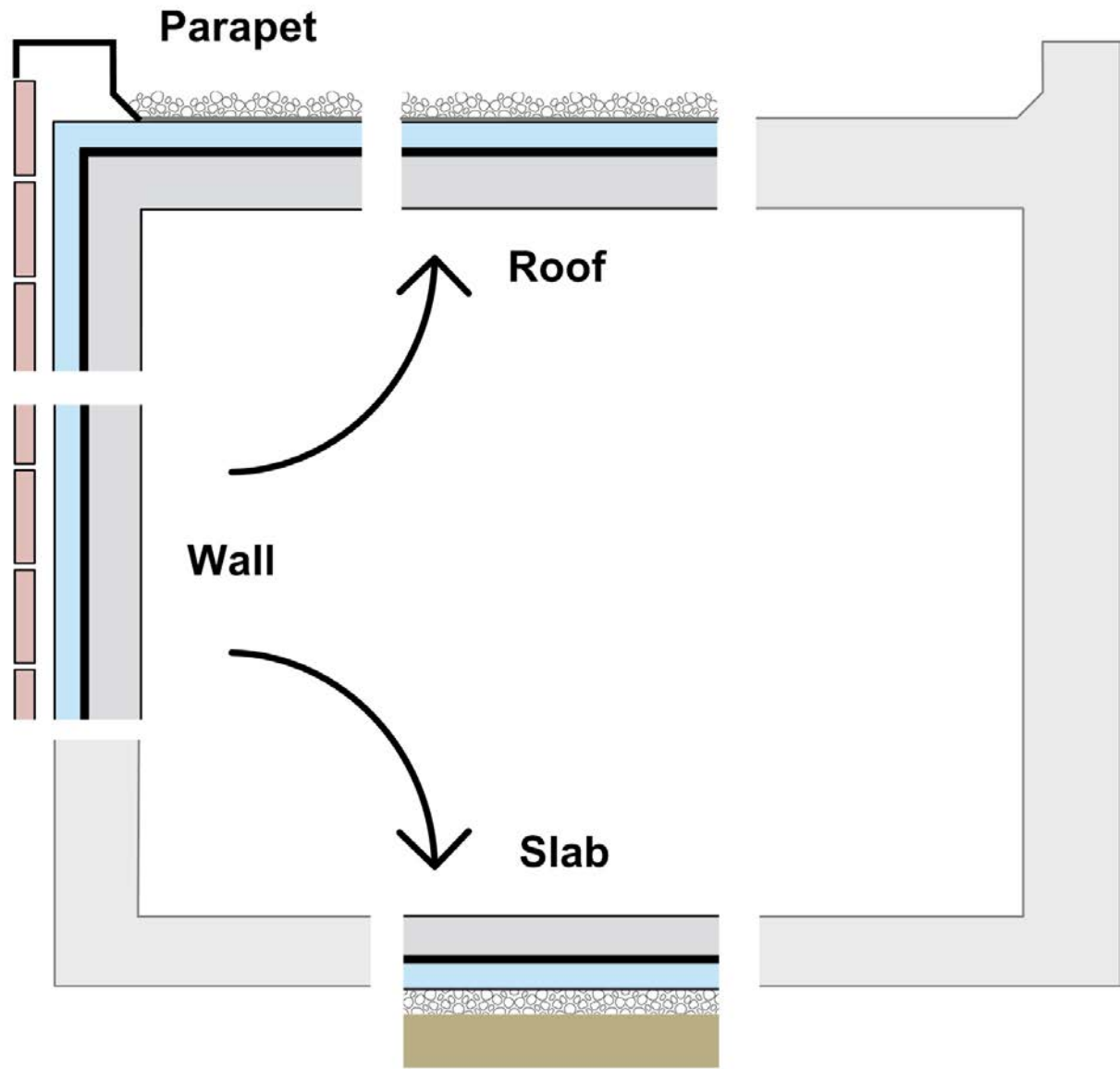


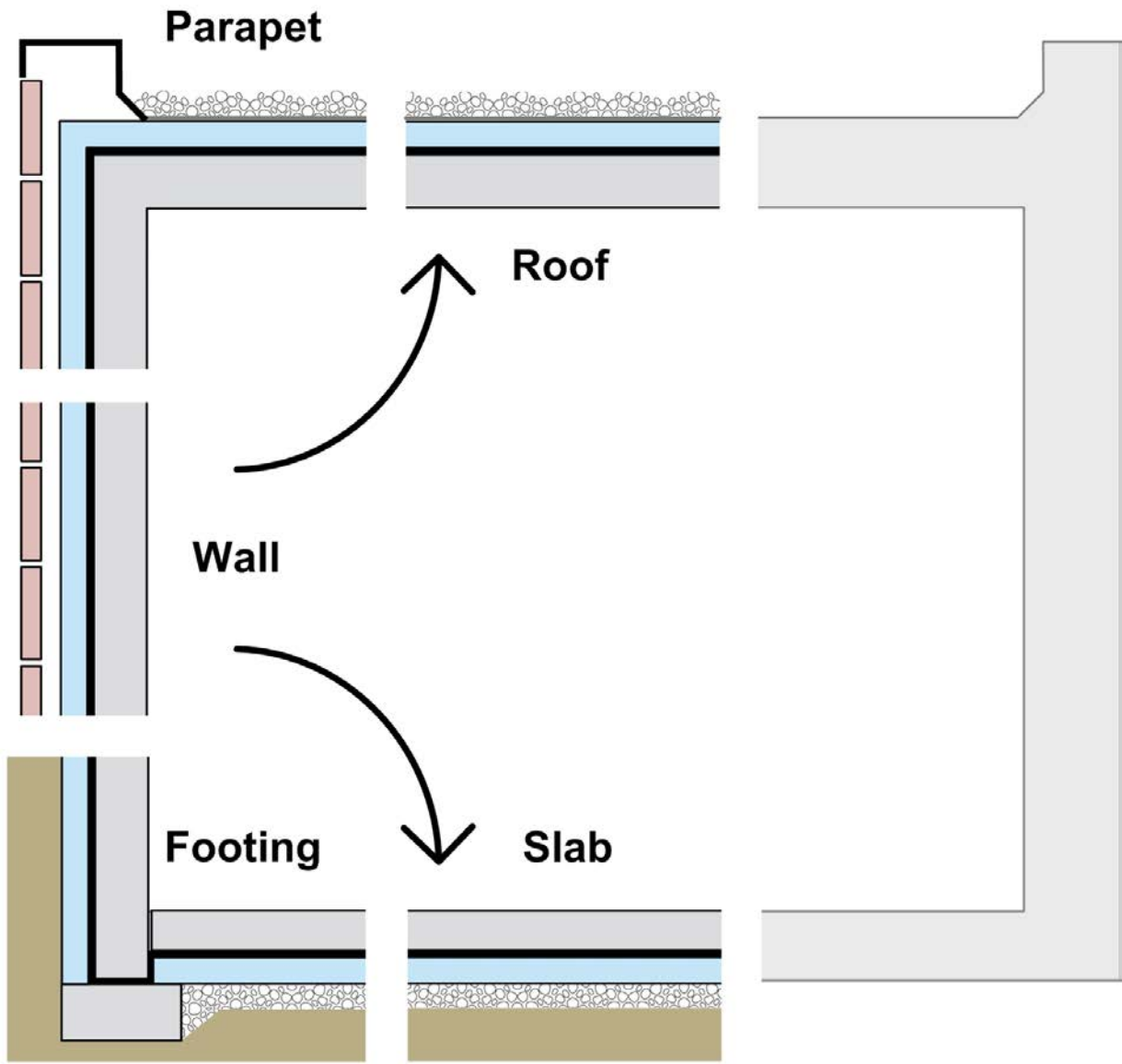


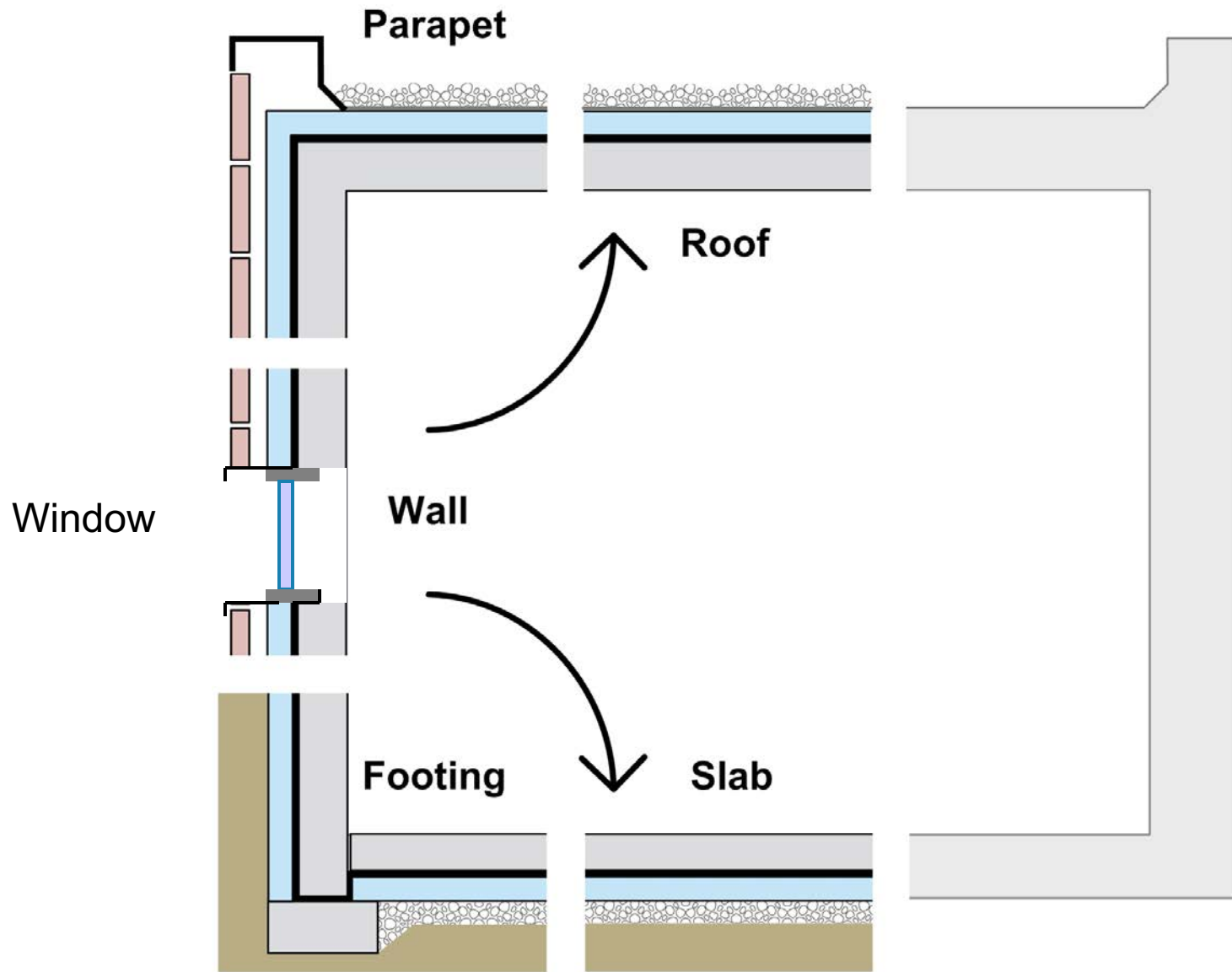


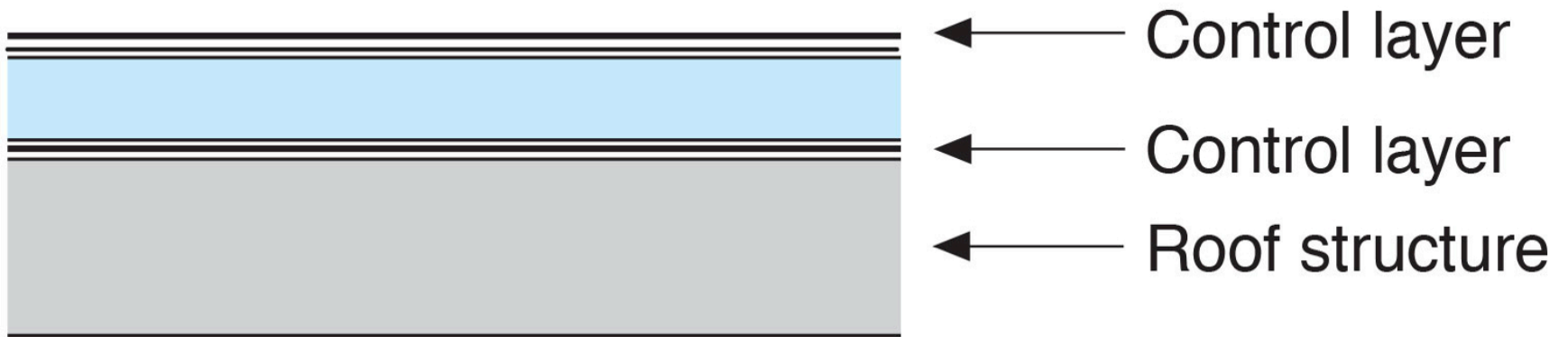


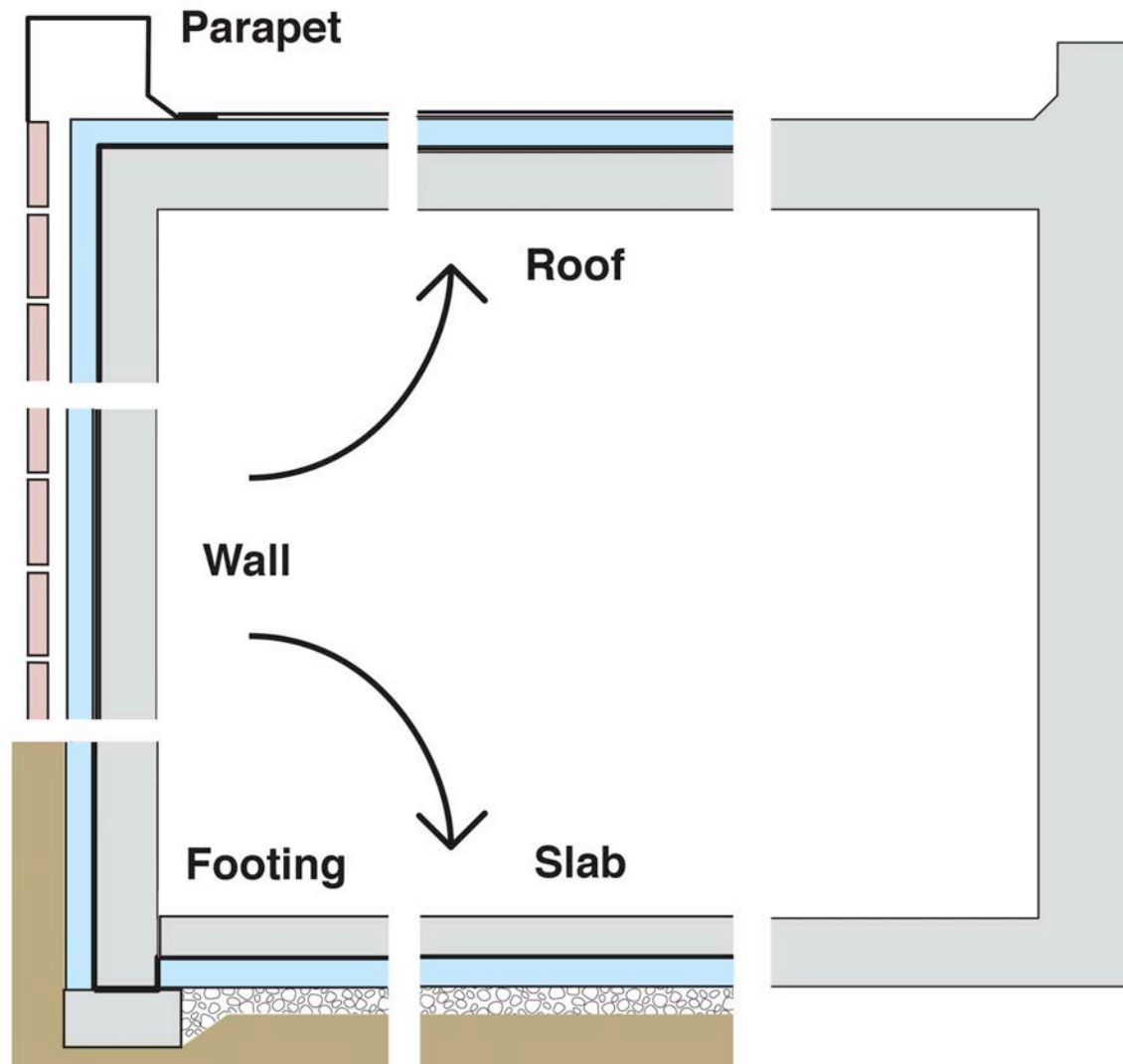


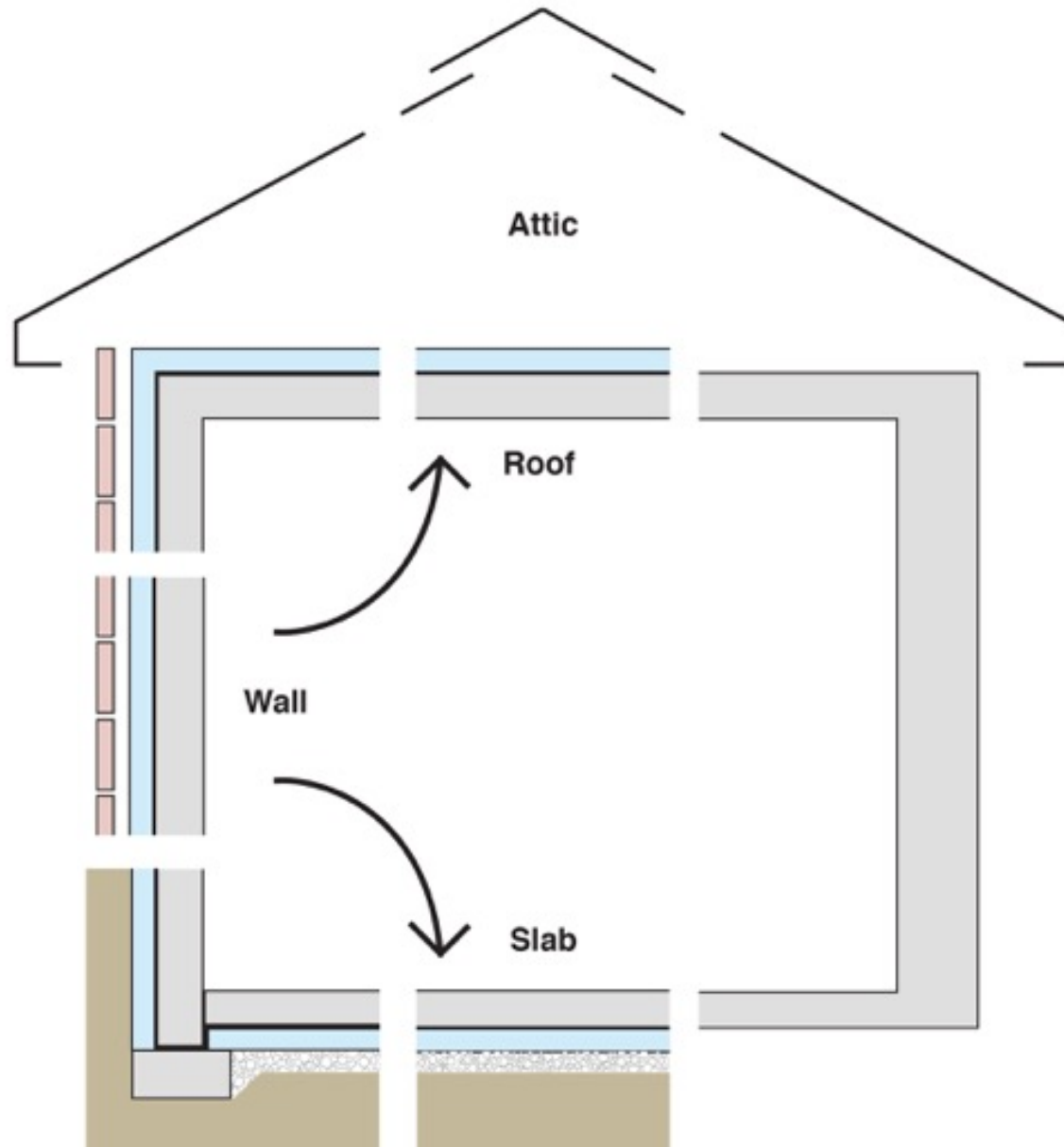


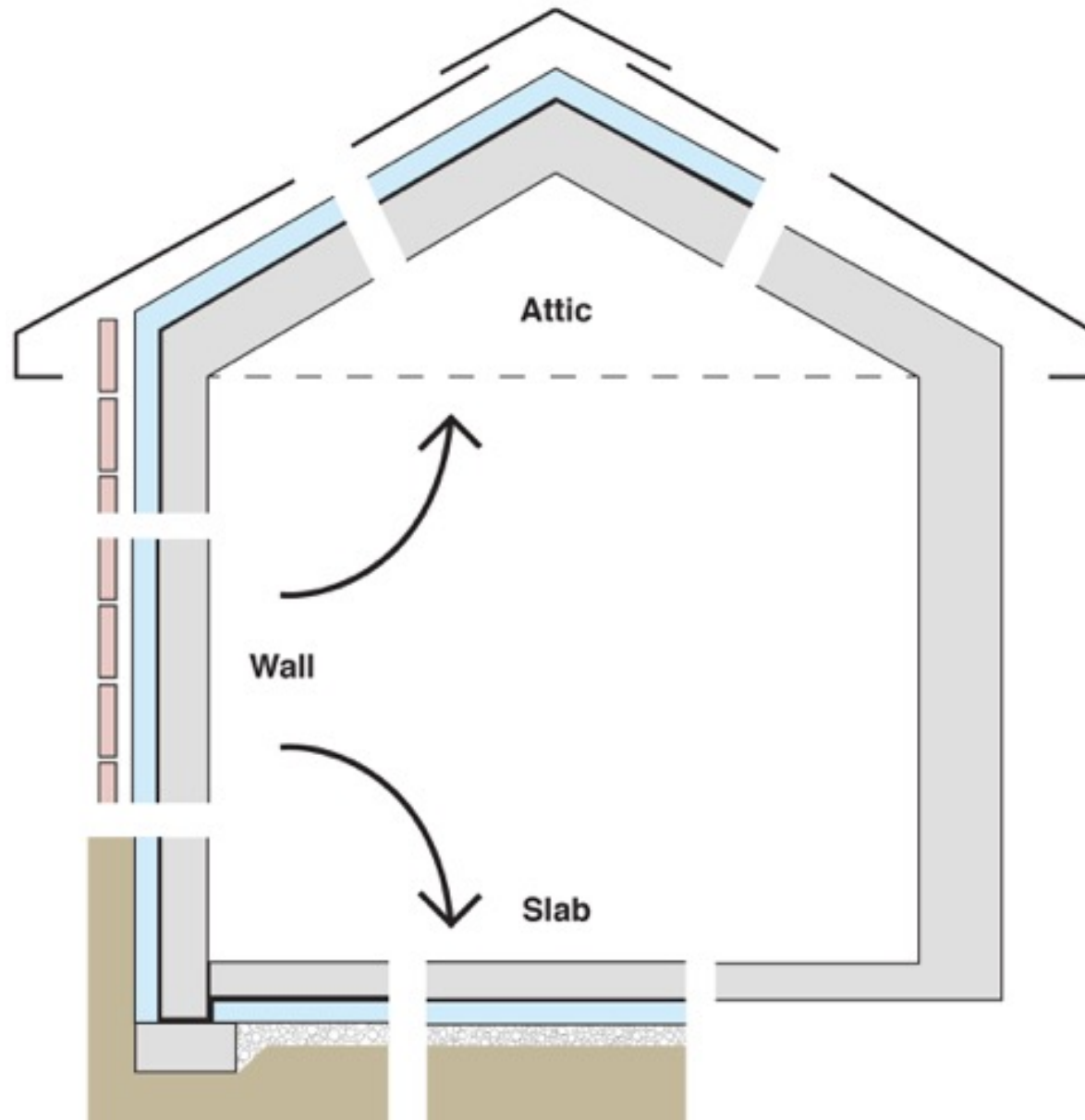


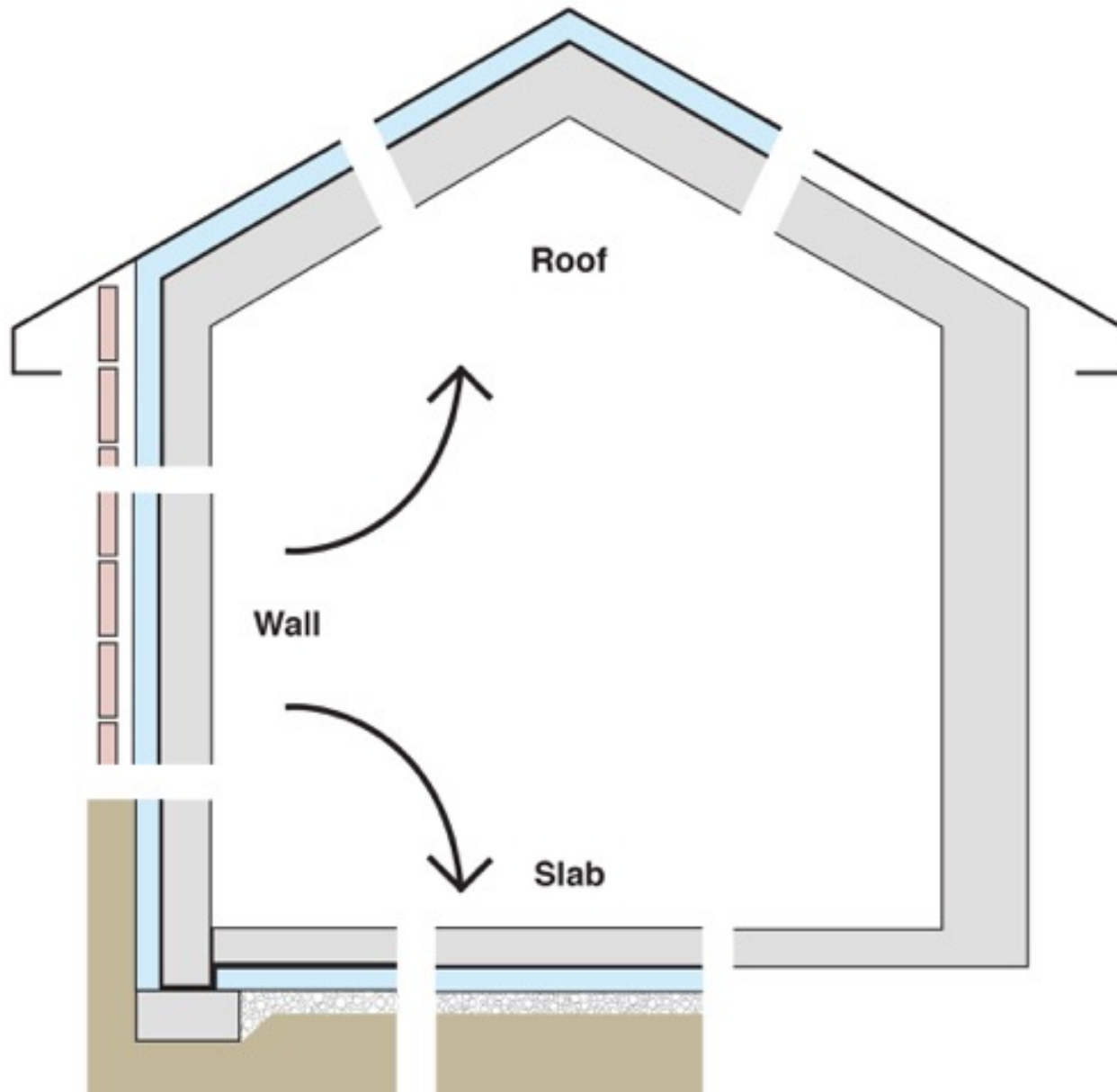


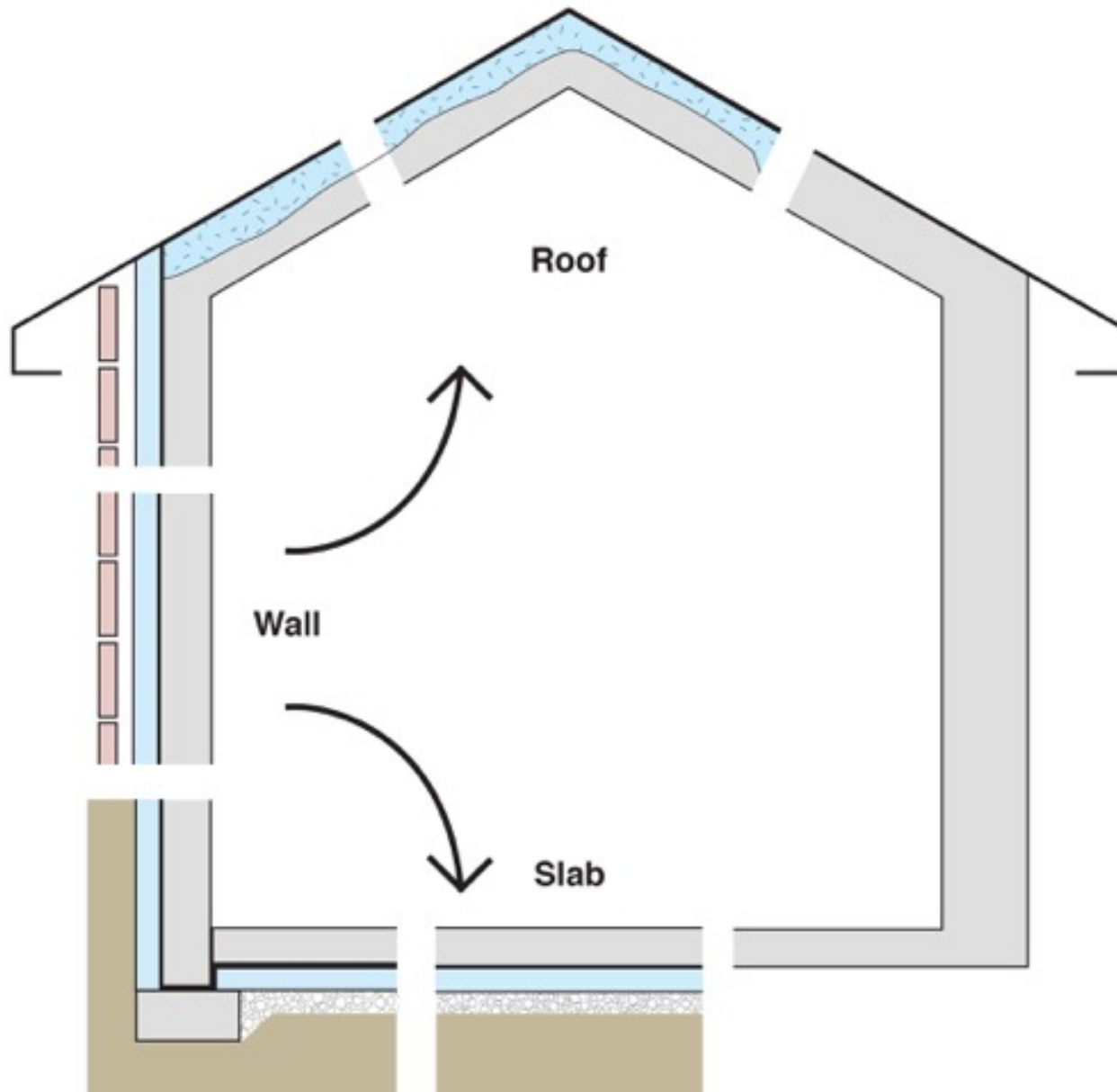




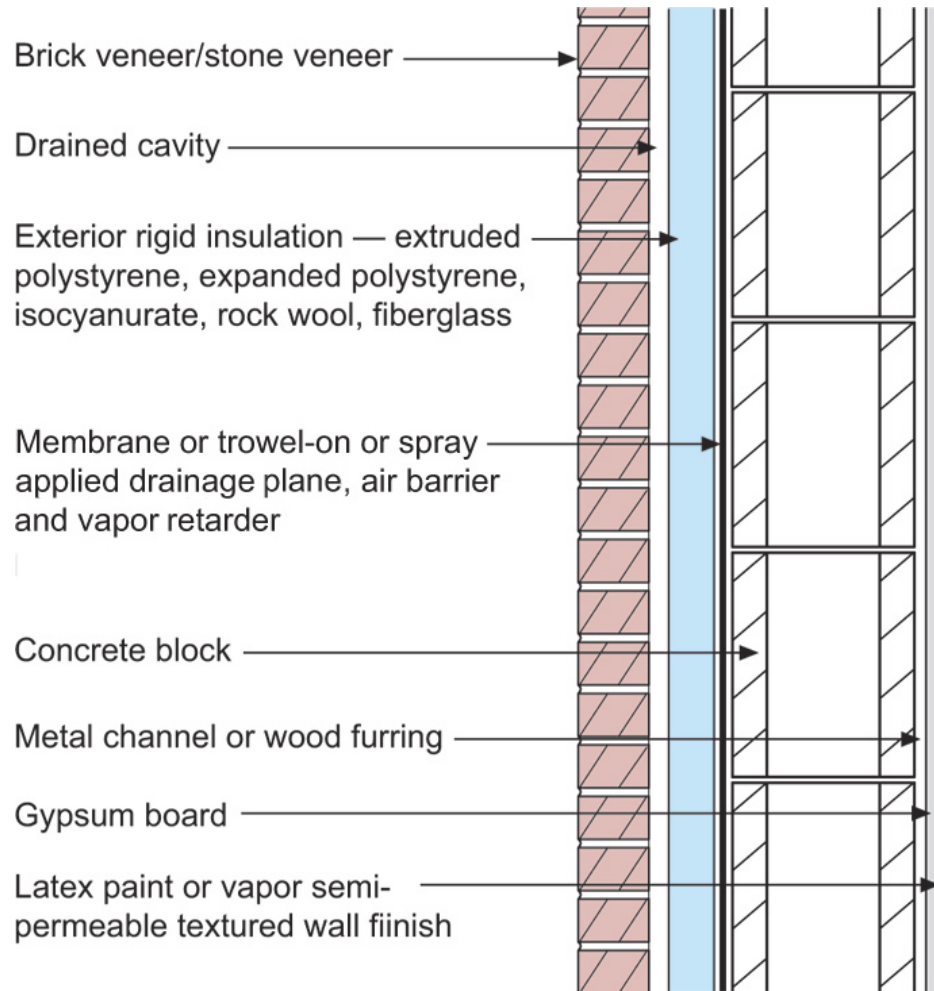




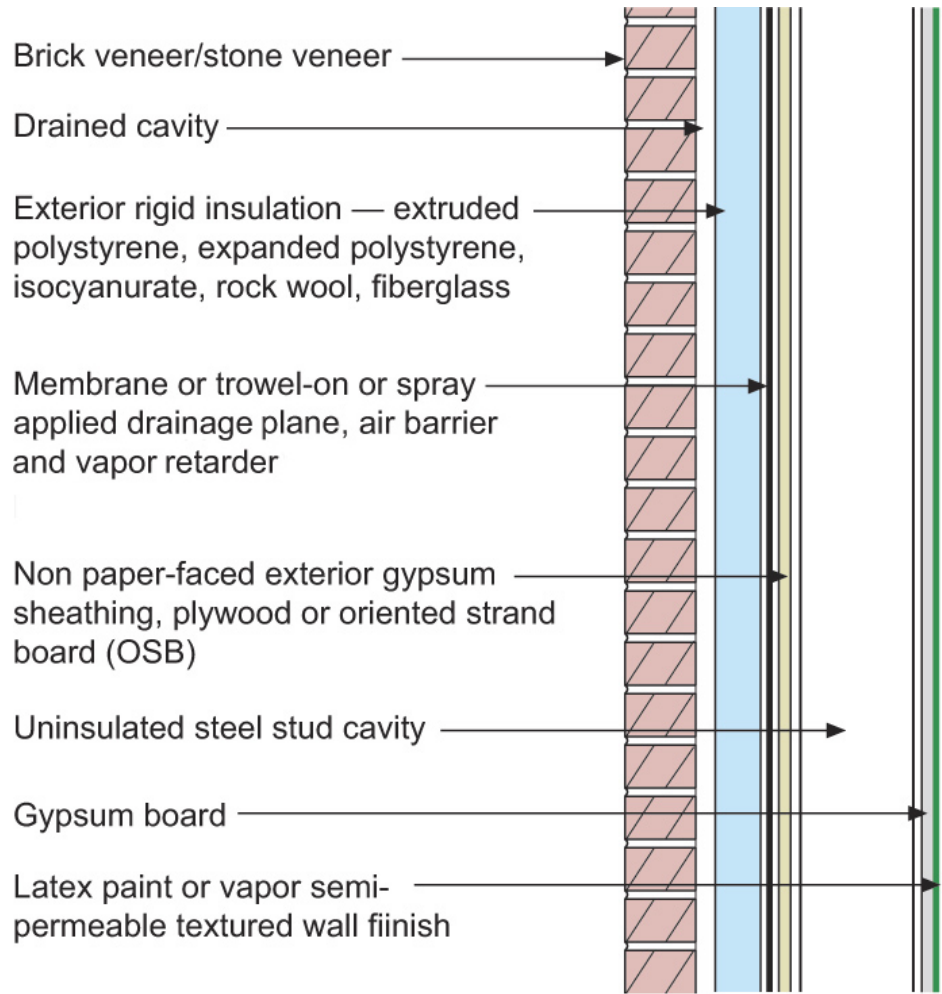


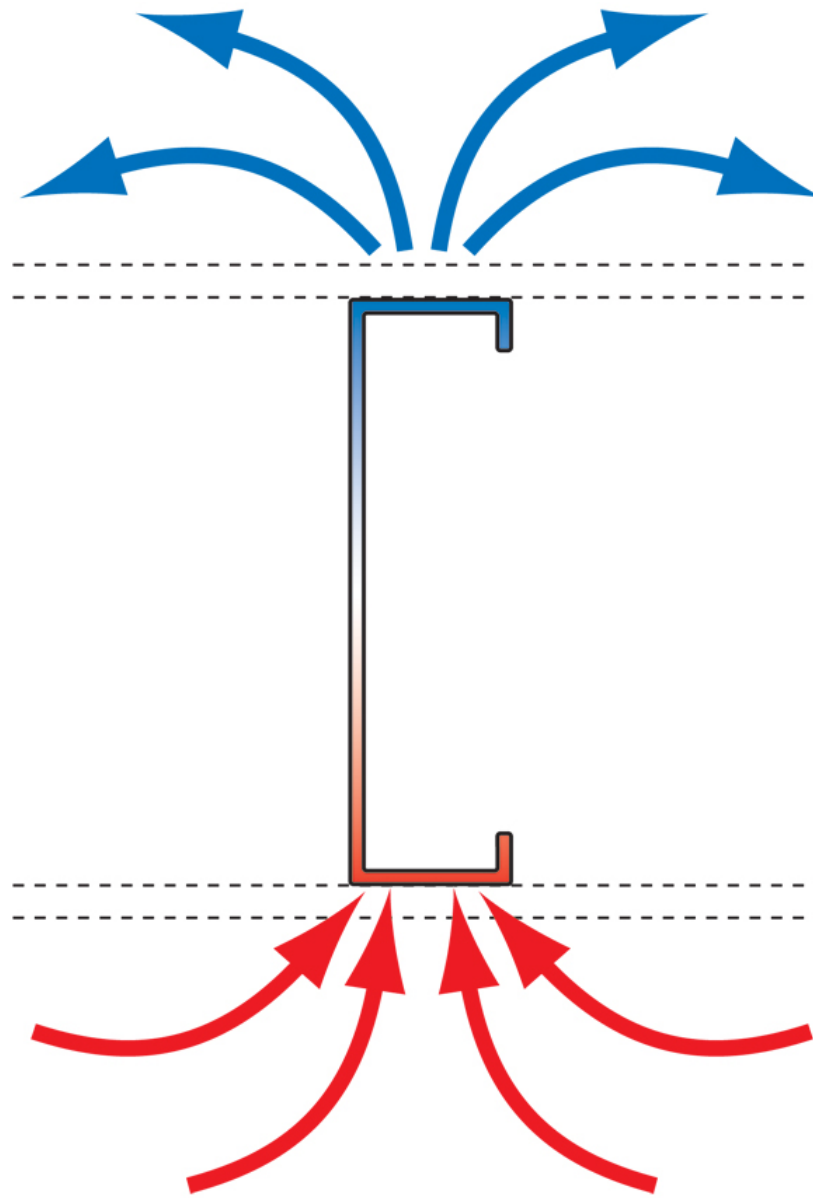


Configurations of the Perfect Wall

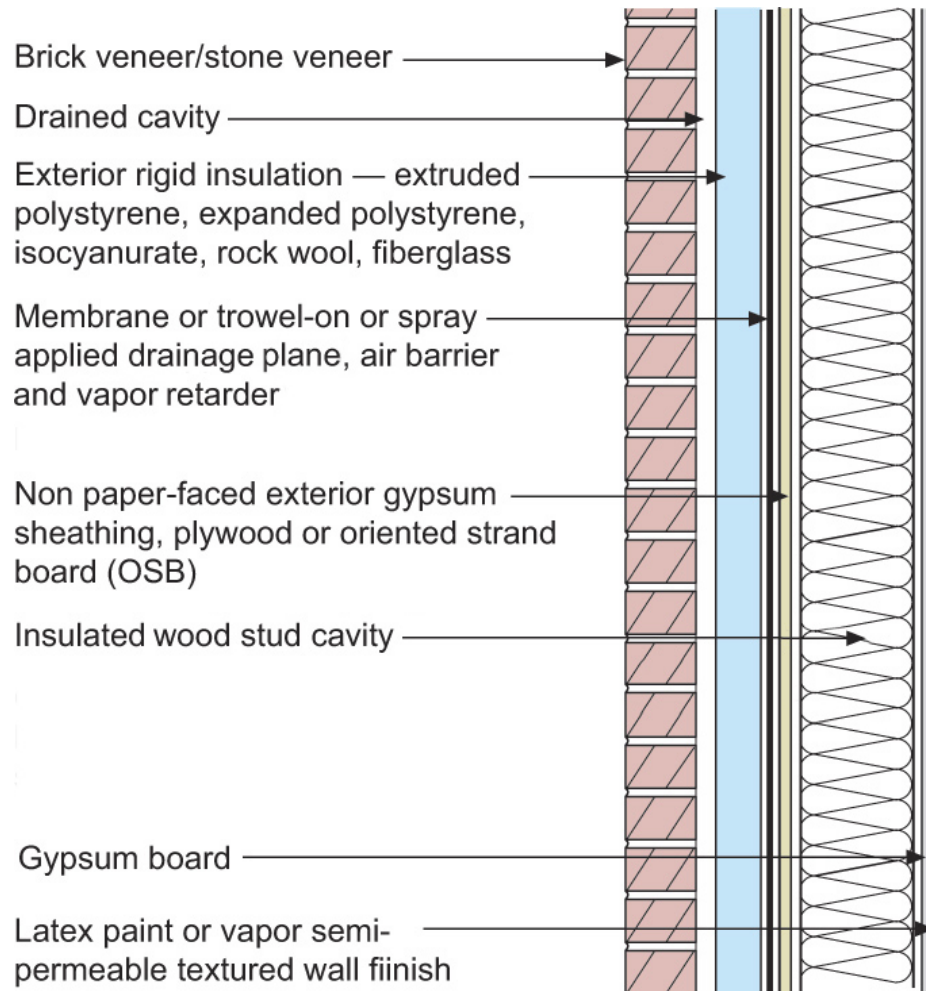


Vapor Profile



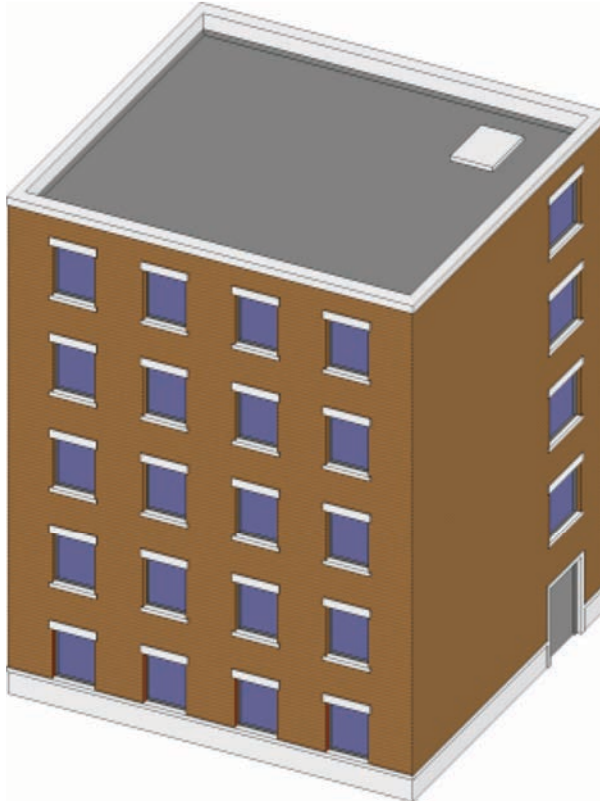




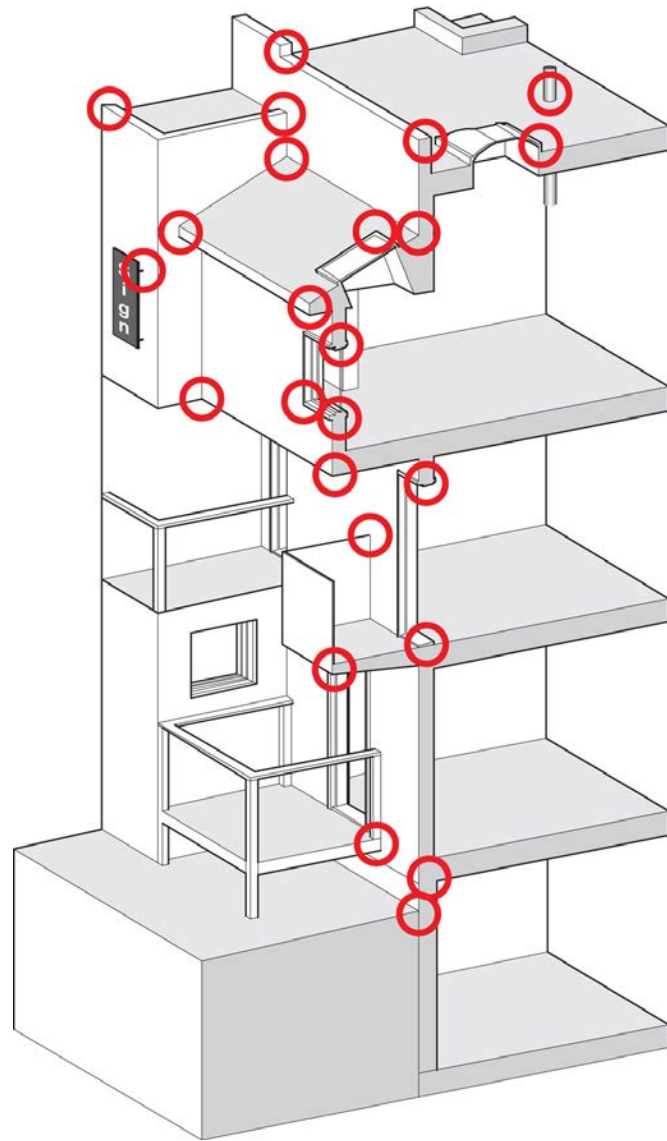


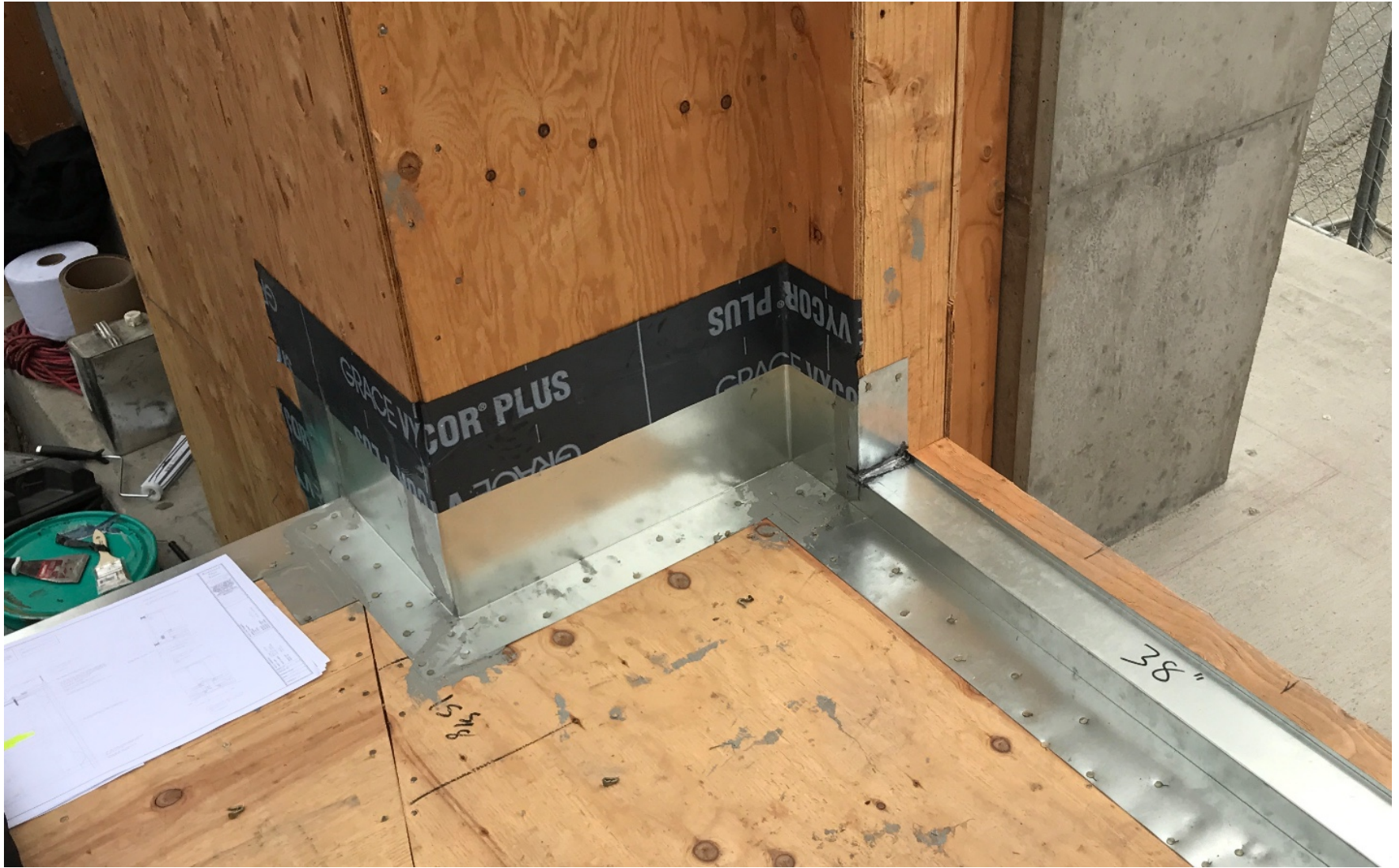
Vapor Profile

Commercial Enclosure: Simple Layers



- Structure
- Rain/Air/Vapor
- Insulation
- Finish



























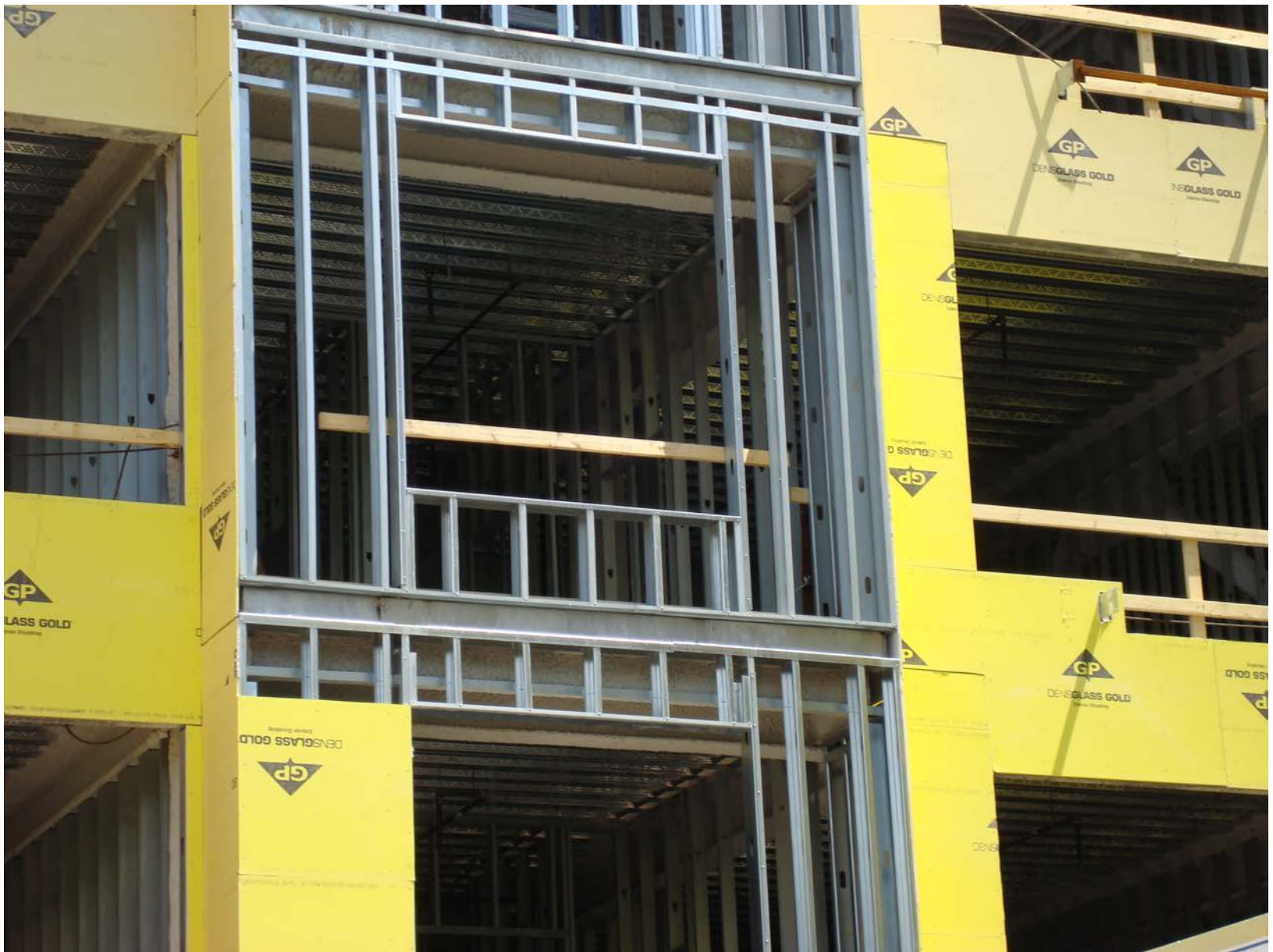






























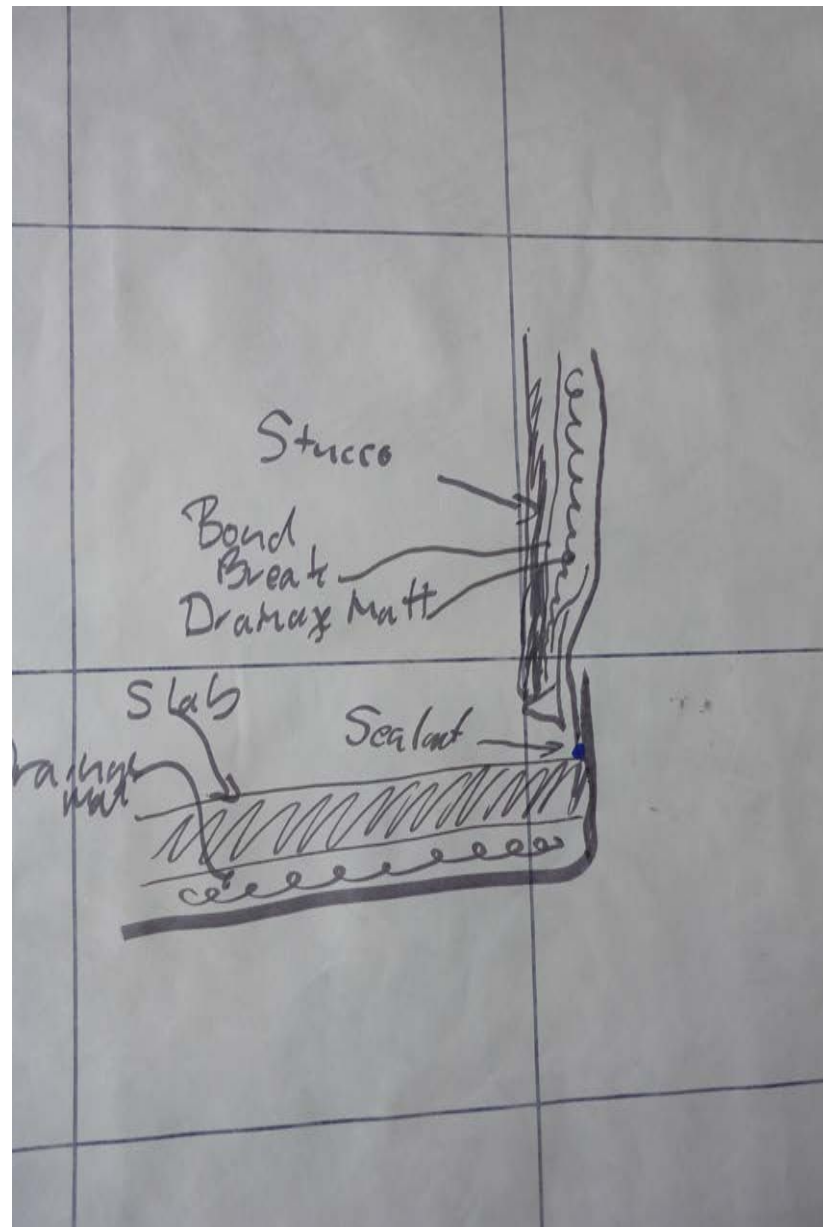






















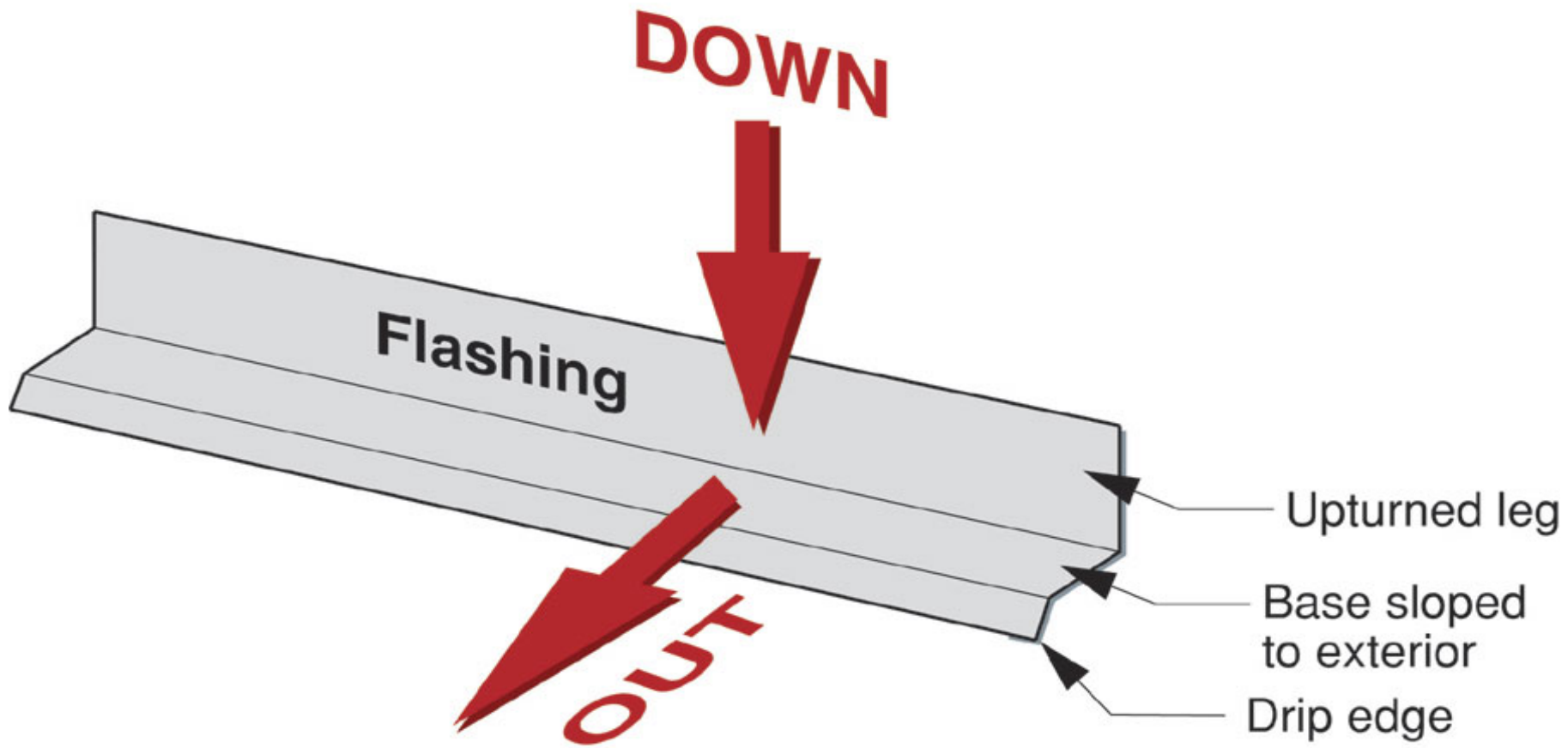


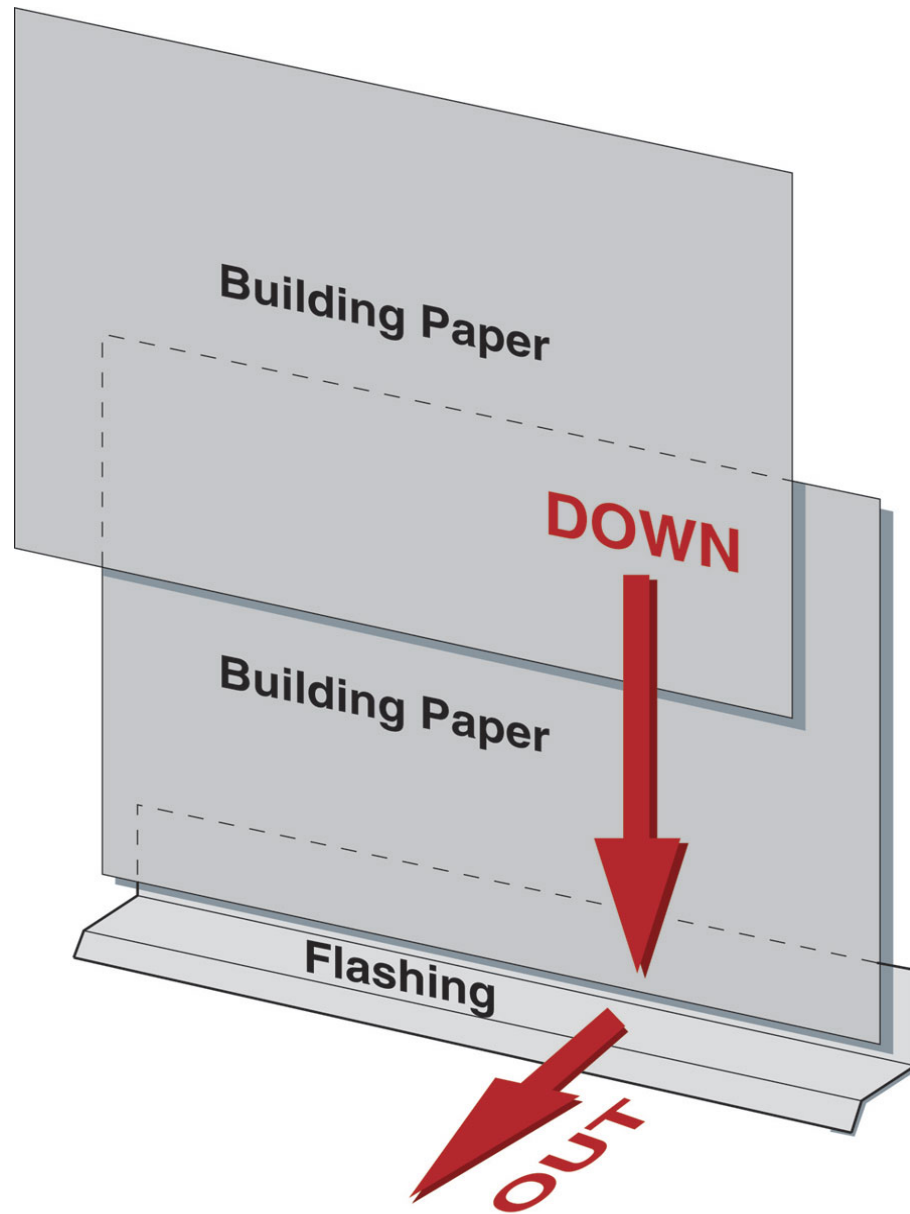


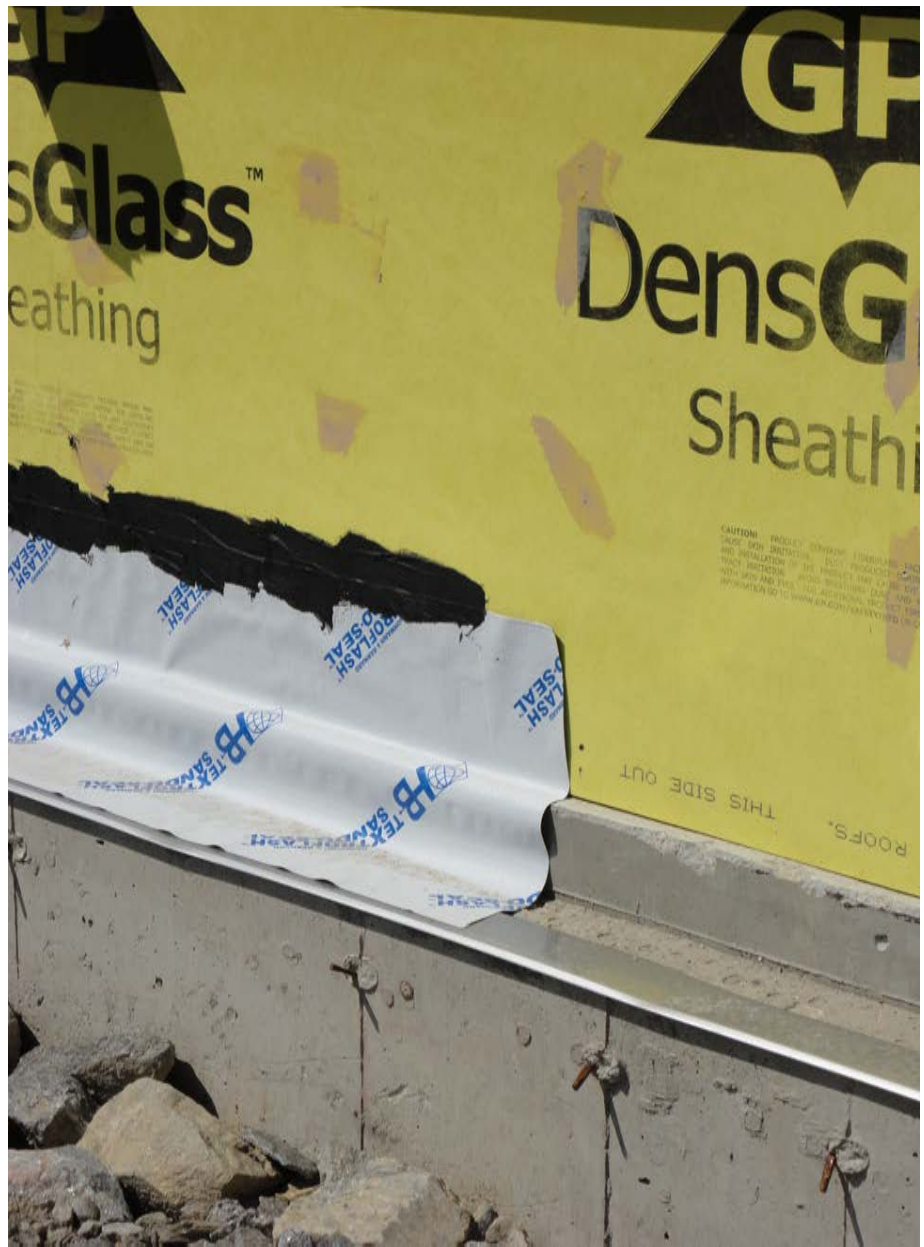




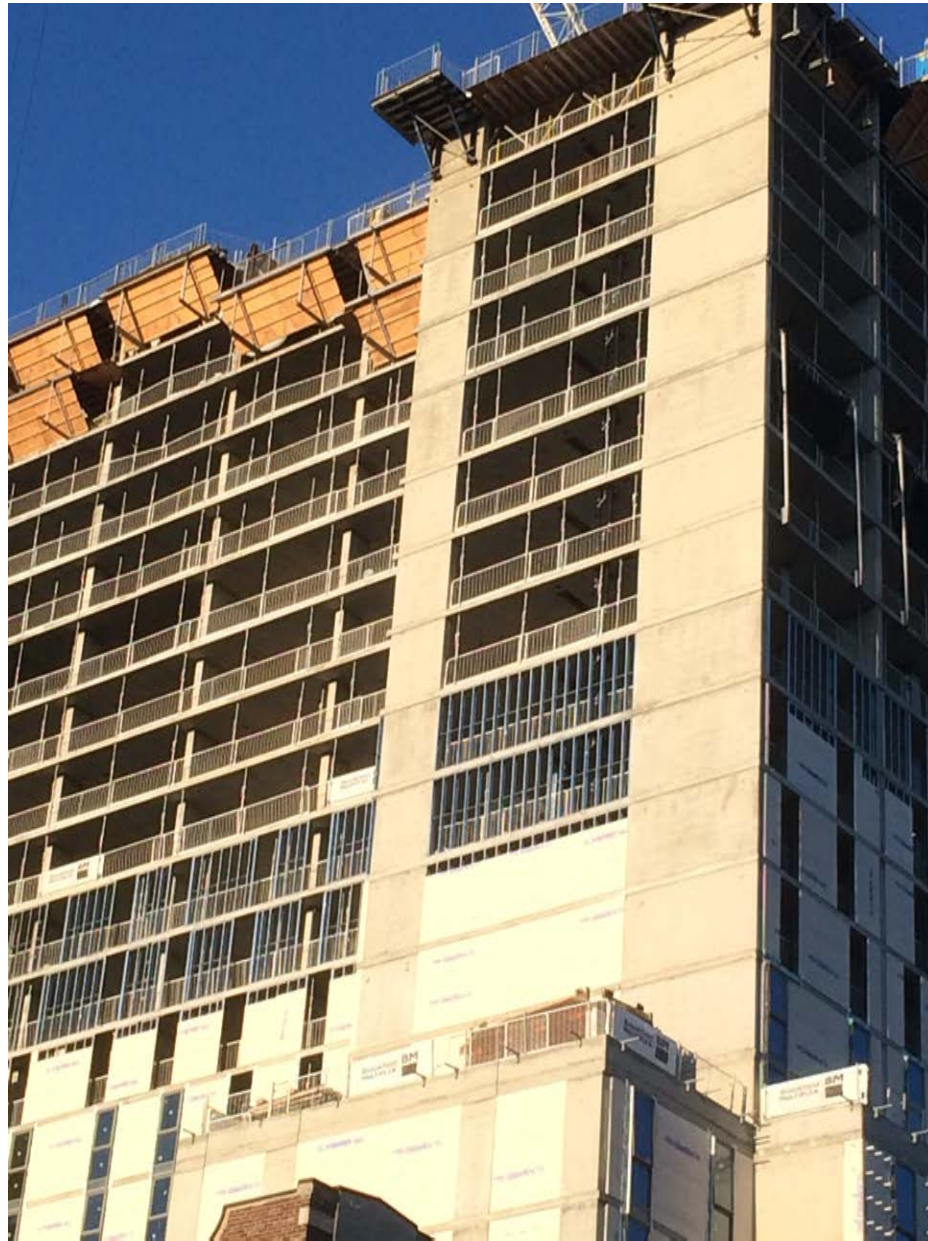










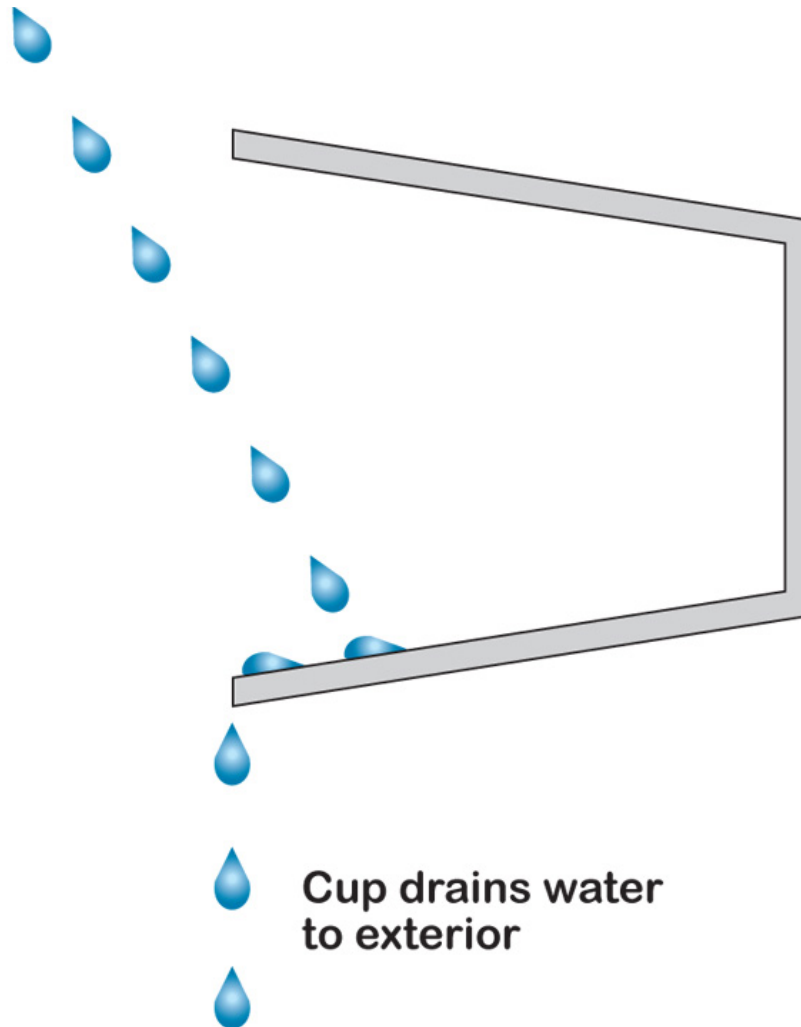








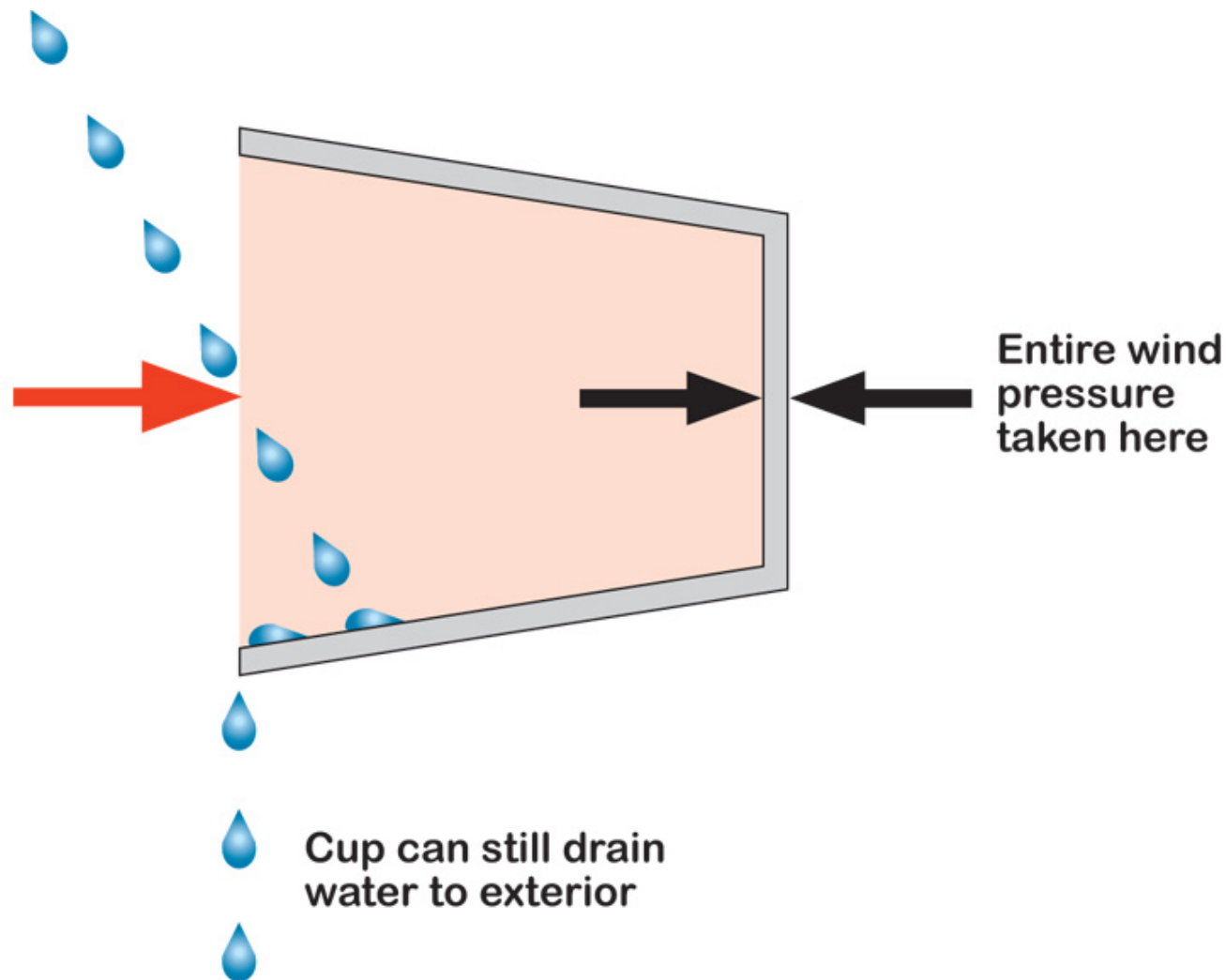
Rain enters cup
due to momentum
("kinetic energy")



Cup drains water
to exterior

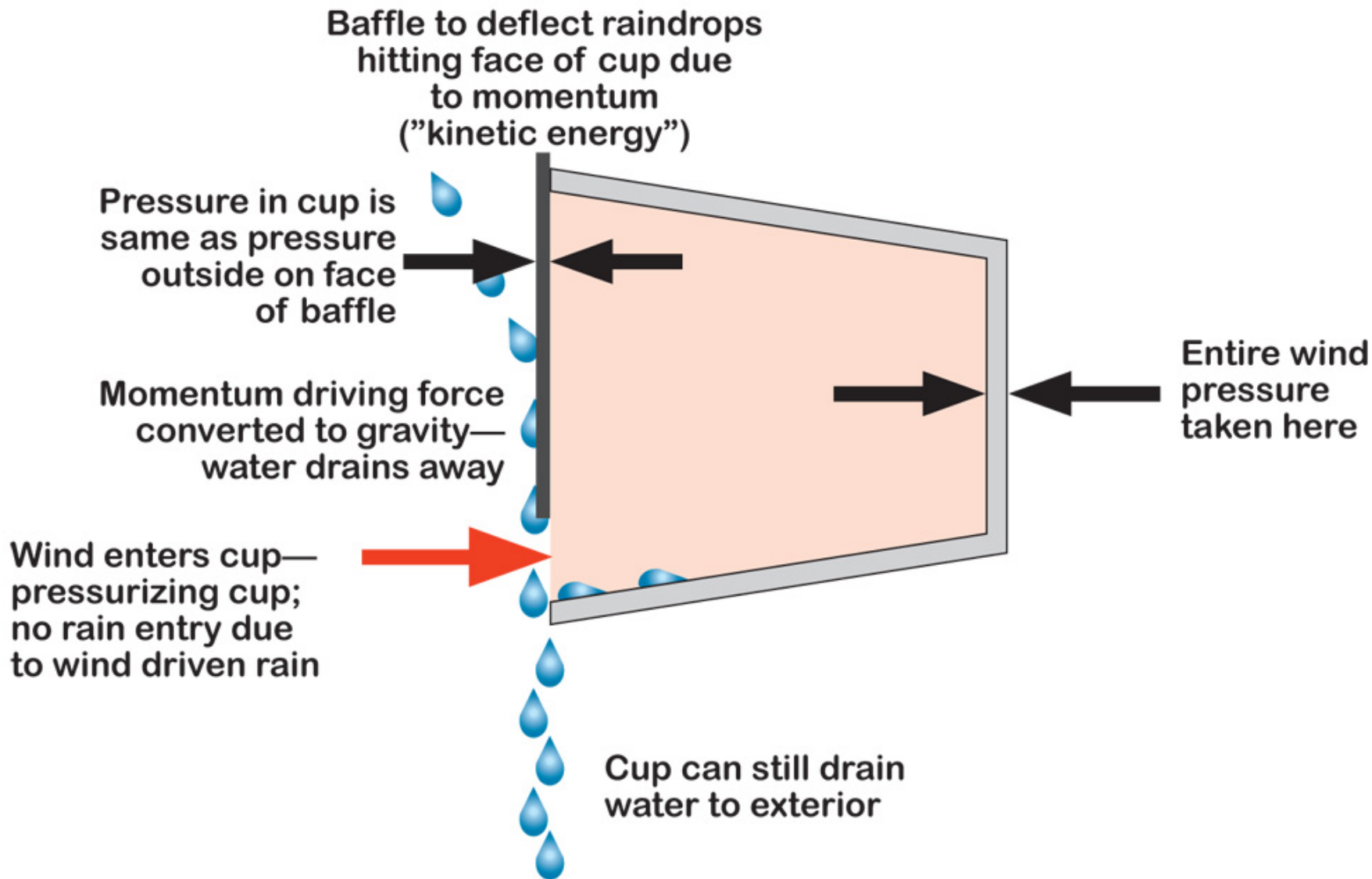
Rain enters cup due to momentum ("kinetic energy")

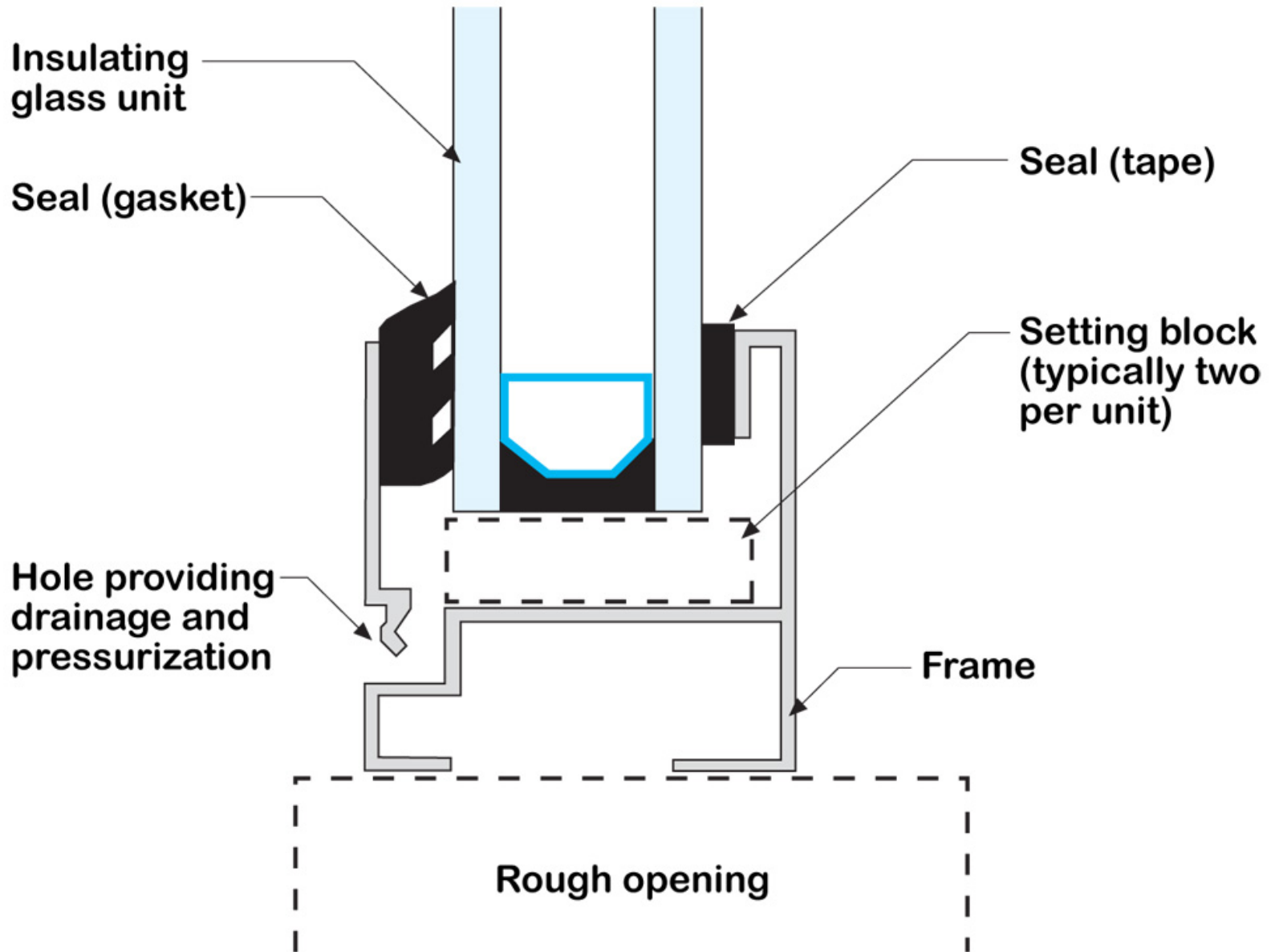
Wind enters cup—pressurizing cup; no rain entry due to wind driven rain

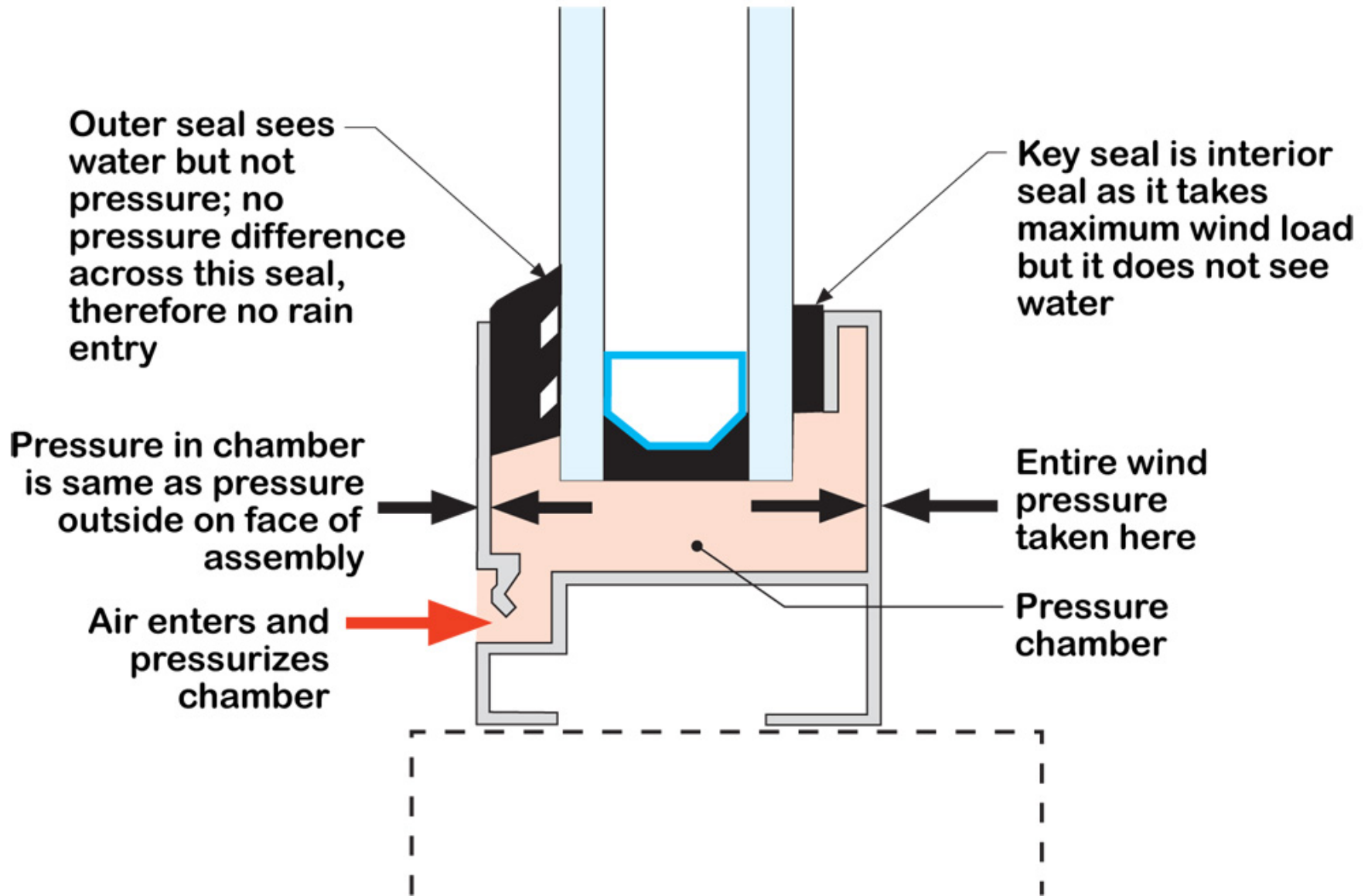


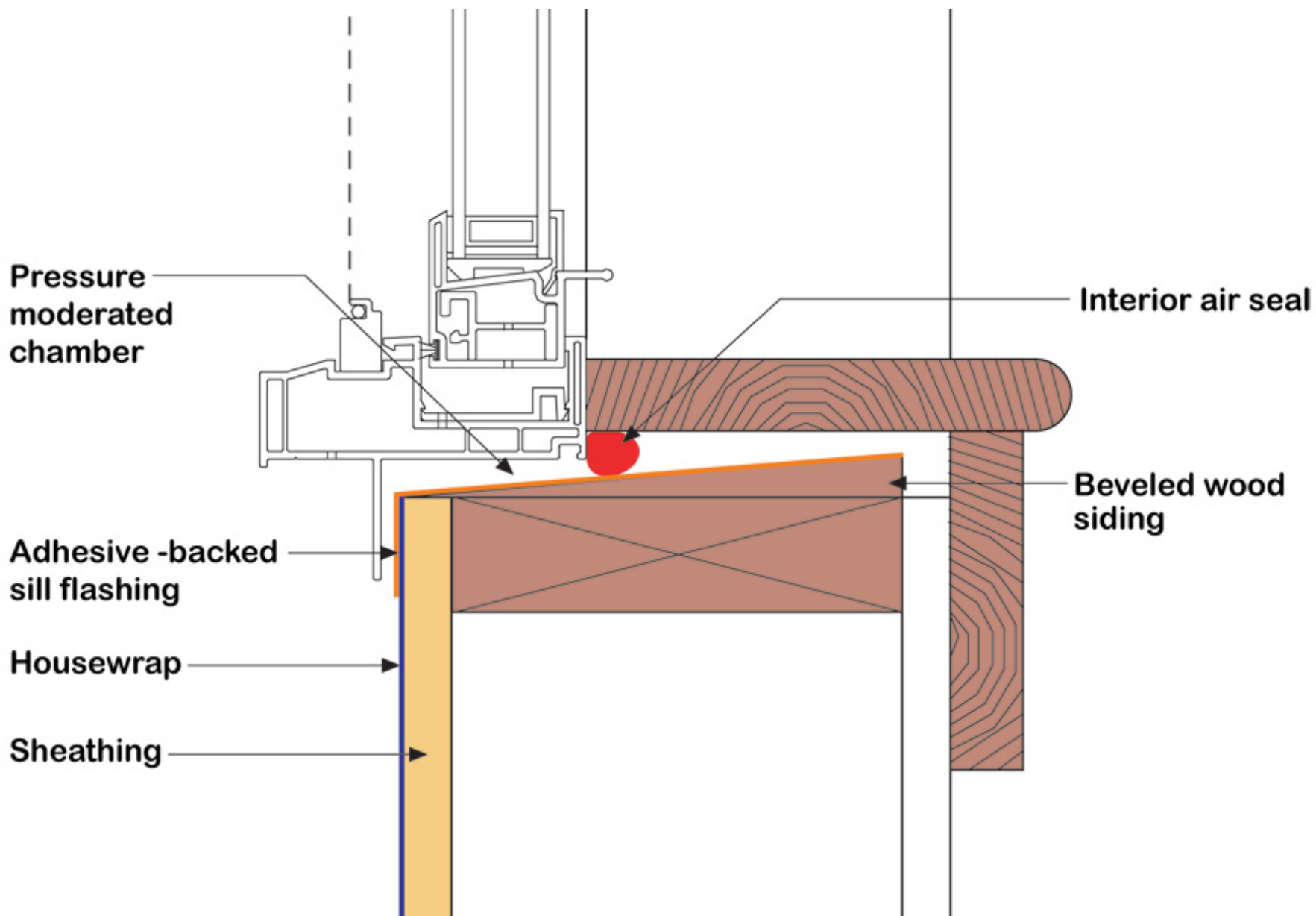
Entire wind pressure taken here

Cup can still drain water to exterior









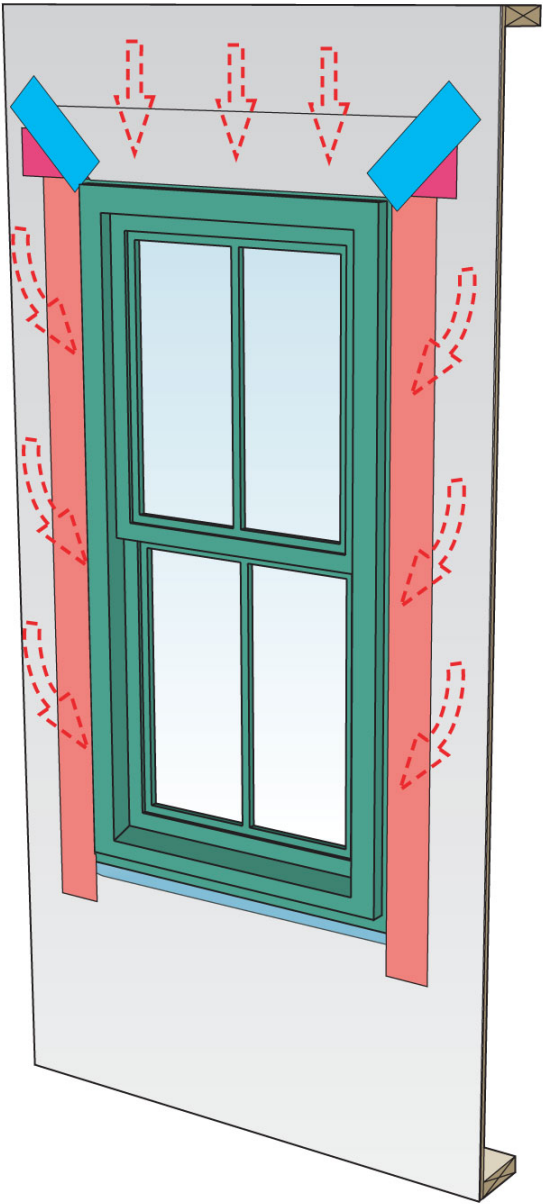


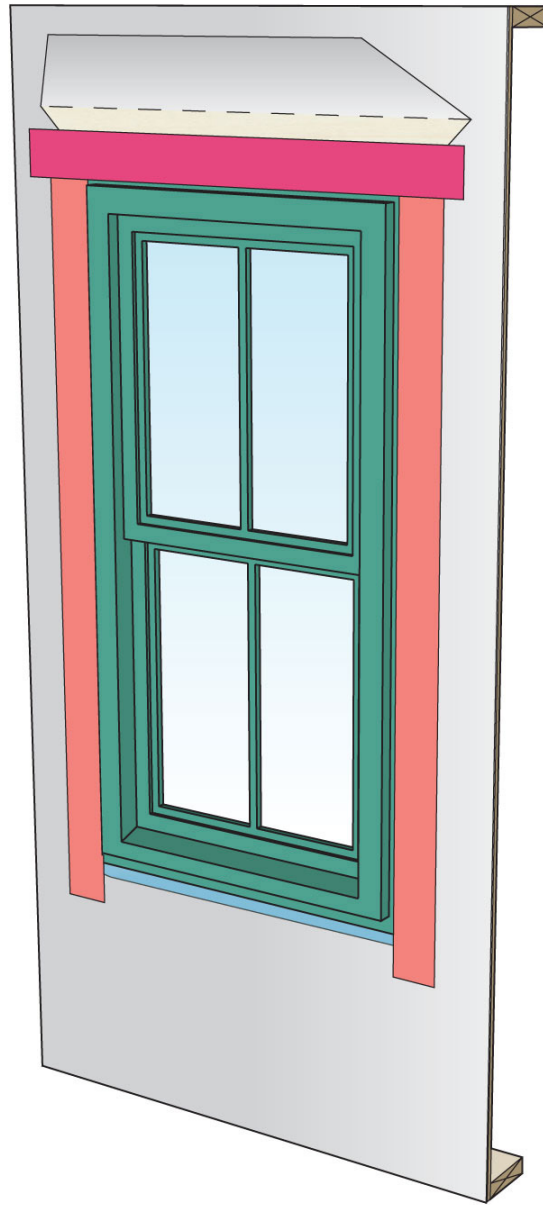




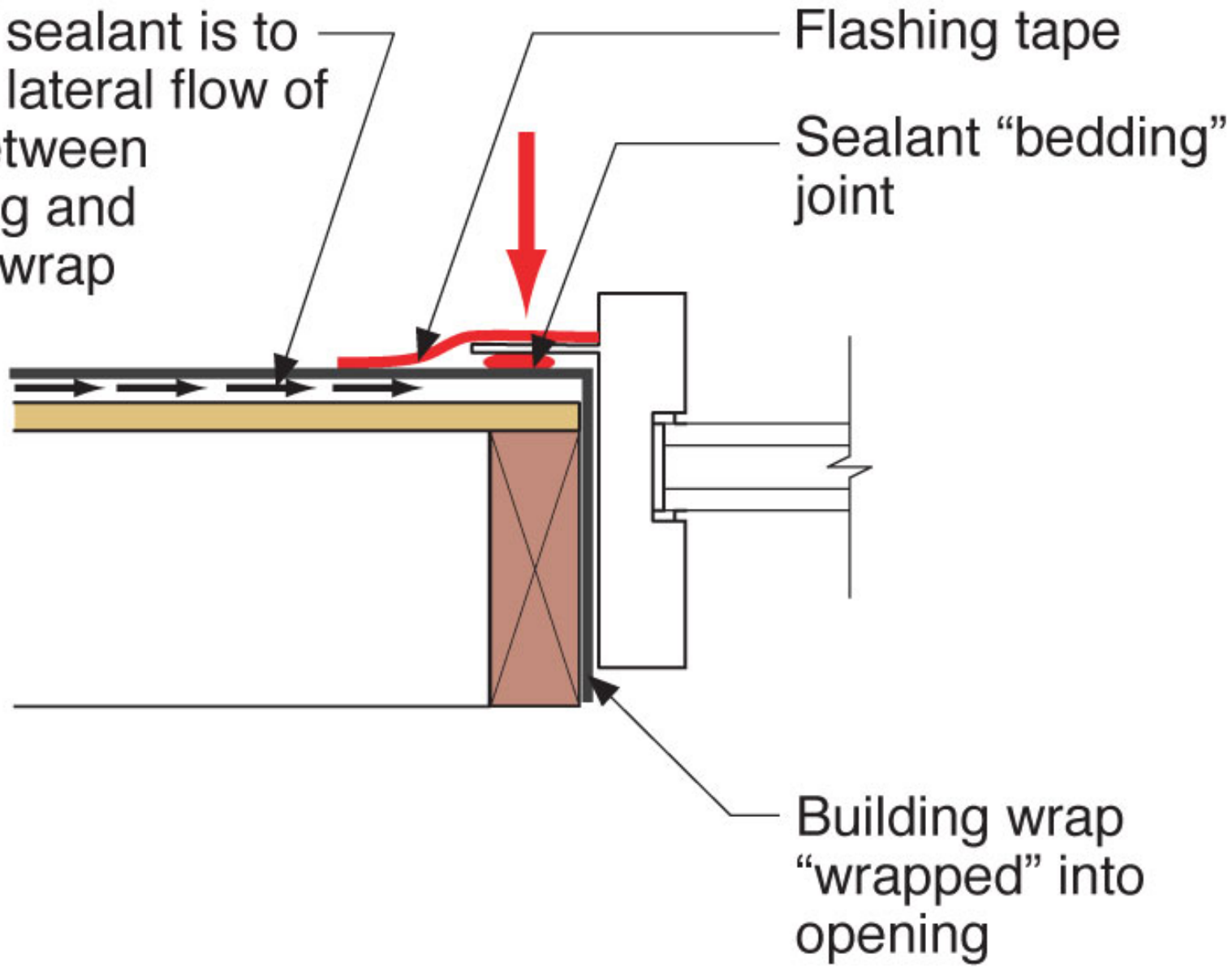


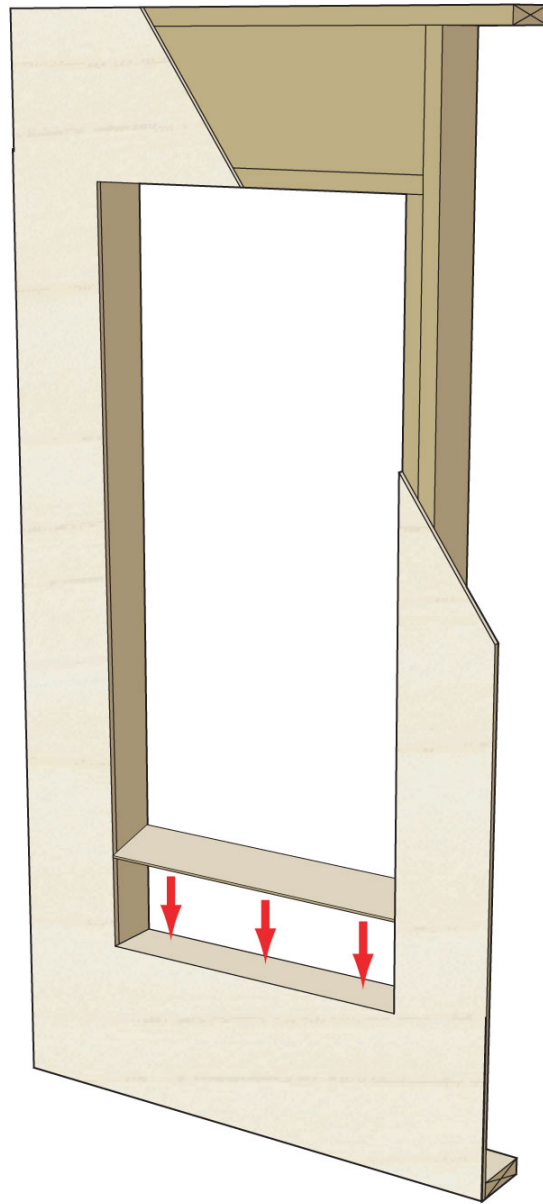


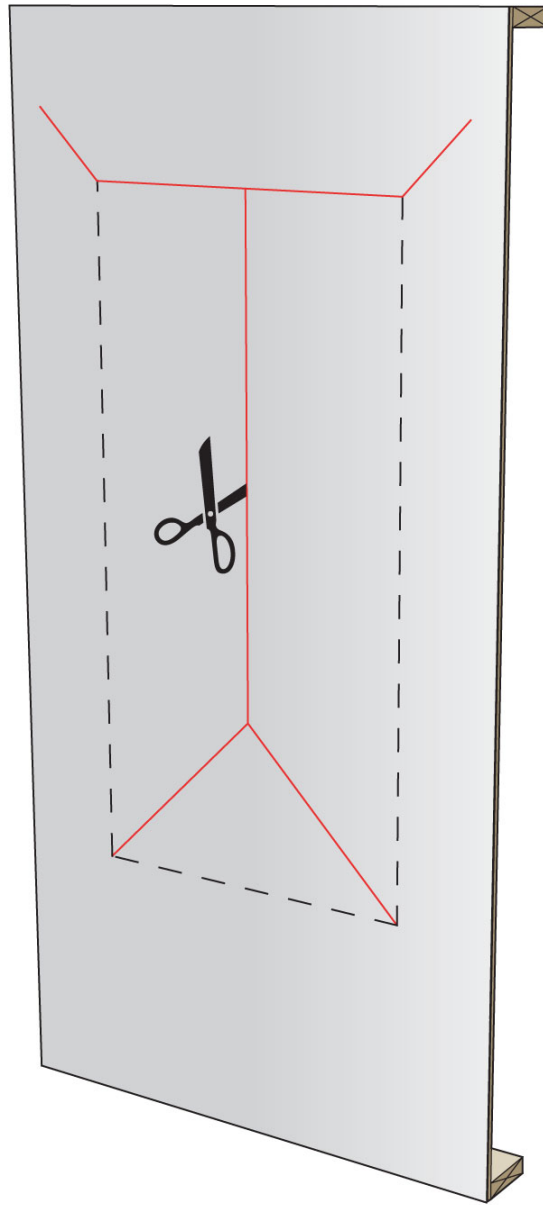


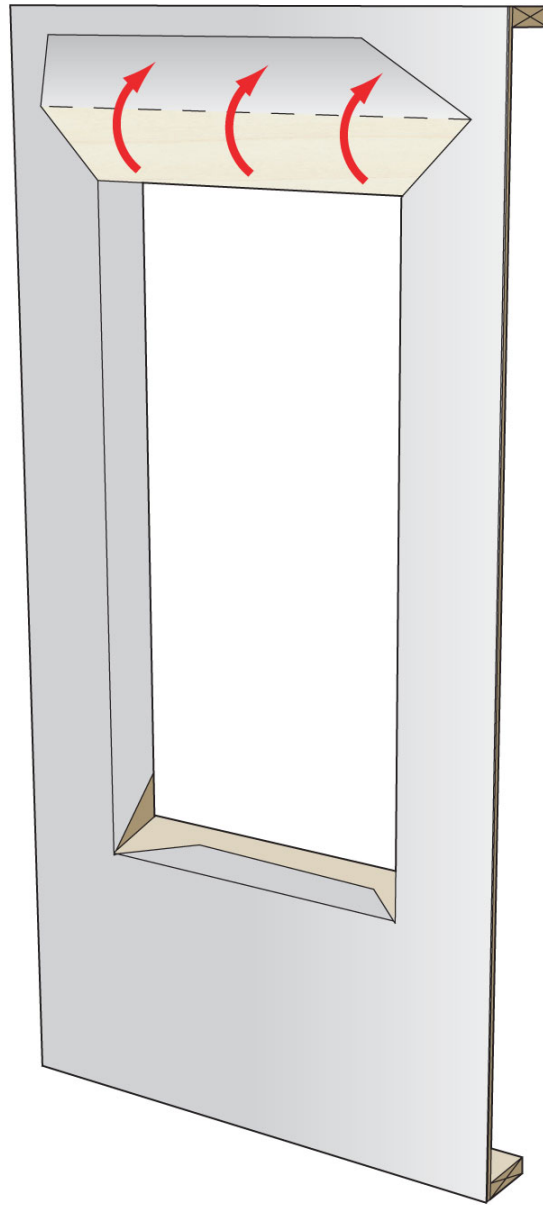


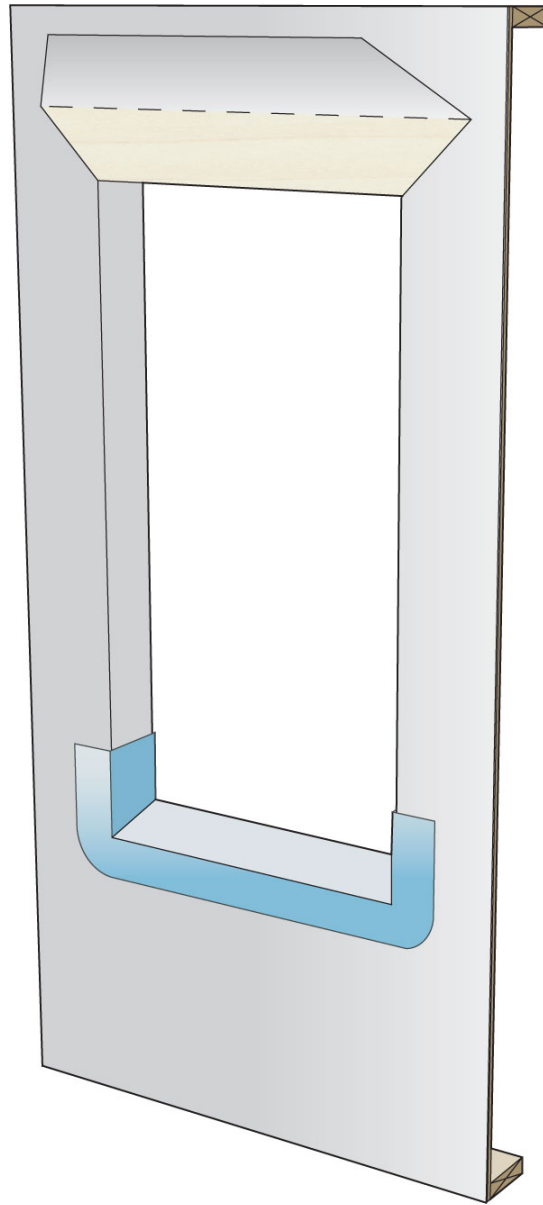
Intent of sealant is to limit this lateral flow of water between sheathing and building wrap

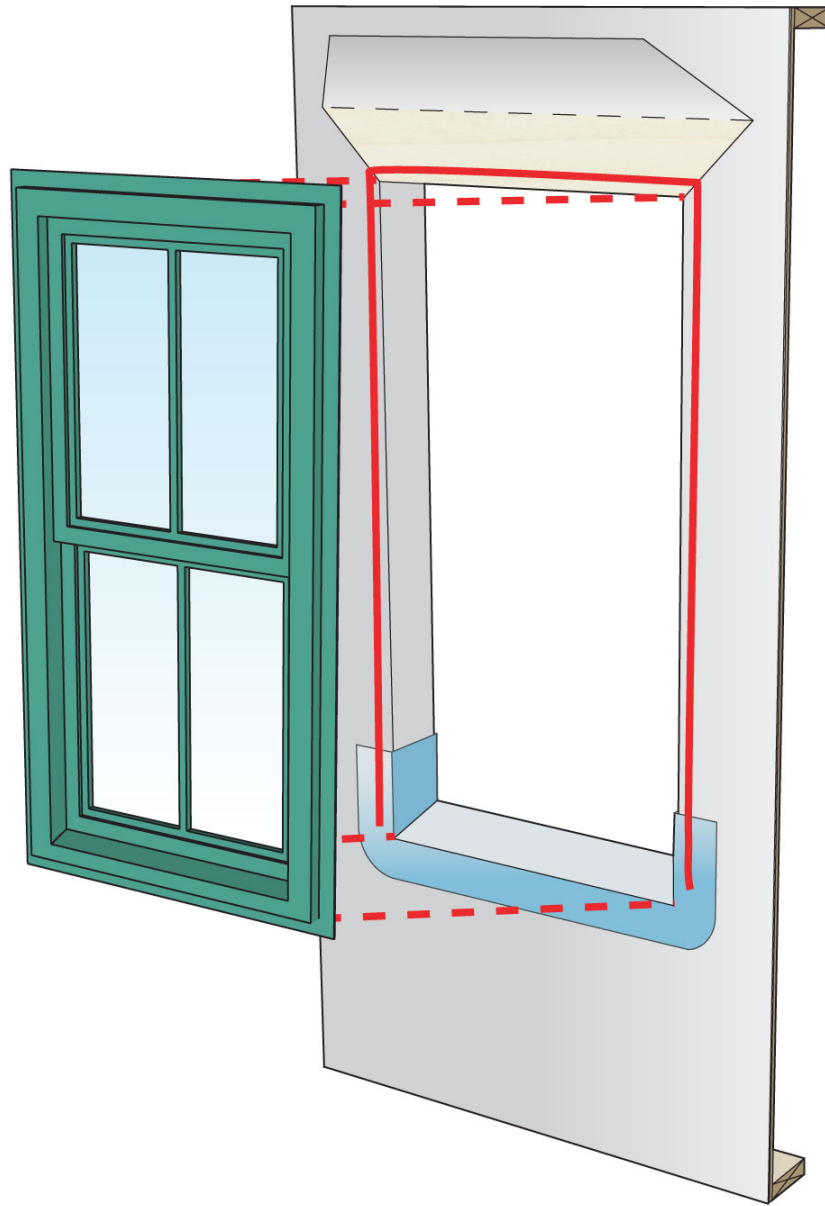


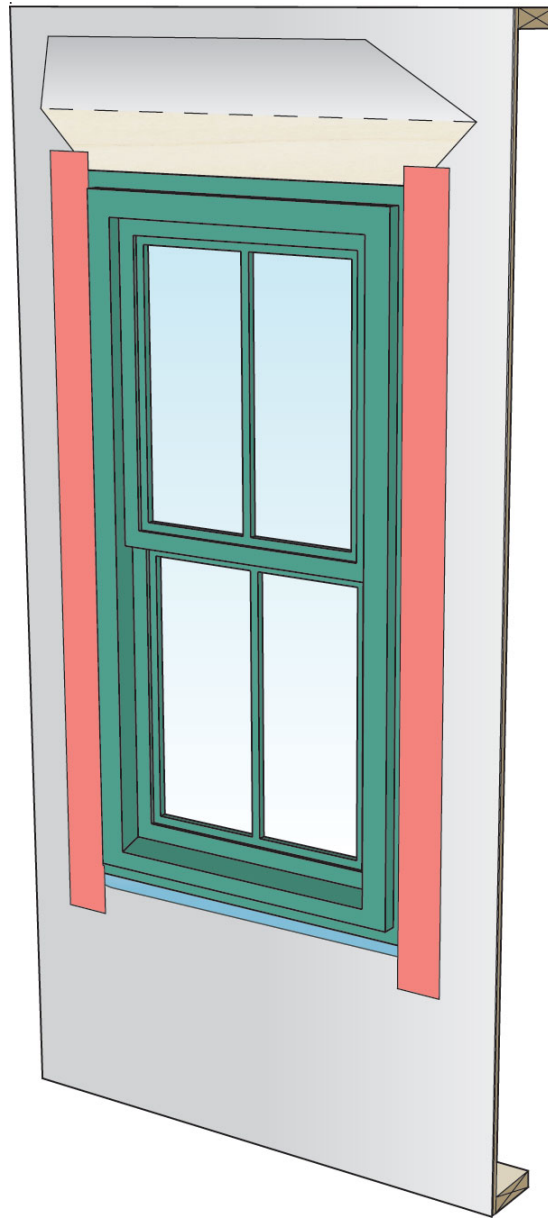


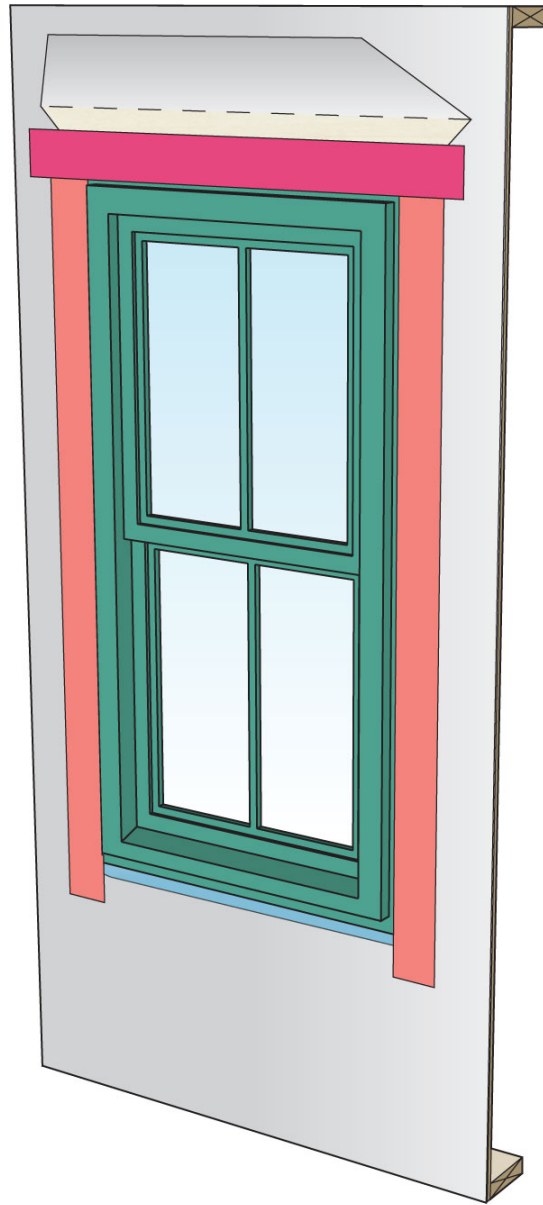


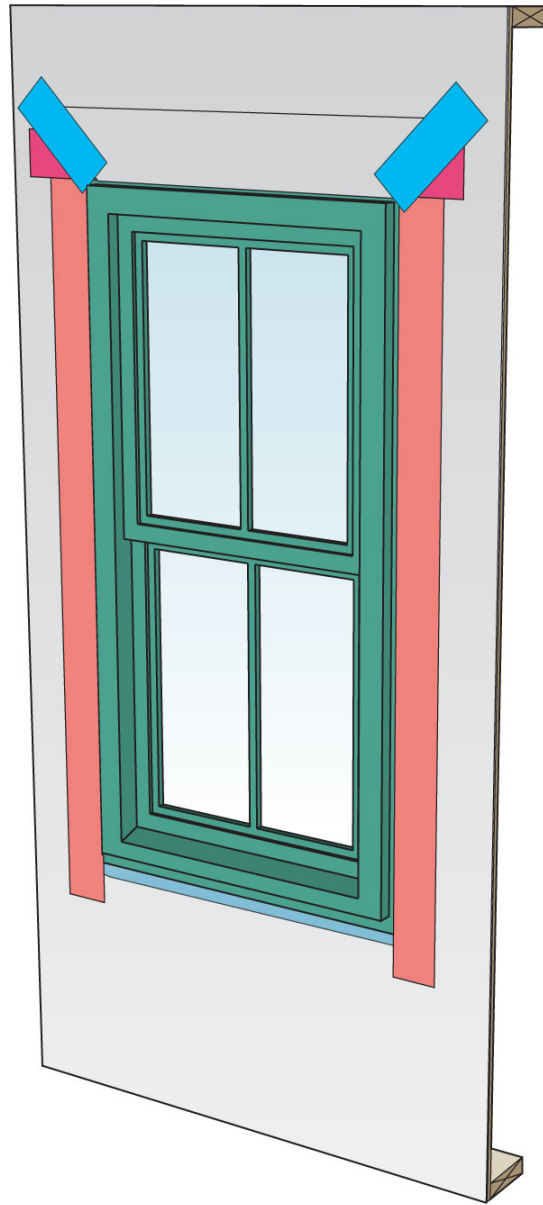


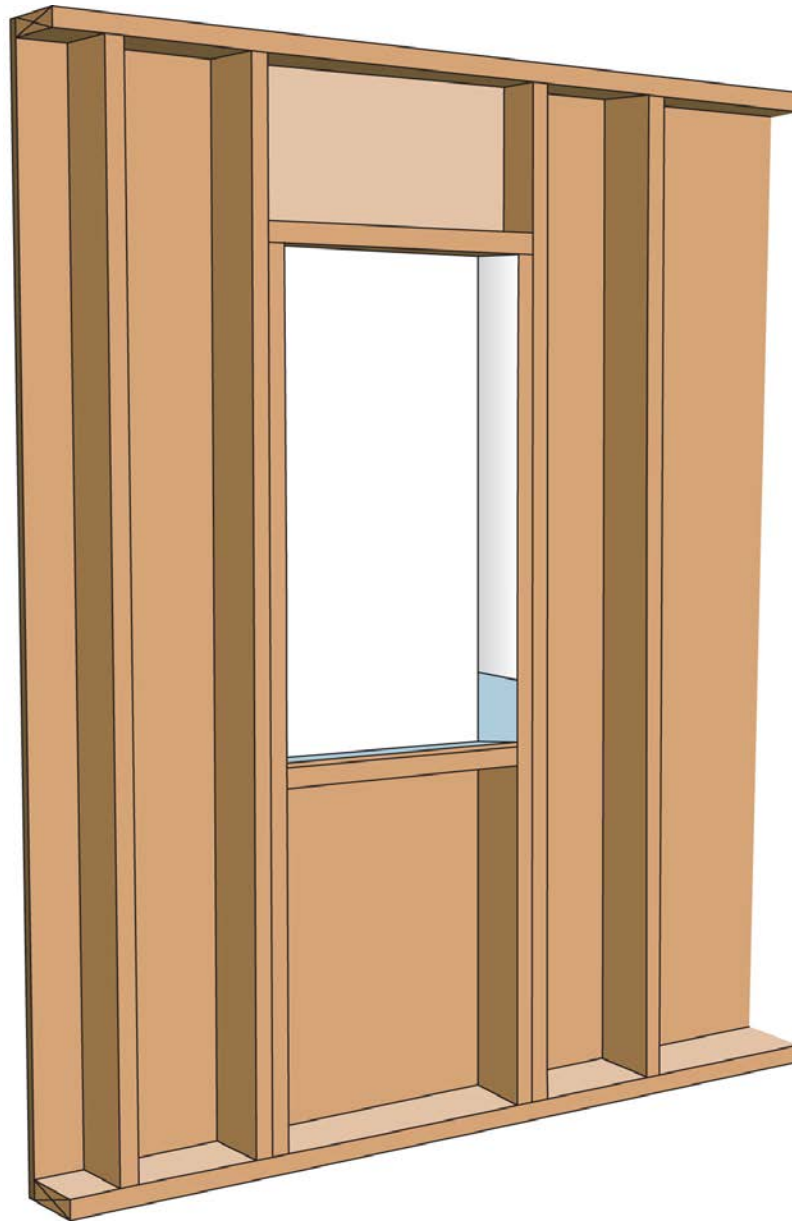








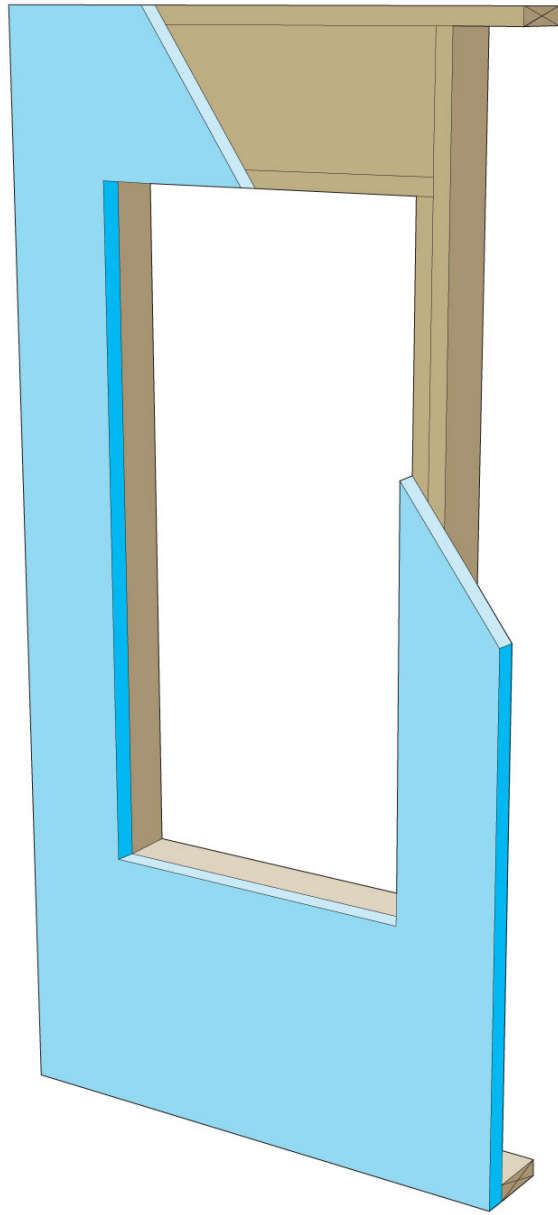


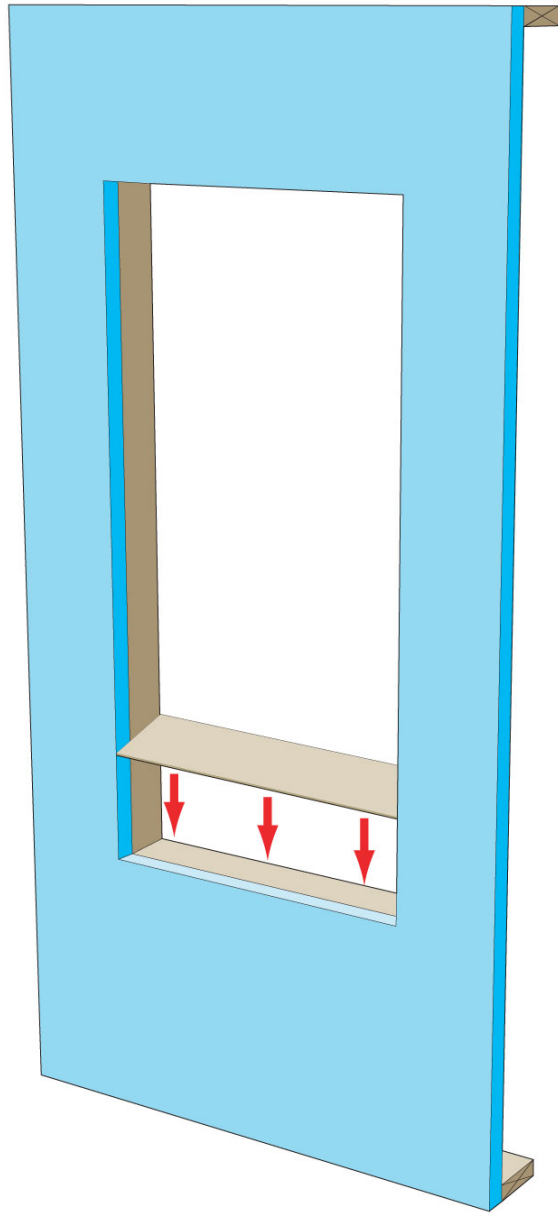


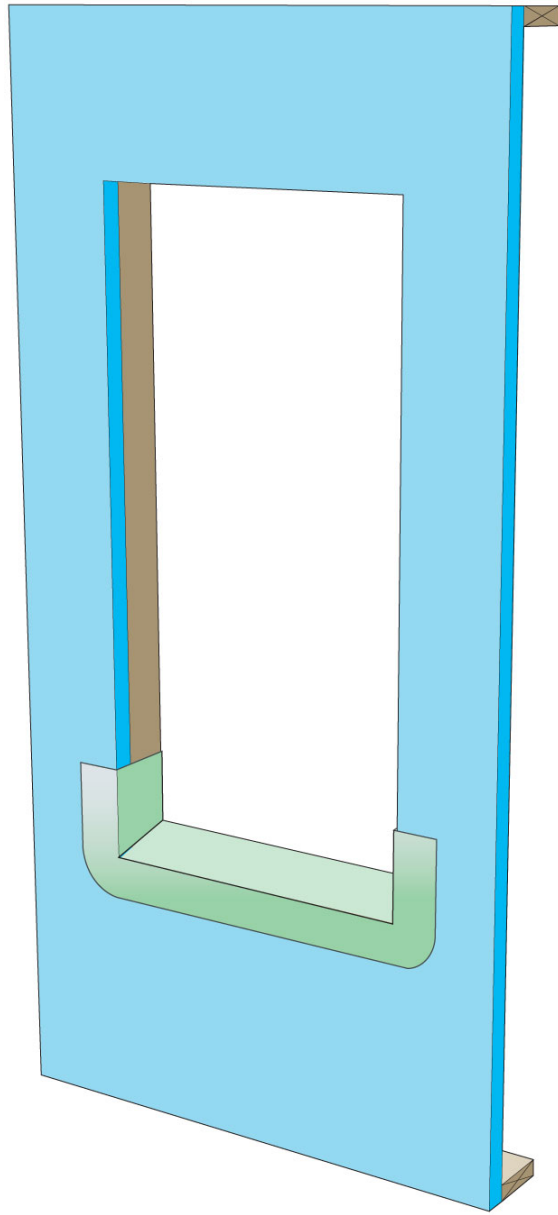


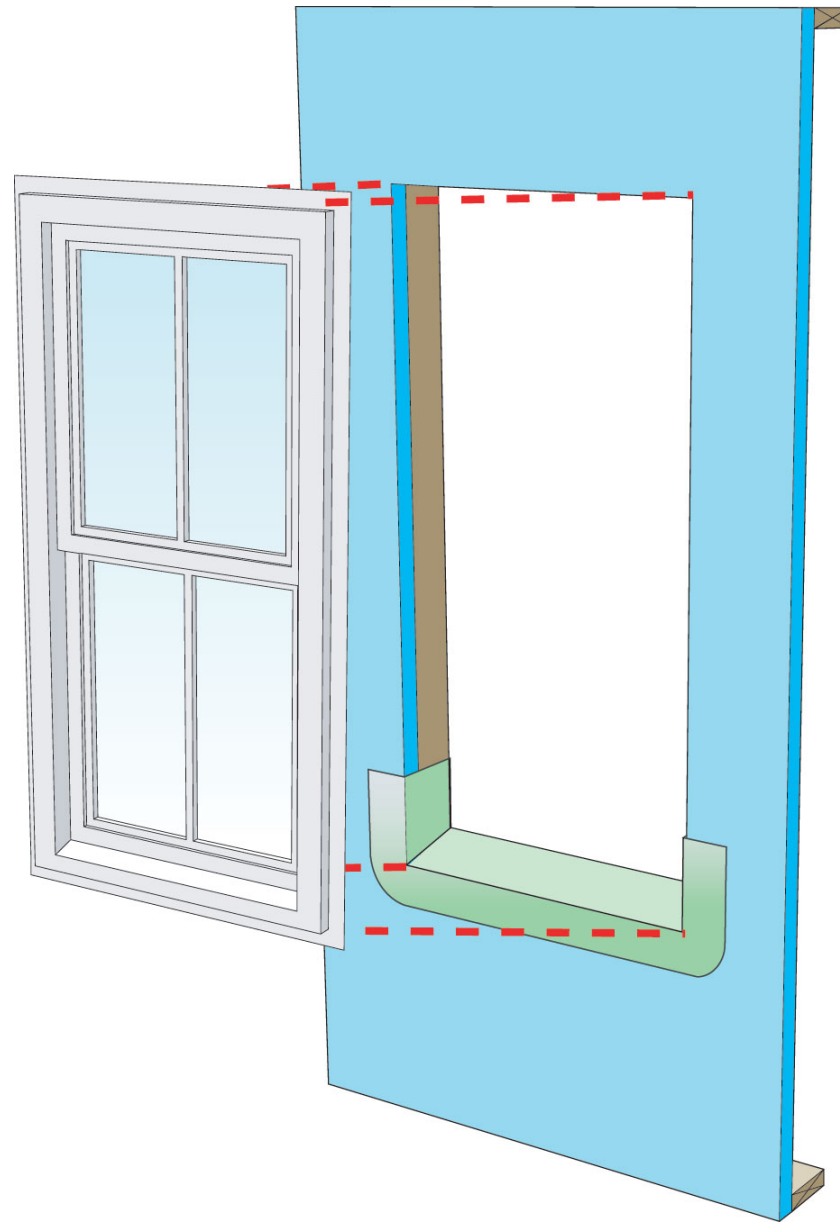


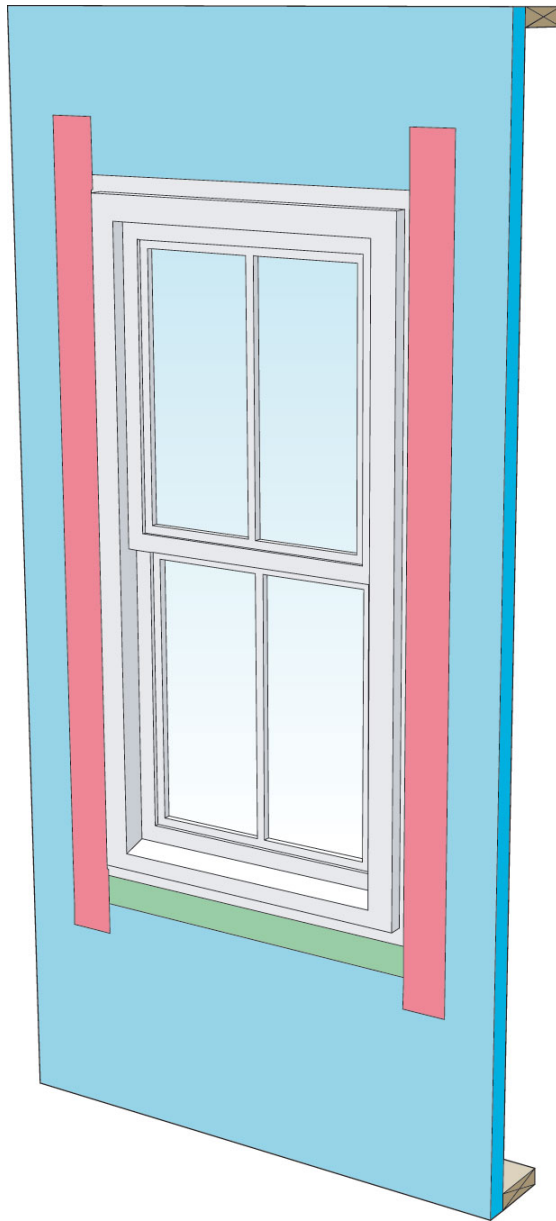


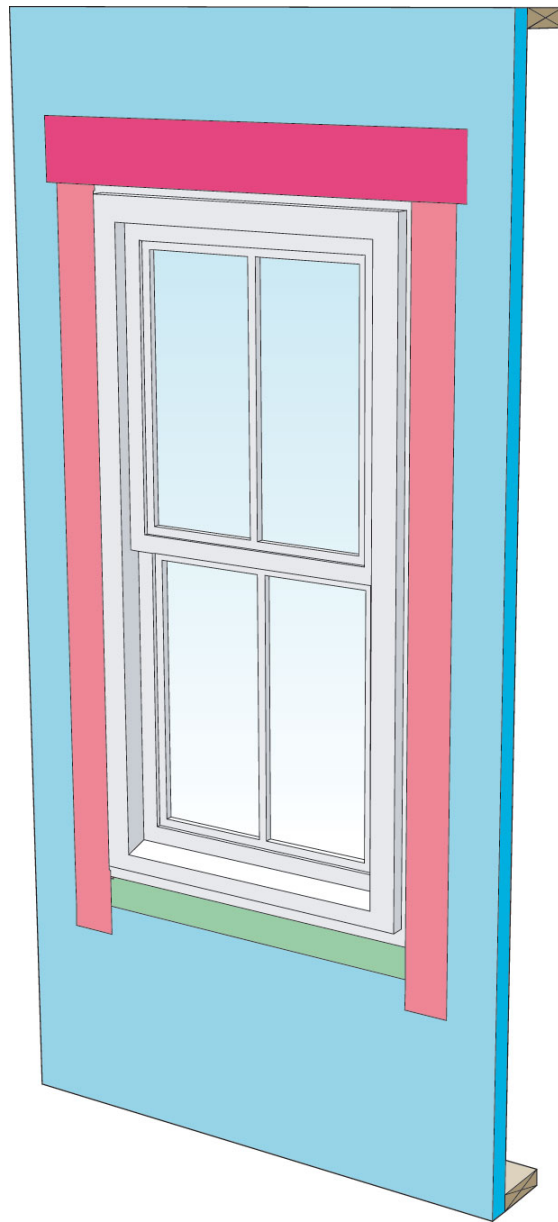


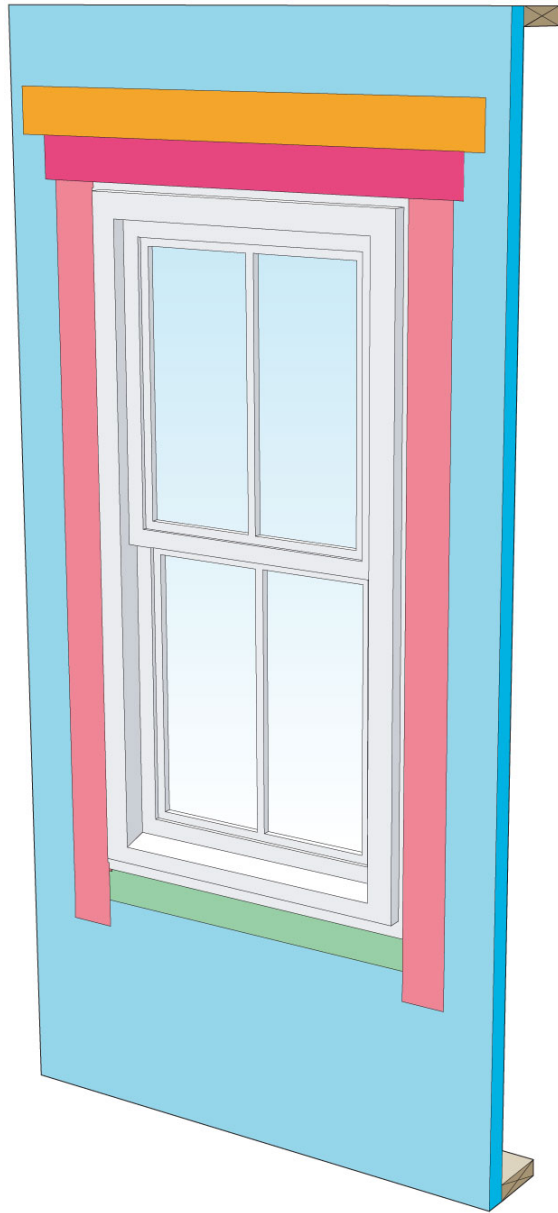


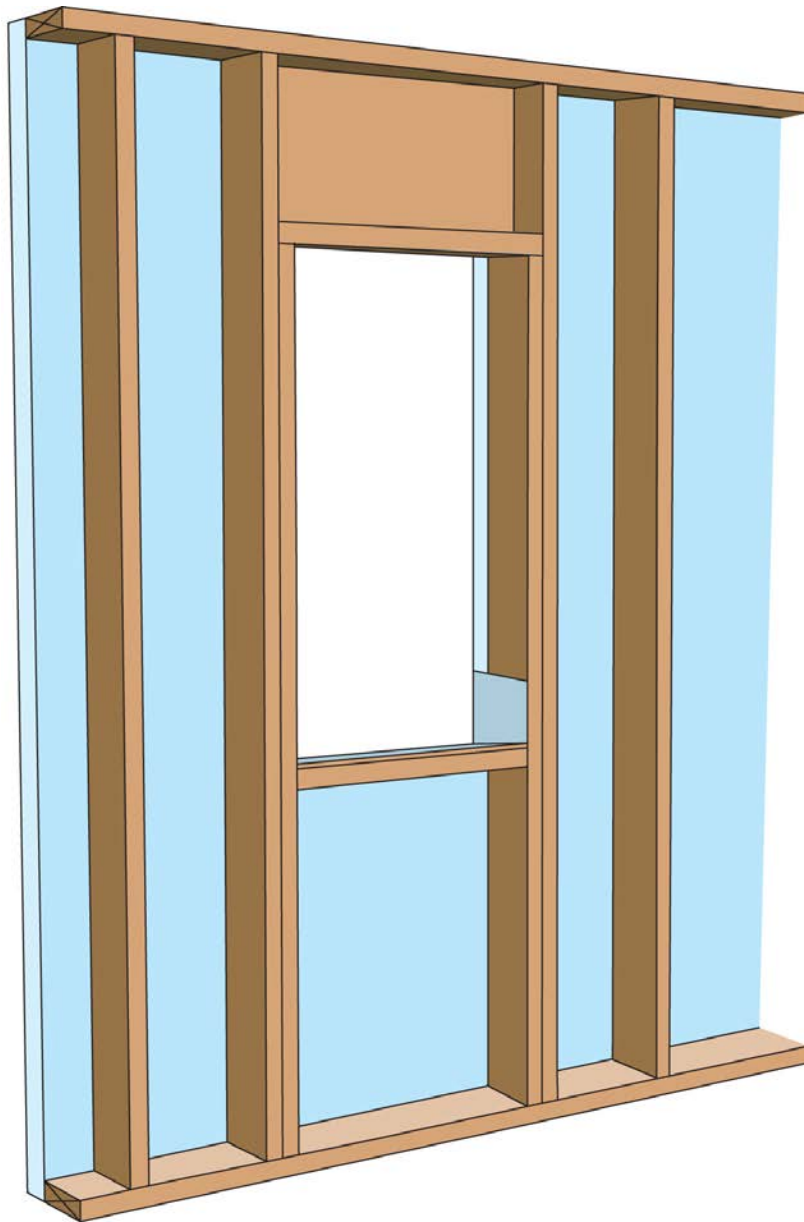




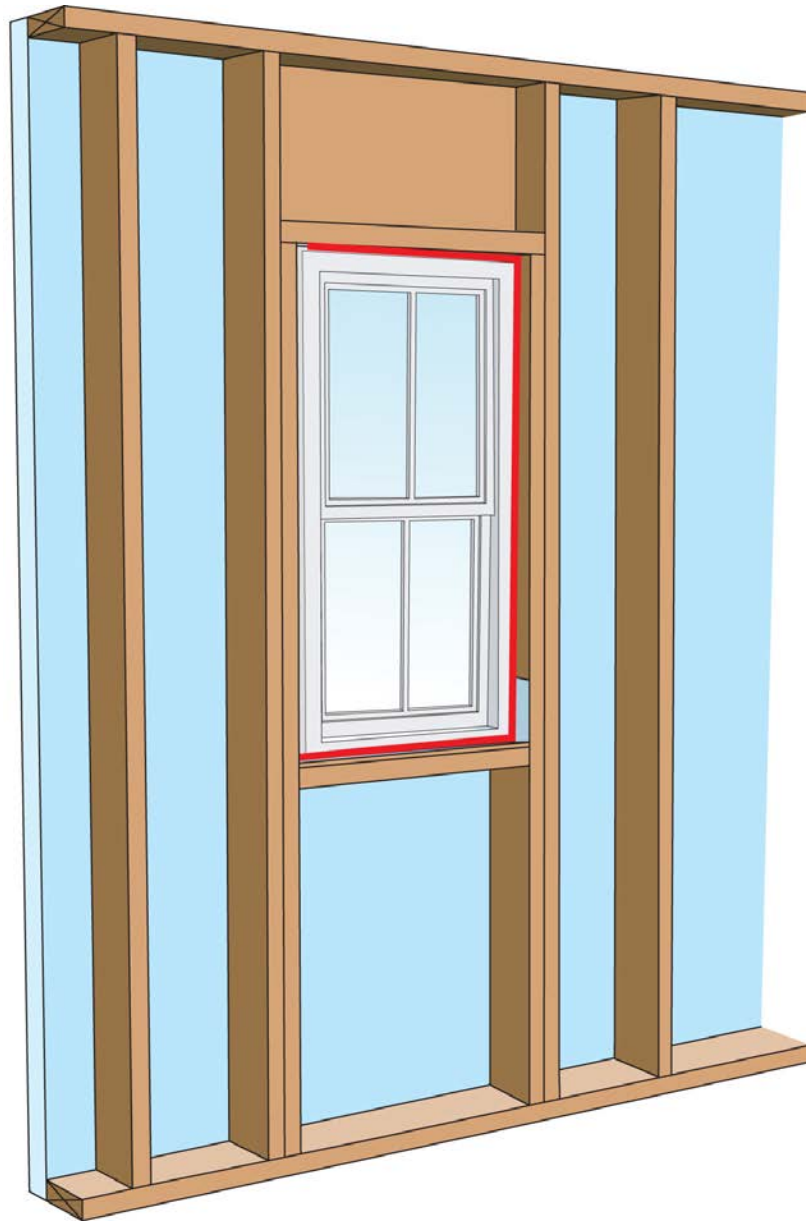






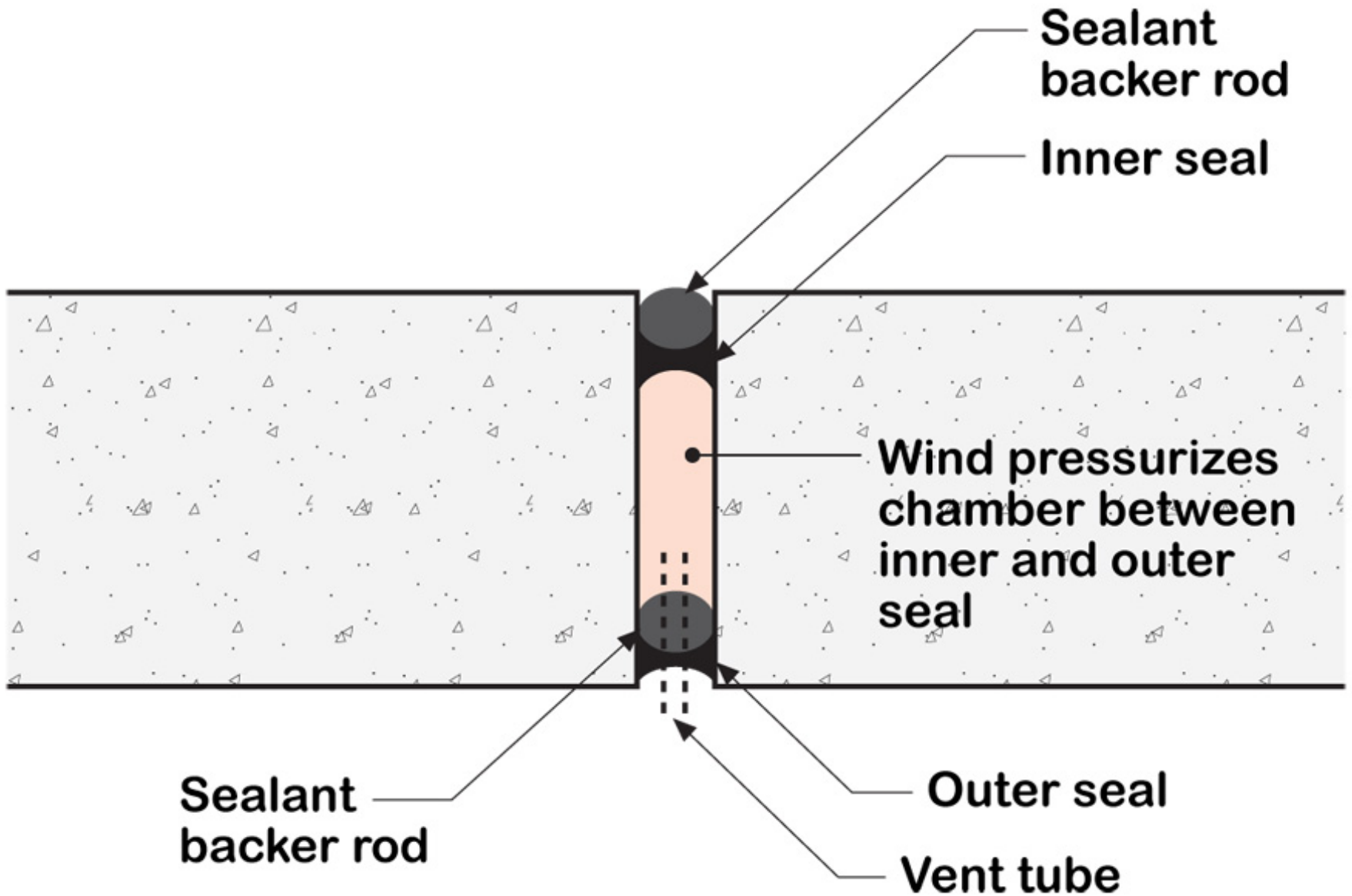


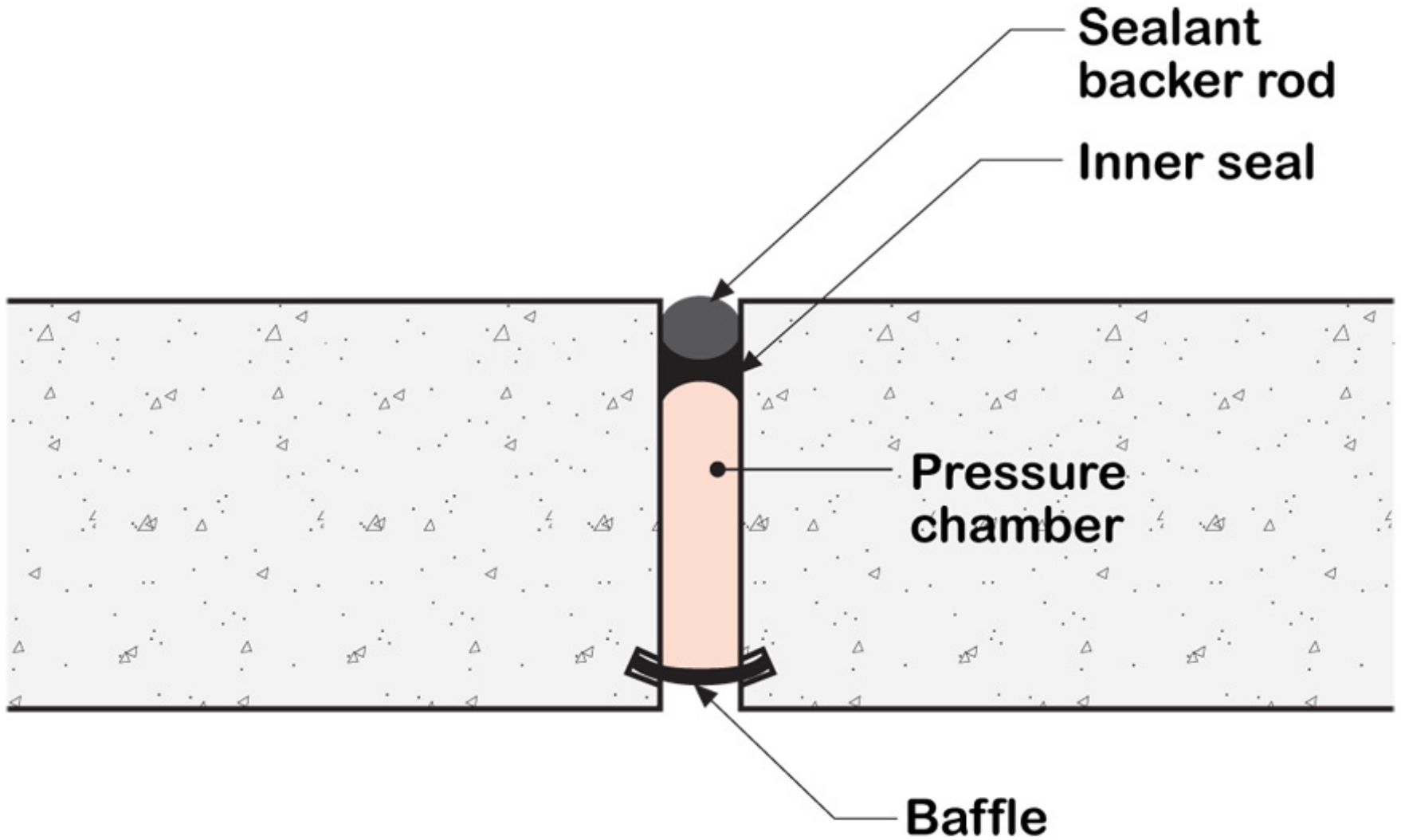


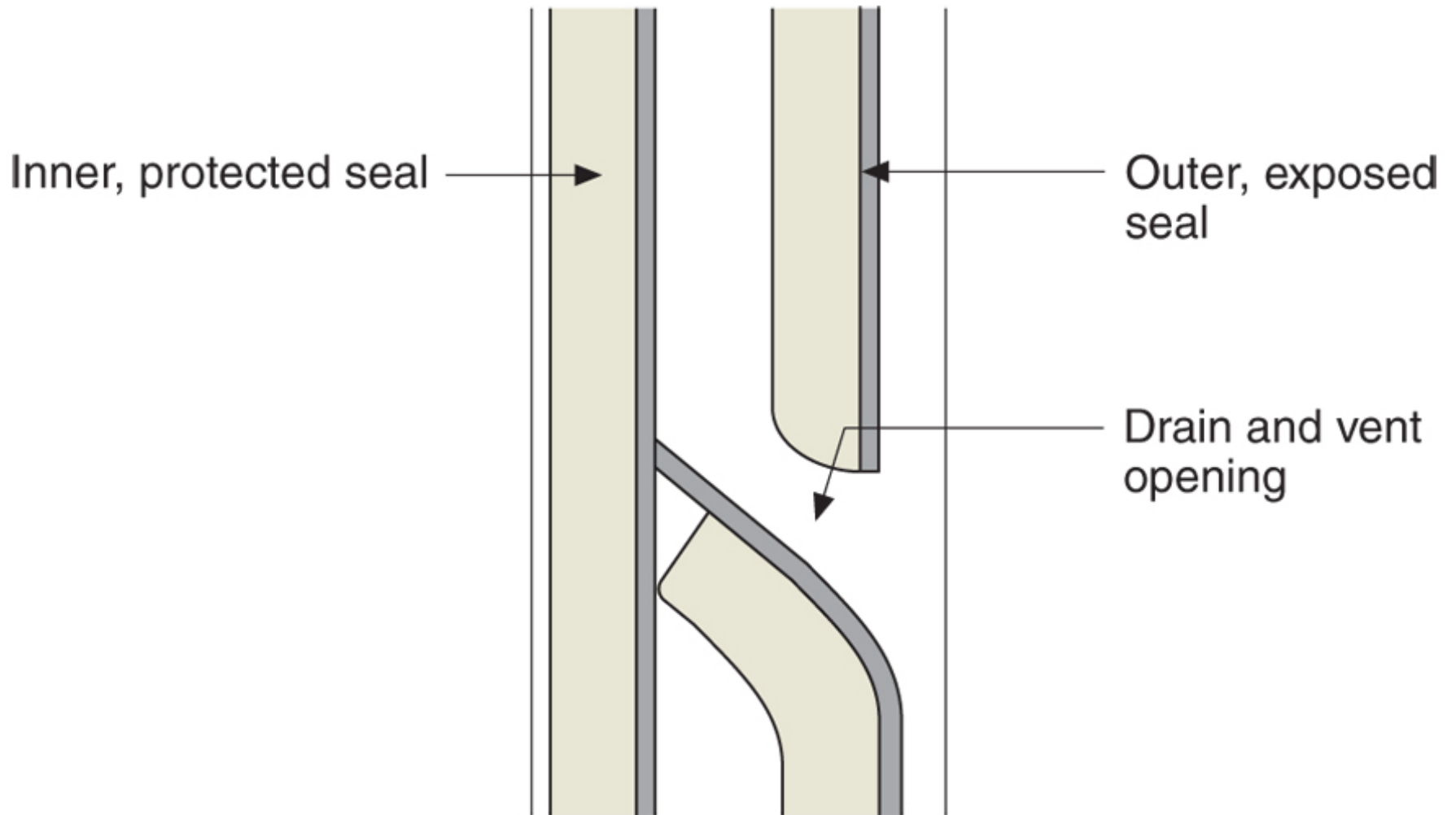


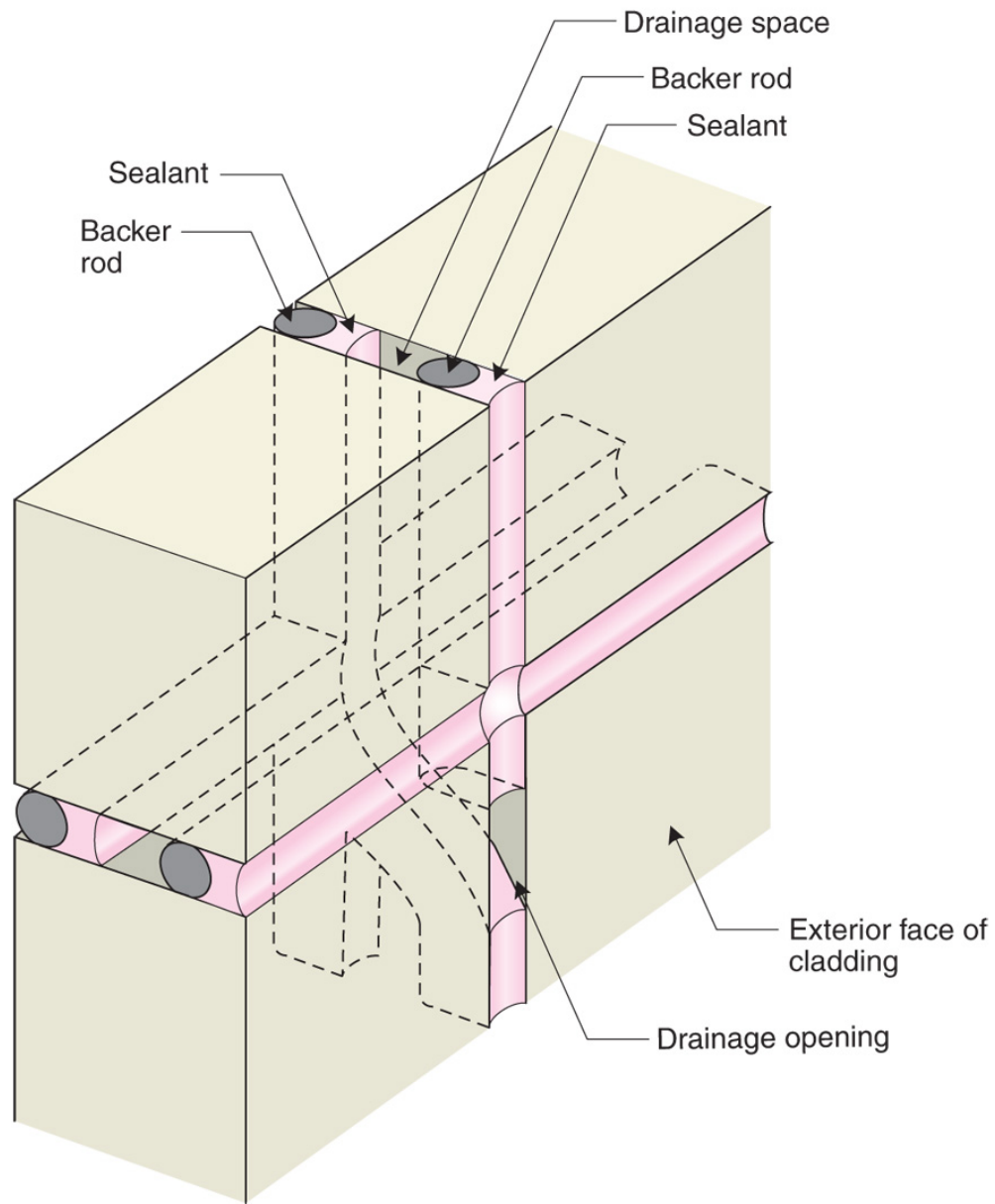




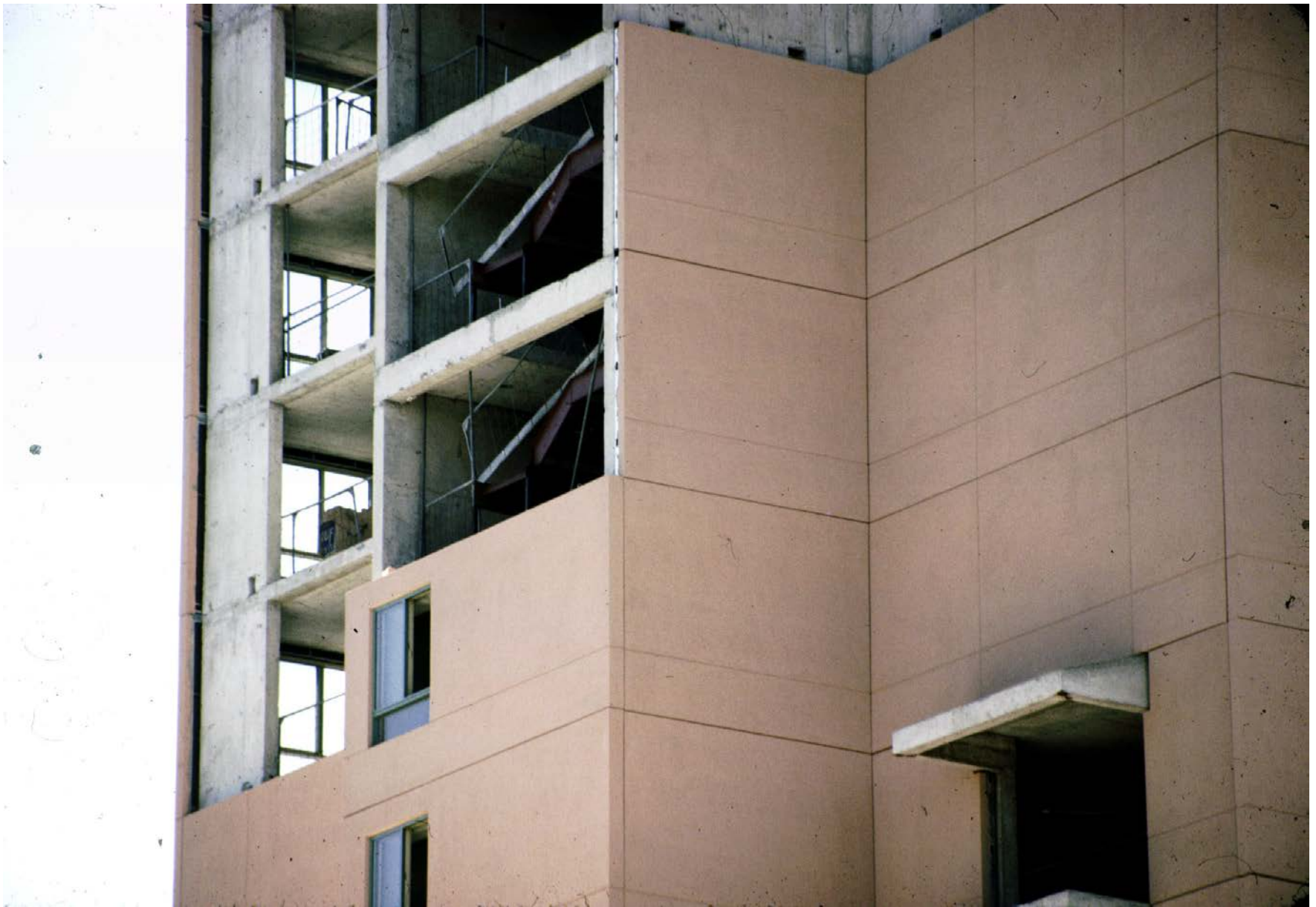
















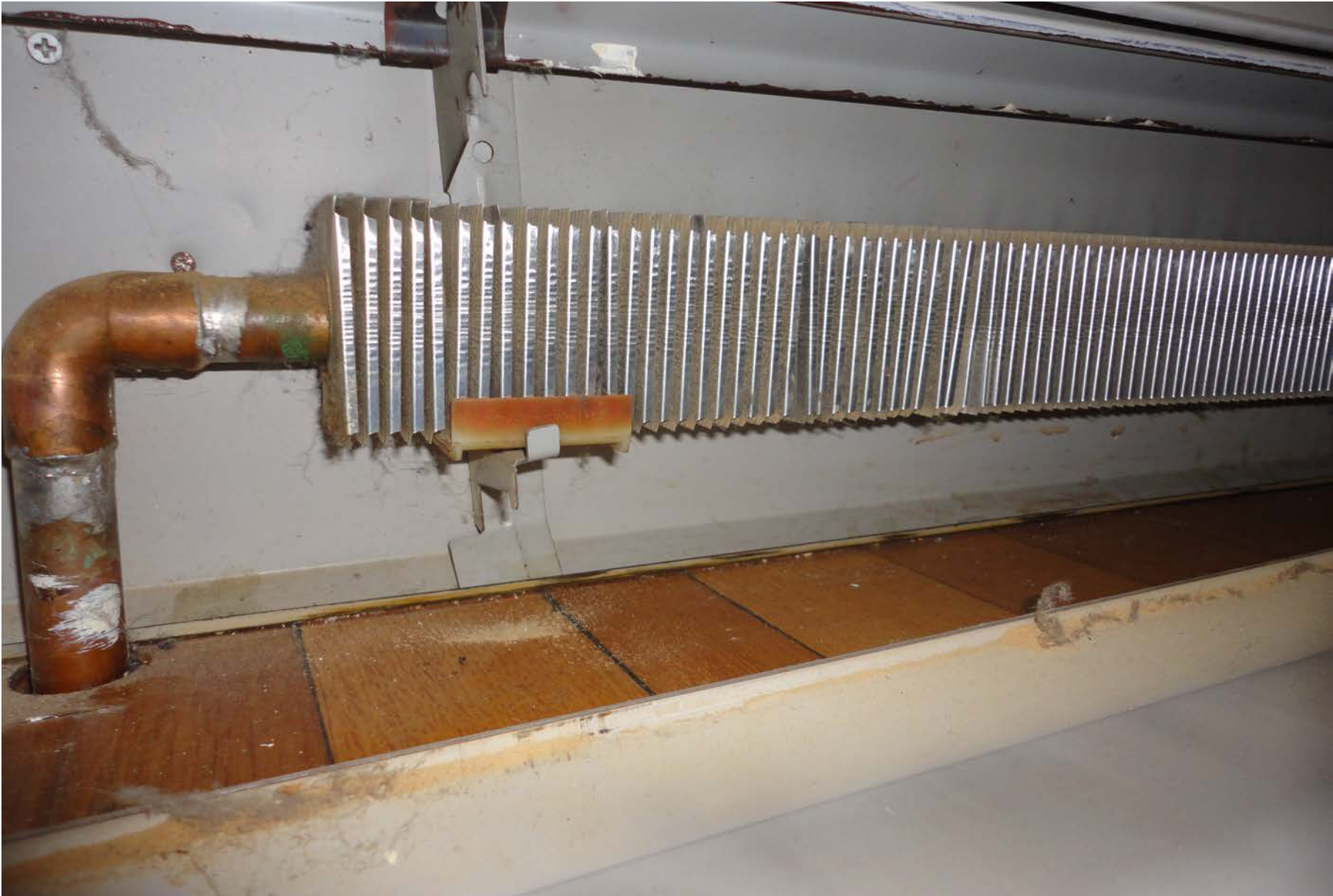
Life is Tough Enough As it Is...

Life is Tough Enough As it Is...
It's Harder When You Are Stupid

Don't Do Stupid Things

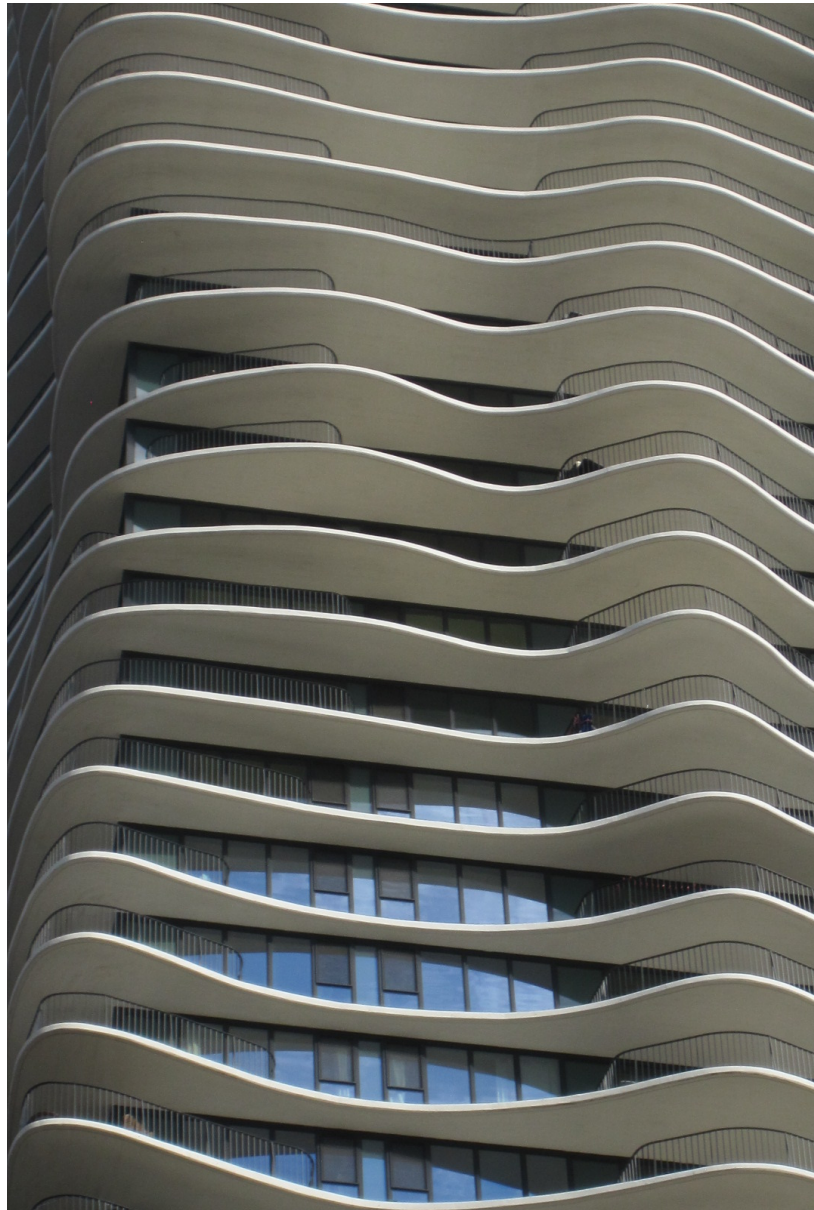


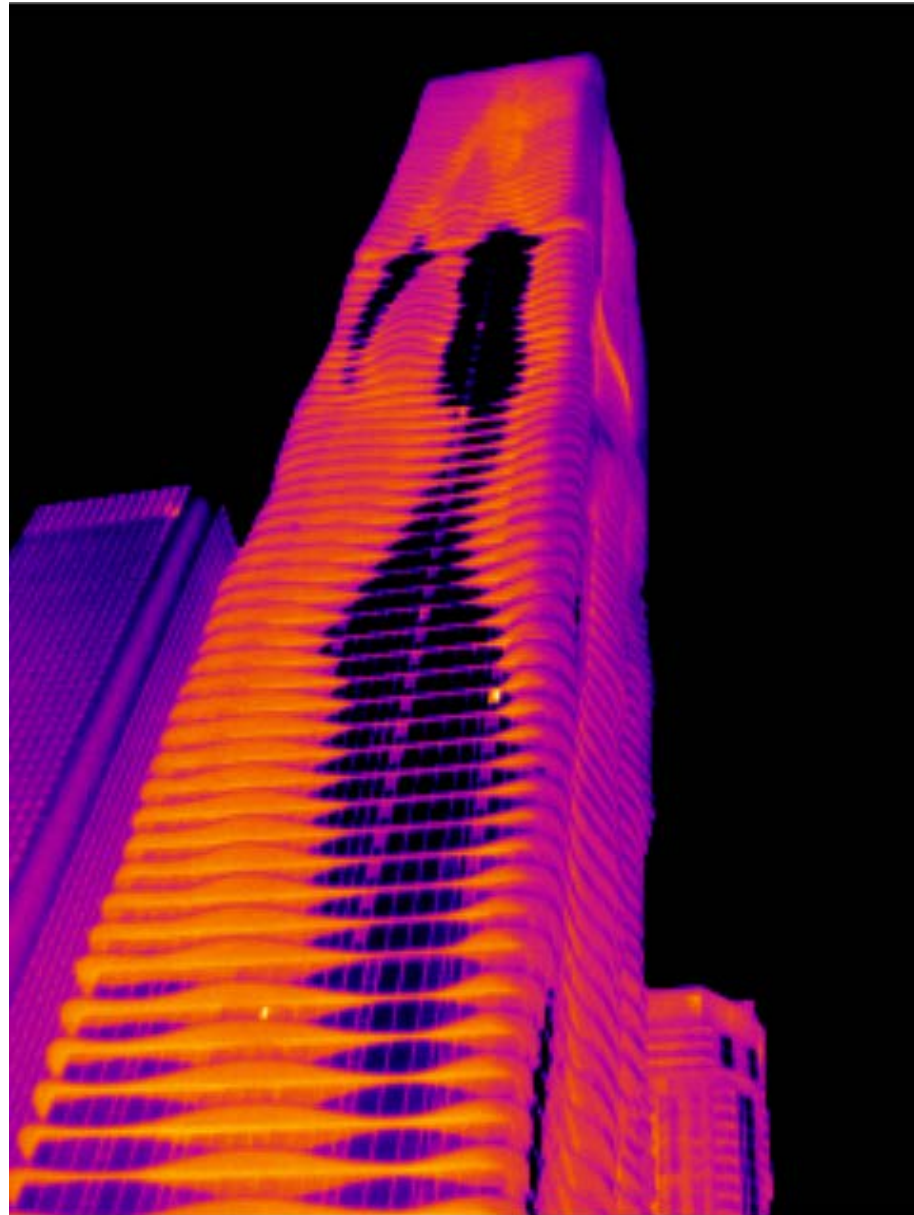


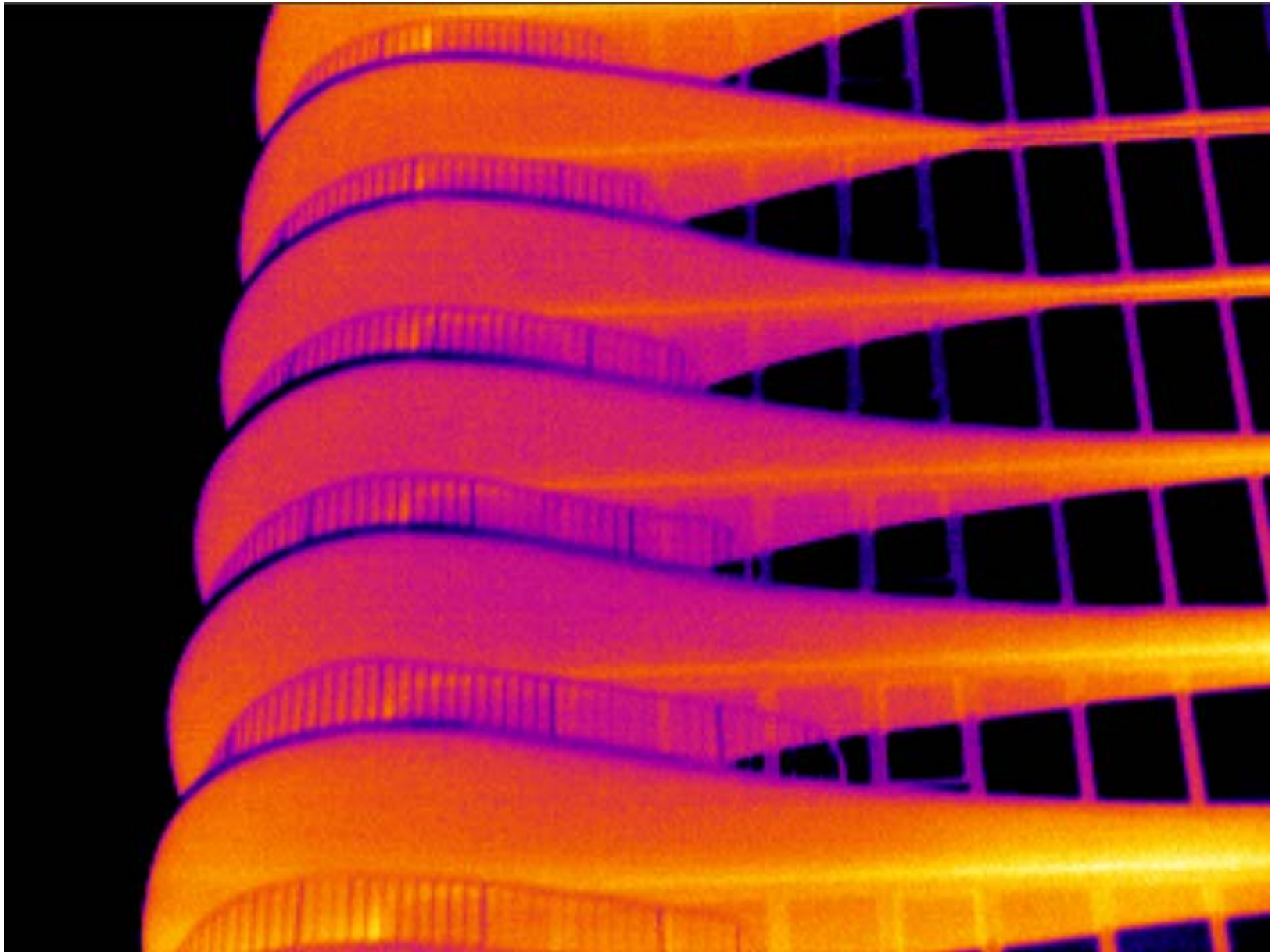


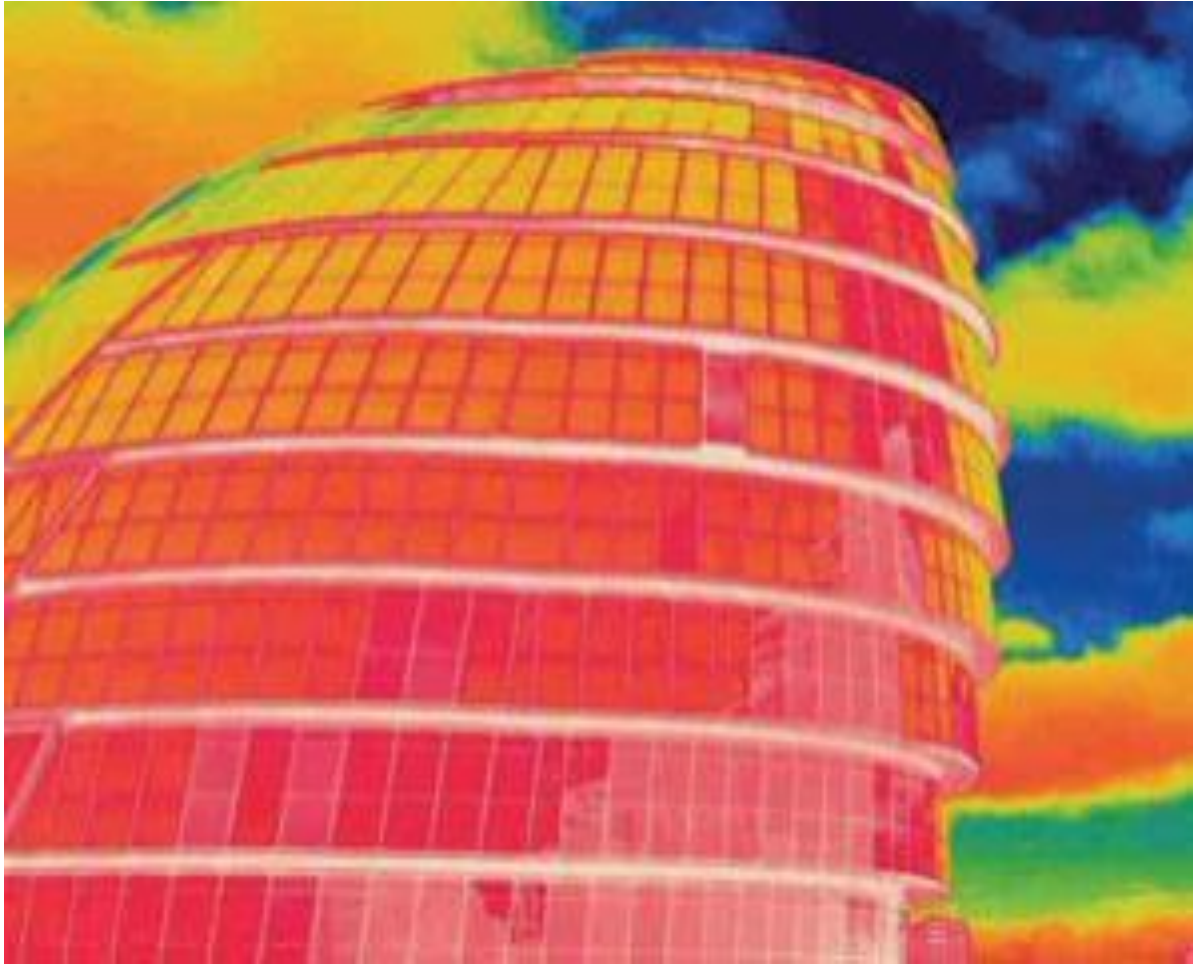






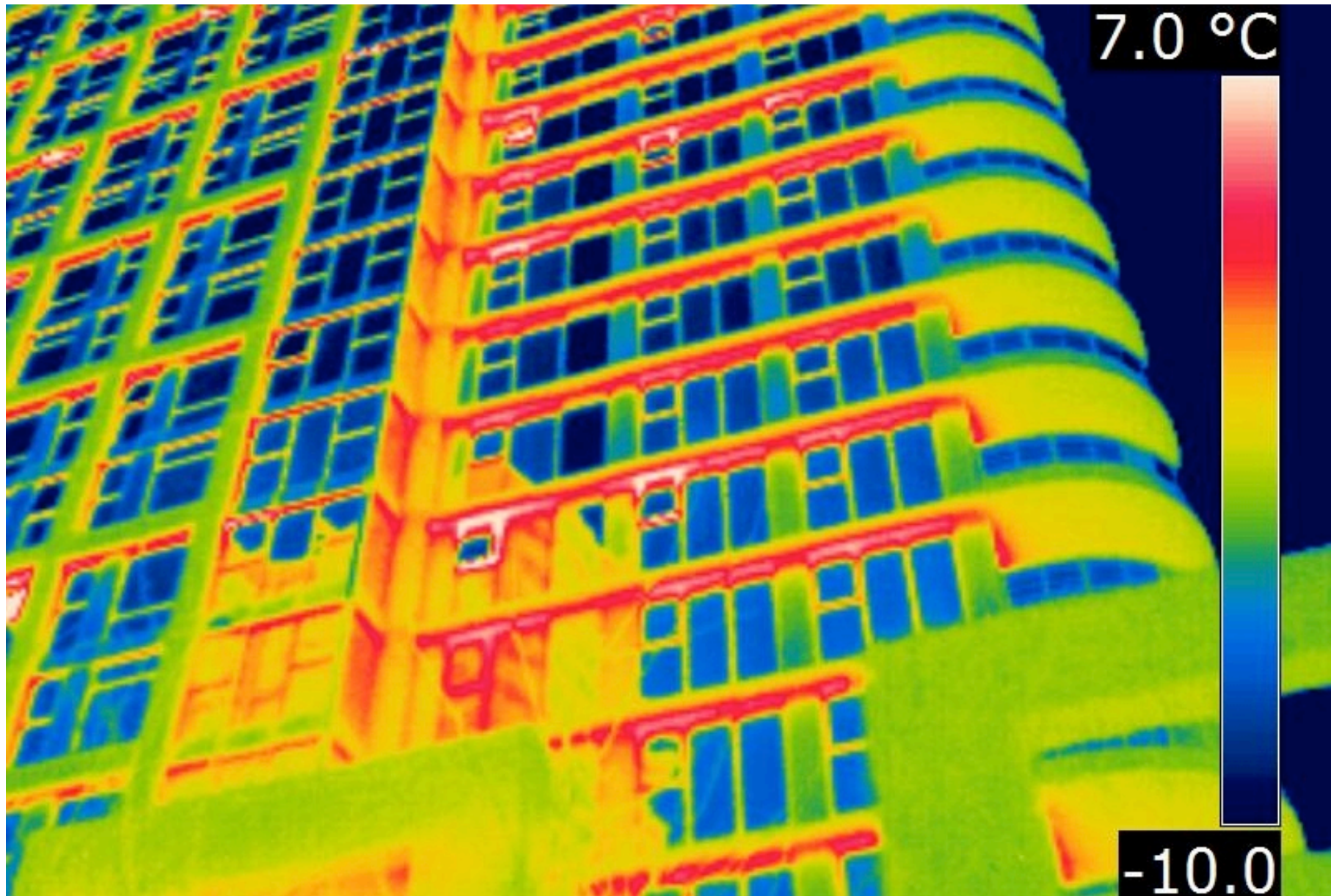


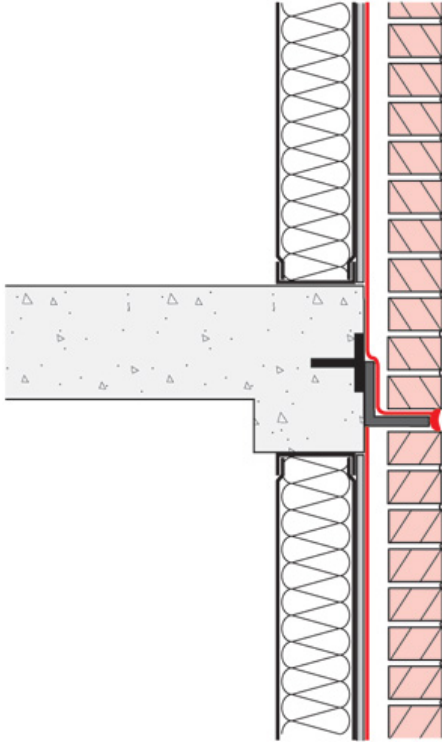




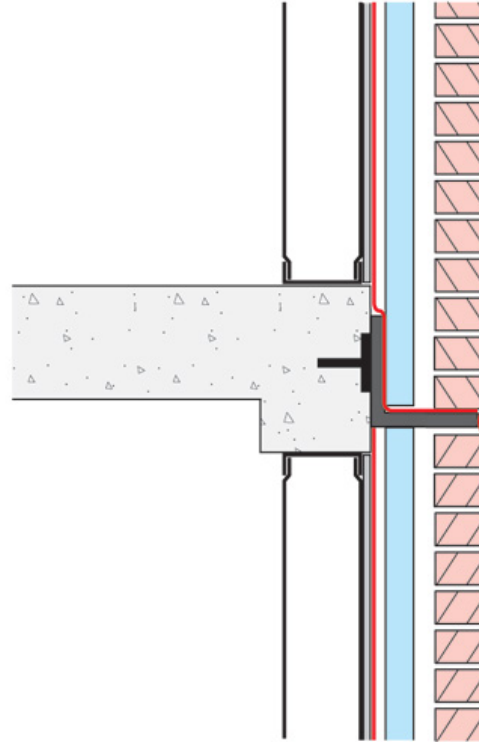




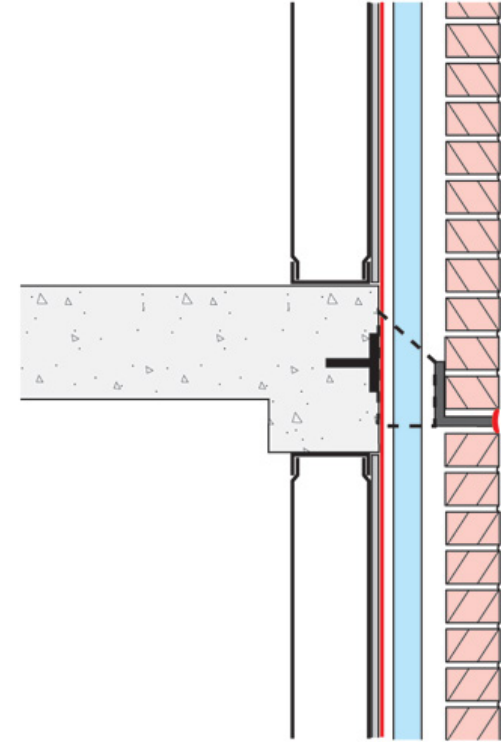




“The Ugly”



“The Bad”



“The Good”

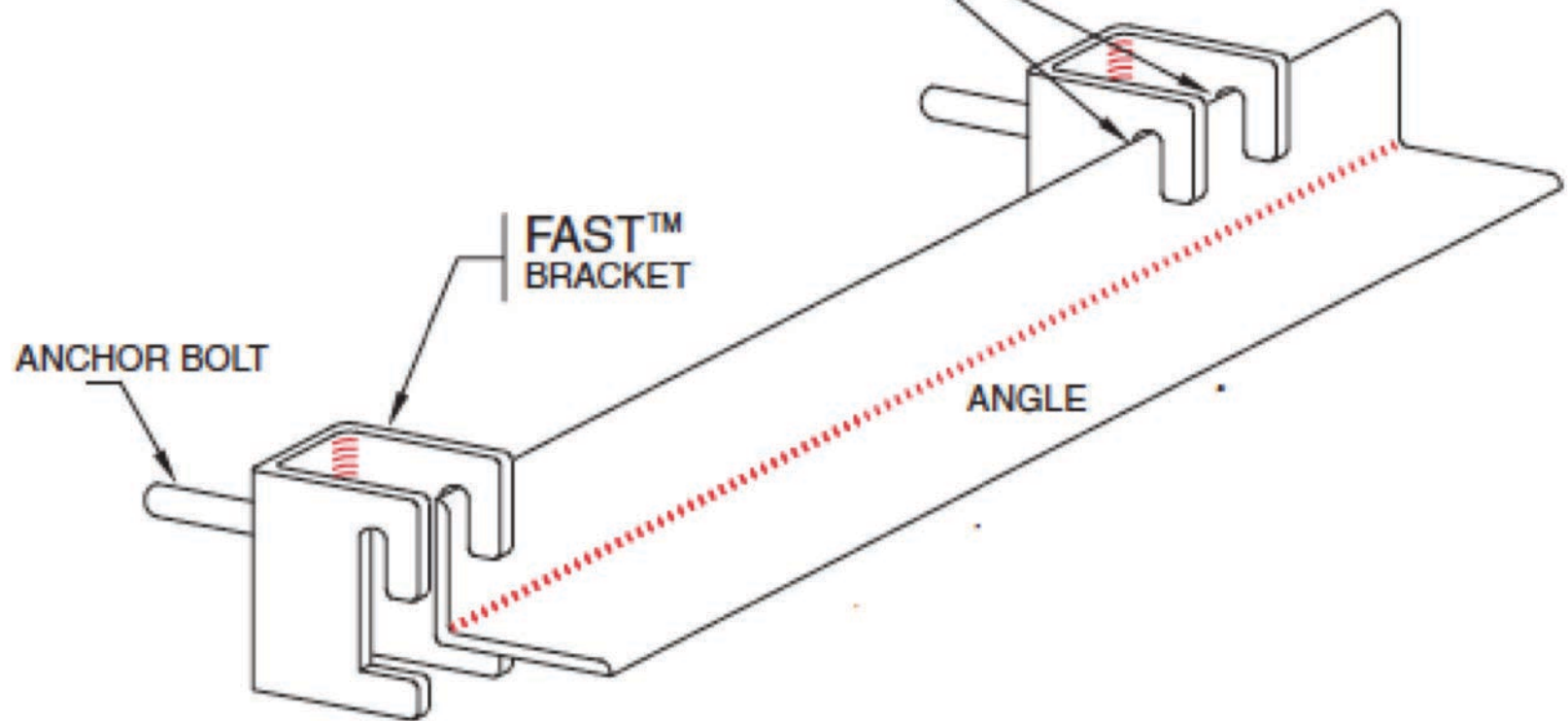






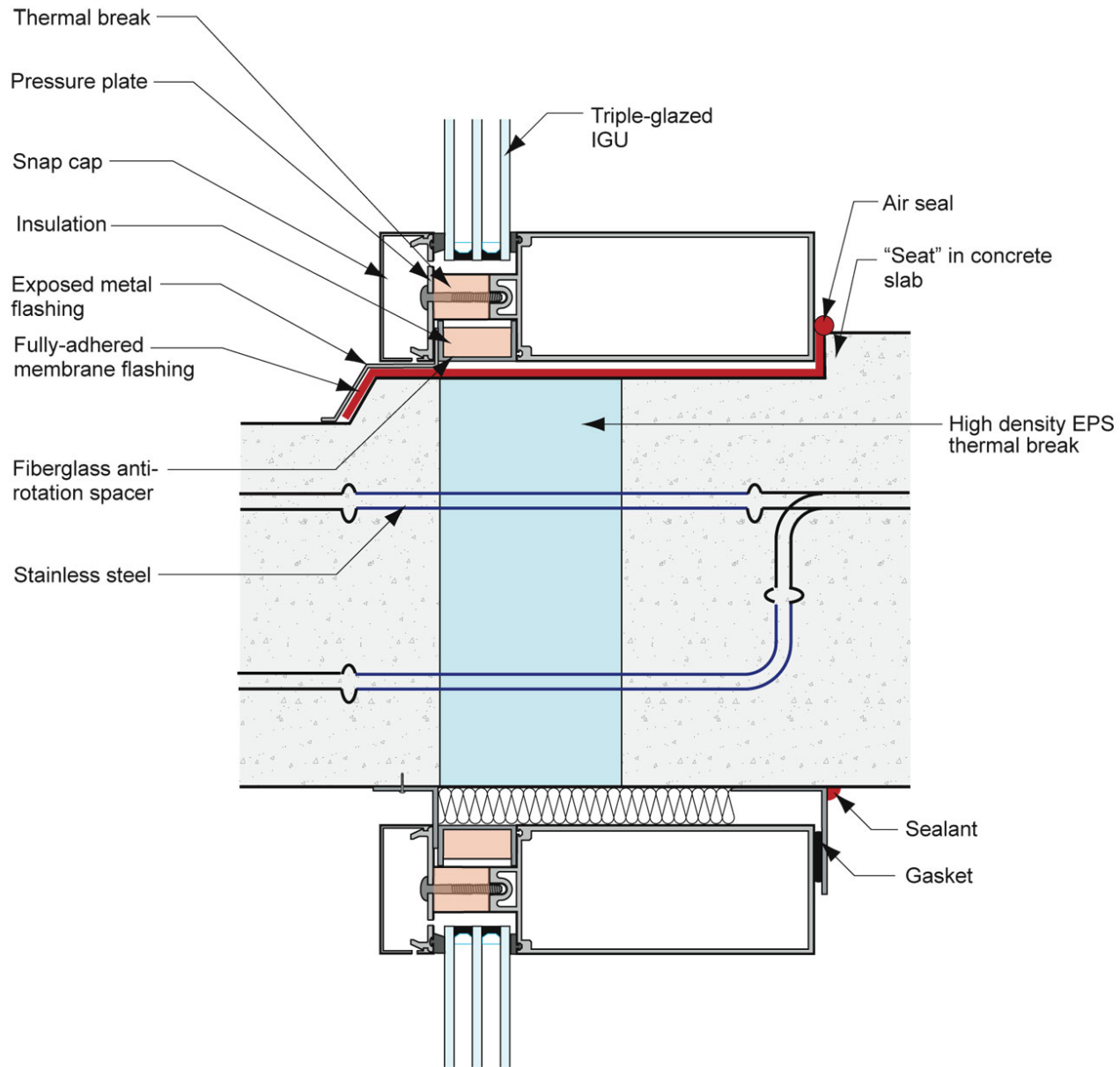


WEDGE SHIMS INSERTED BEHIND/FRONT OF ANGLE TO ENSURE DIRECT BEARING ON BRACKET AND PROVIDE LEVEL (IF NECESSARY)









Zeroth Law – $A=B$ and $B=C$ therefore $A=C$

First Law - Conservation of Energy

Second Law - Entropy

Third Law – Absolute Zero

2nd Law of Thermodynamics

In an isolated system, a process can occur only if it increases the total entropy of the system

Rudolf Clausius

Heat Flow Is From Warm To Cold

Moisture Flow Is From Warm To Cold

Moisture Flow Is From More To Less

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Lower Pressure

Gravity Acts Down

Moisture Flow Is From Warm To Cold
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Thermal Gradient – Thermal Diffusion
Concentration Gradient – Molecular Diffusion

Moisture Flow Is From Warm To Cold
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Thermal Gradient – Thermal Diffusion
Concentration Gradient – Molecular Diffusion

Vapor Diffusion

Thermodynamic Potential



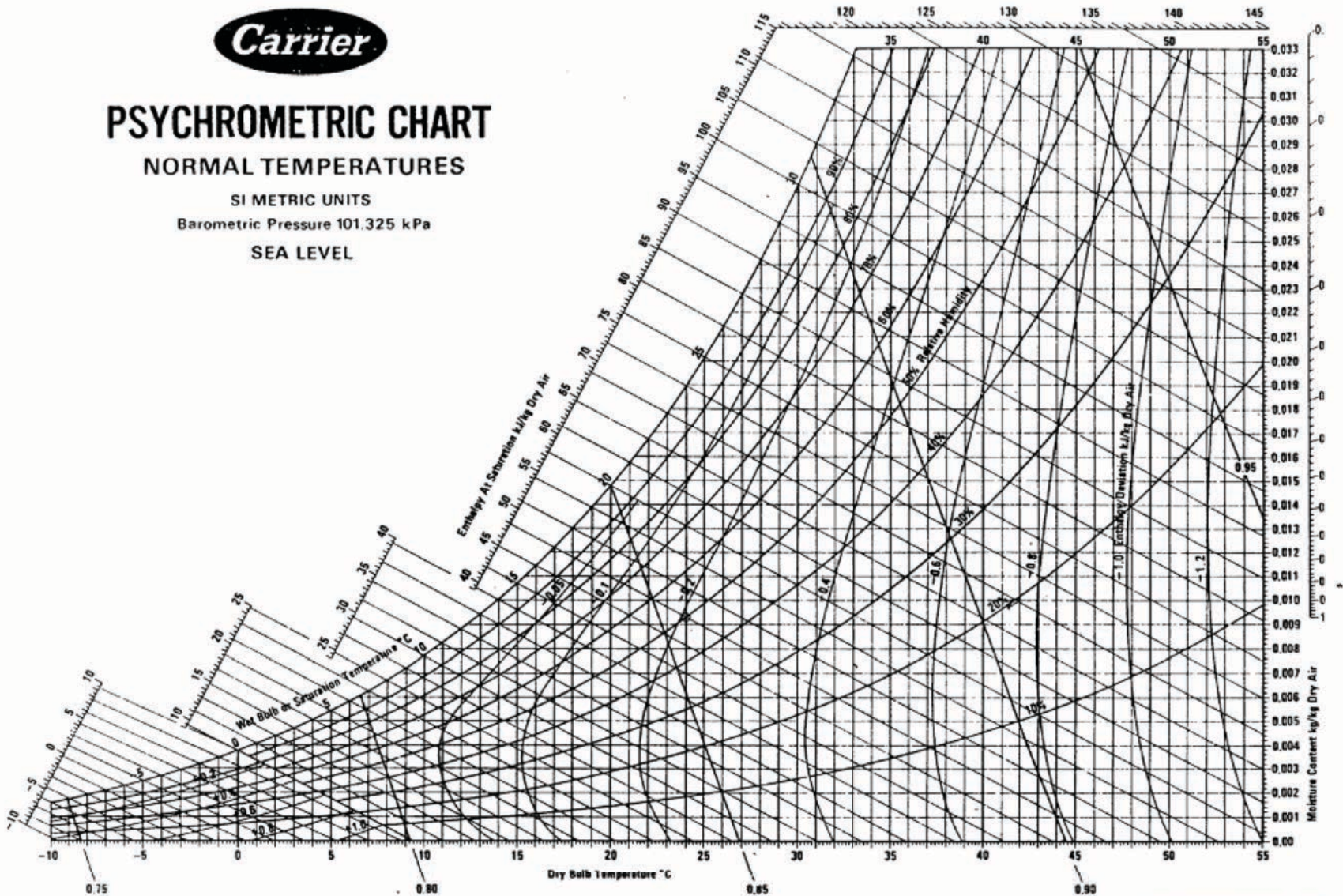
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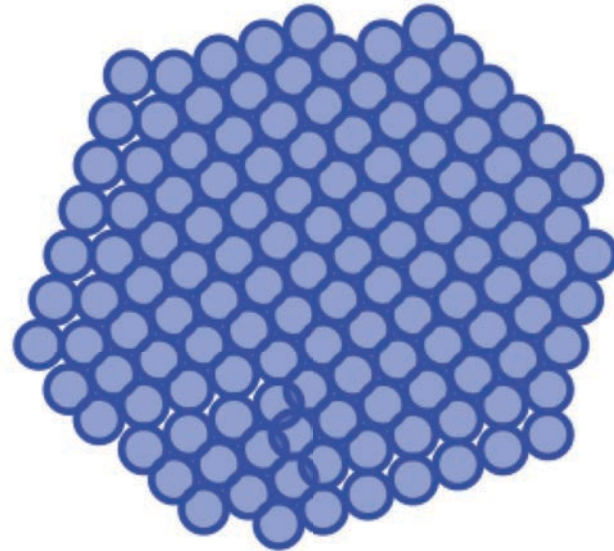


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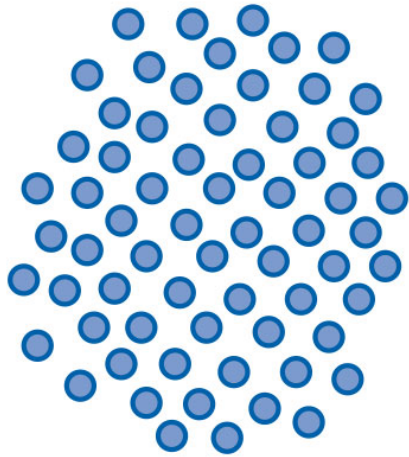
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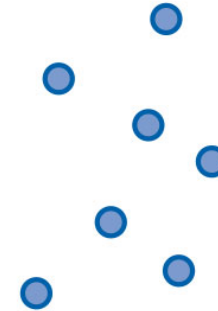
Vapor



Liquid



DIFFUSION

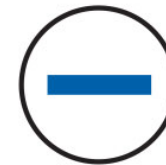


**Higher Dewpoint Temperature
Higher Water Vapor Density
or Concentration
(Higher Vapor Pressure)
on Warm Side of Assembly**

**Low Dewpoint Temperature
Lower Water Vapor Density
or Concentration
(Lower Vapor Pressure)
on Cold Side of Assembly**

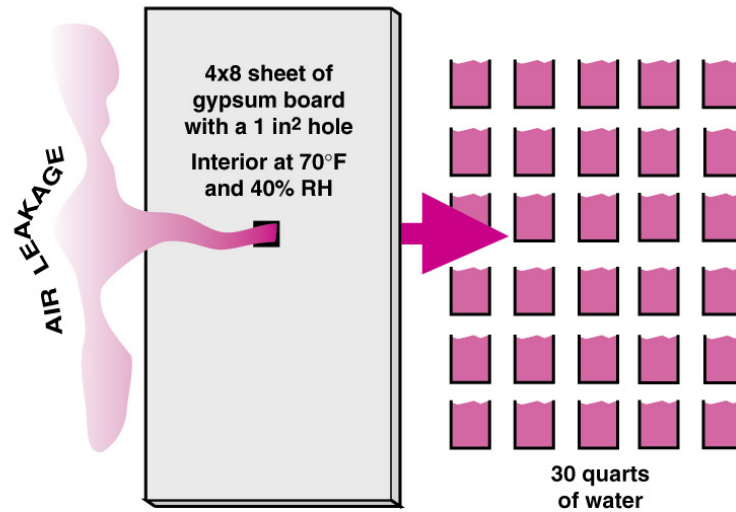
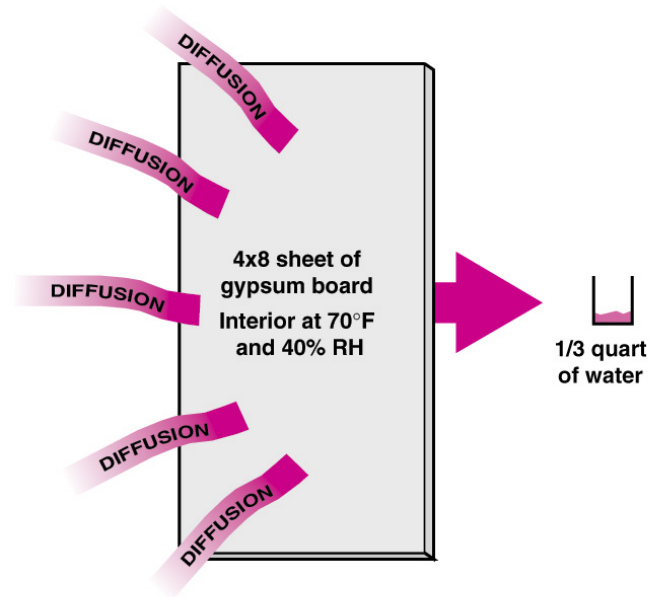


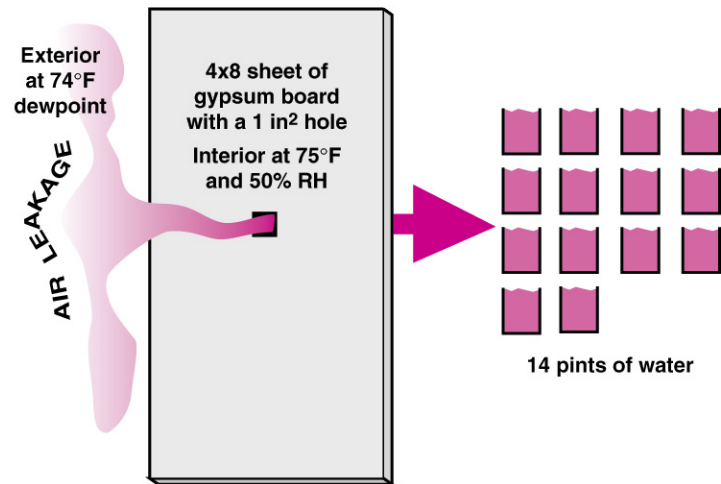
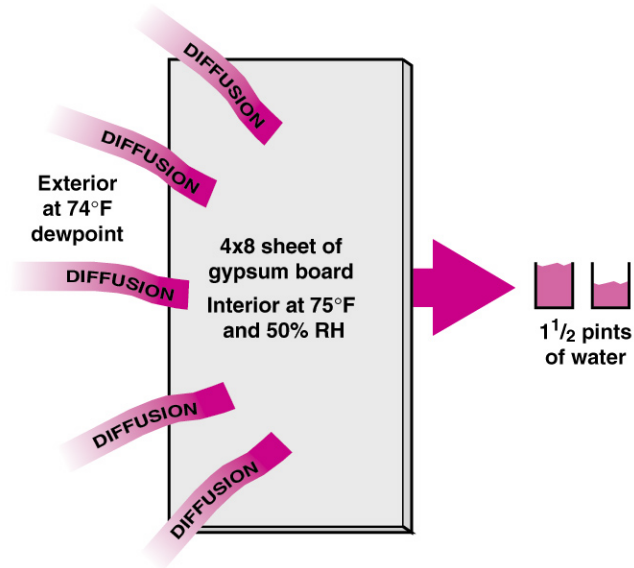
AIR TRANSPORT

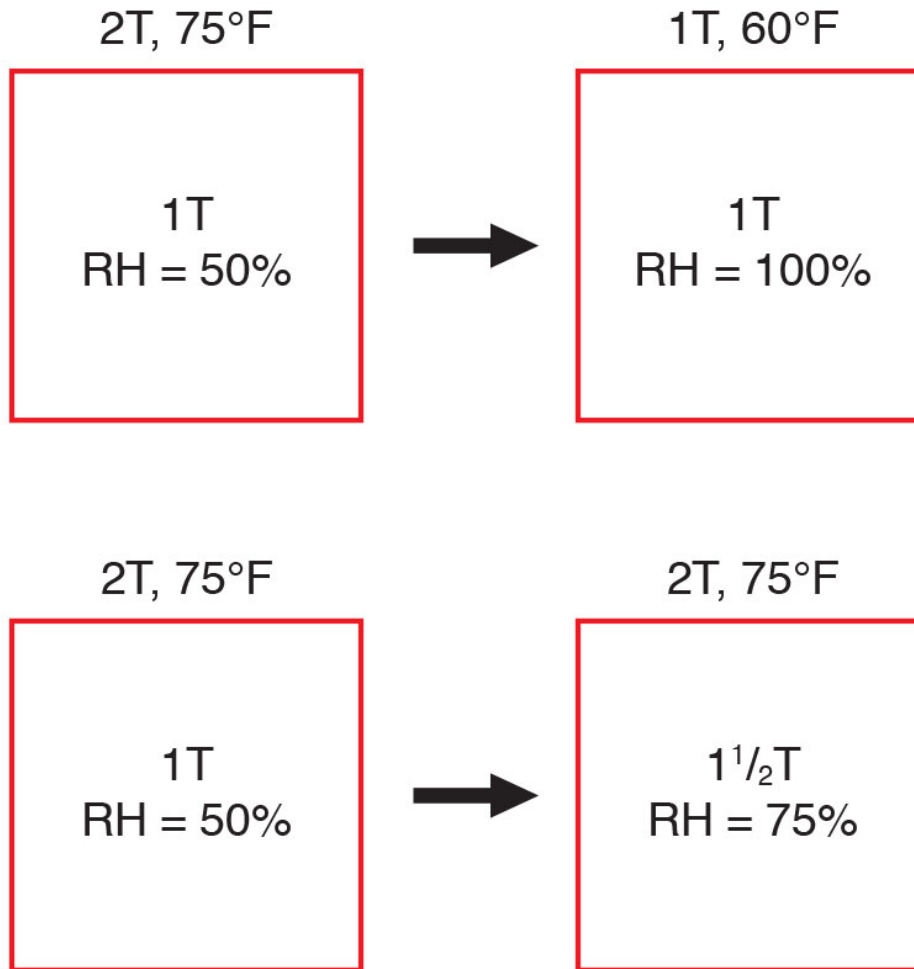


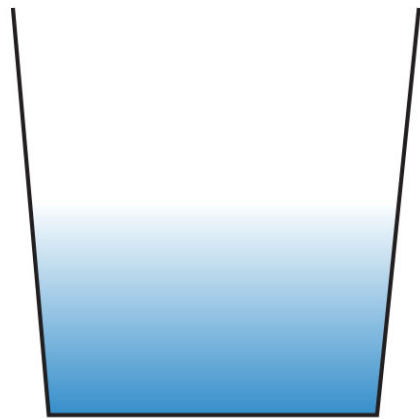
**Higher Air
Pressure**

**Lower Air
Pressure**

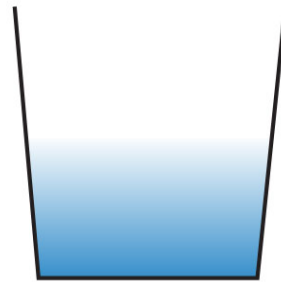




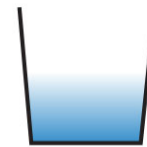




90°F
50% RH



75°F
50% RH



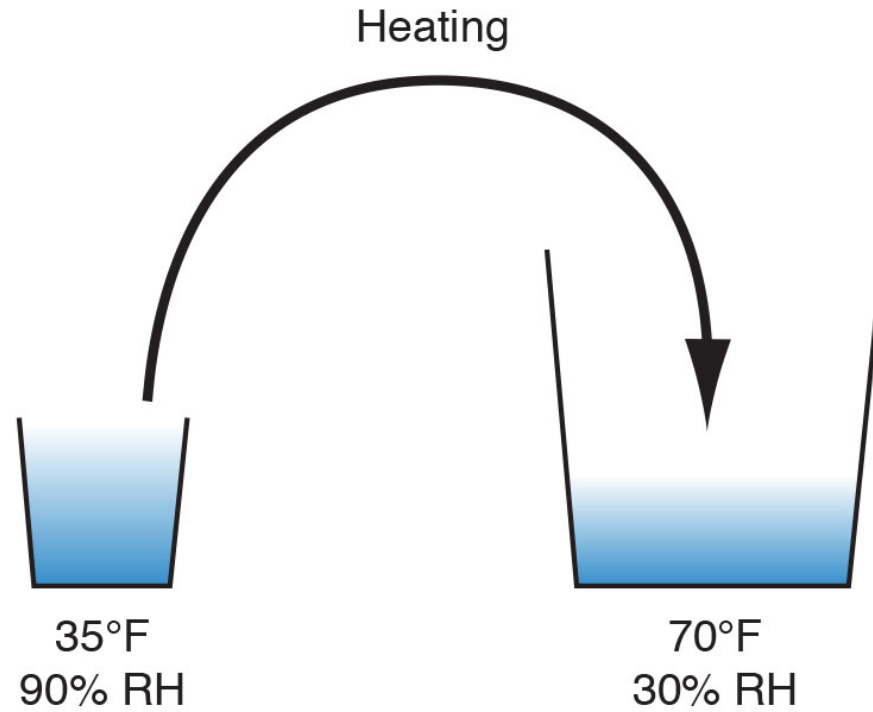
60°F
50% RH

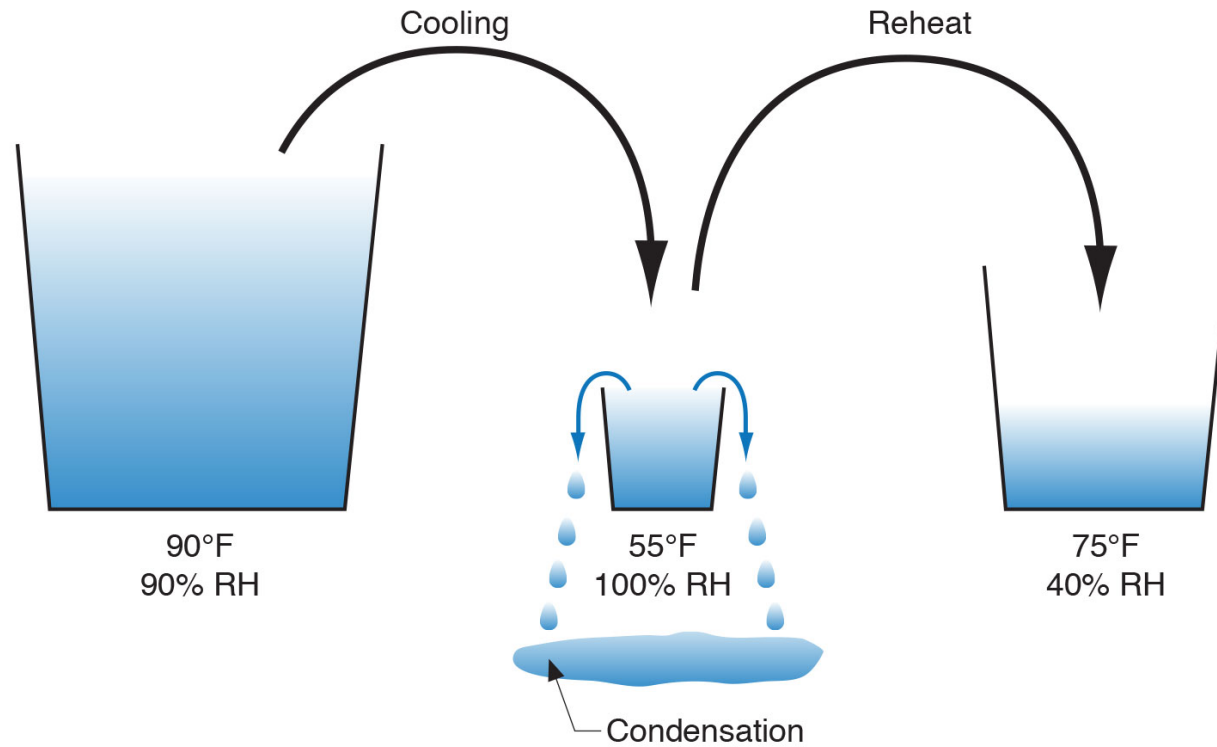


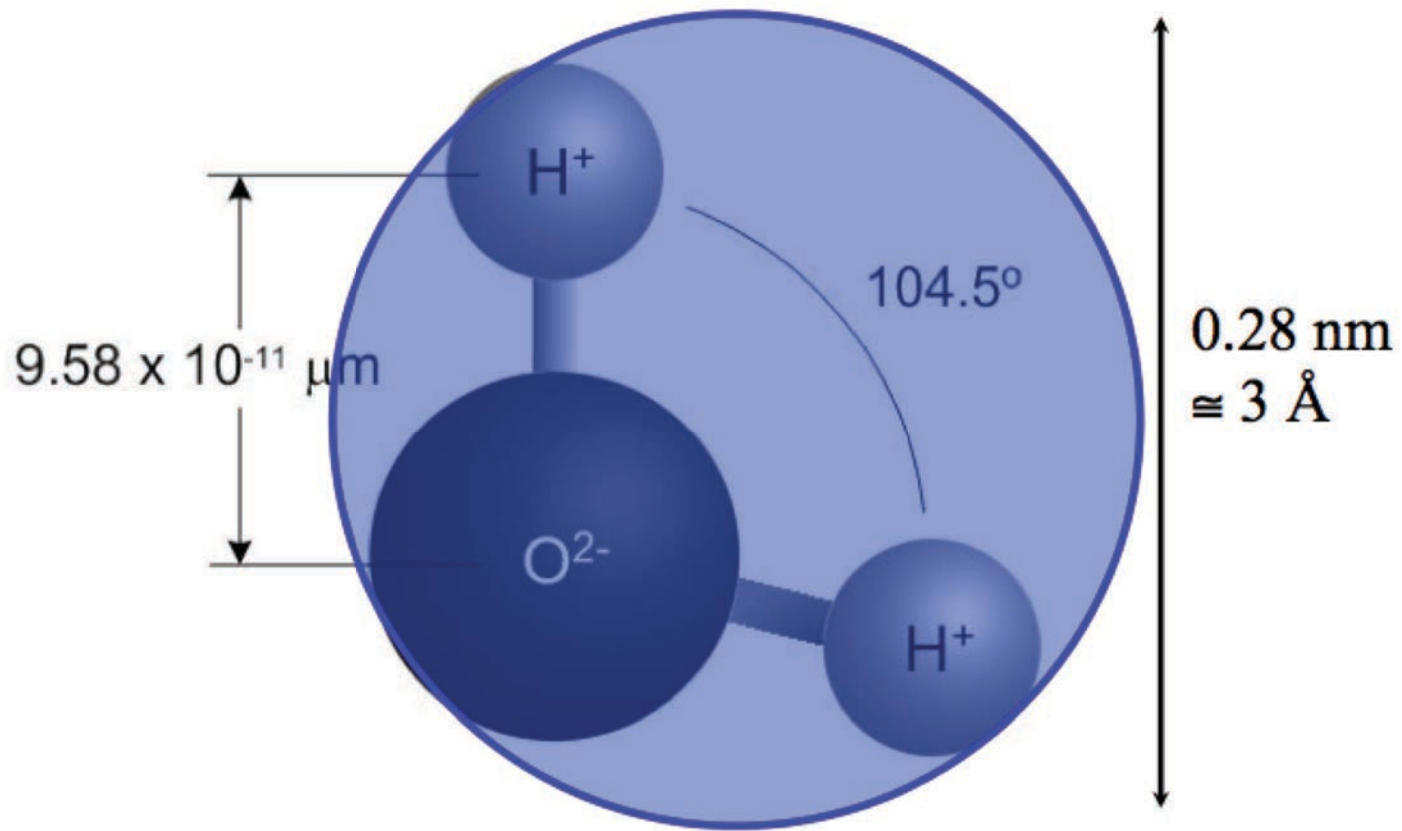
45°F
50% RH

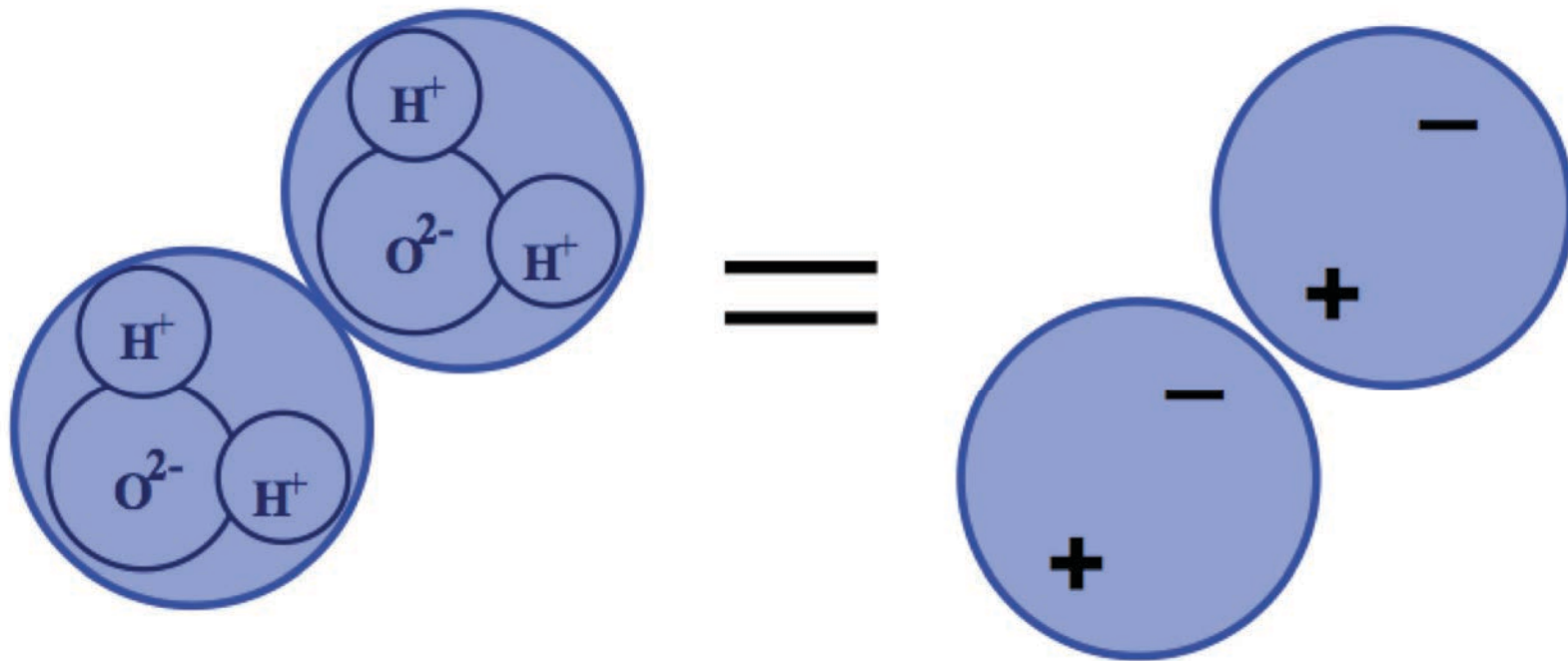


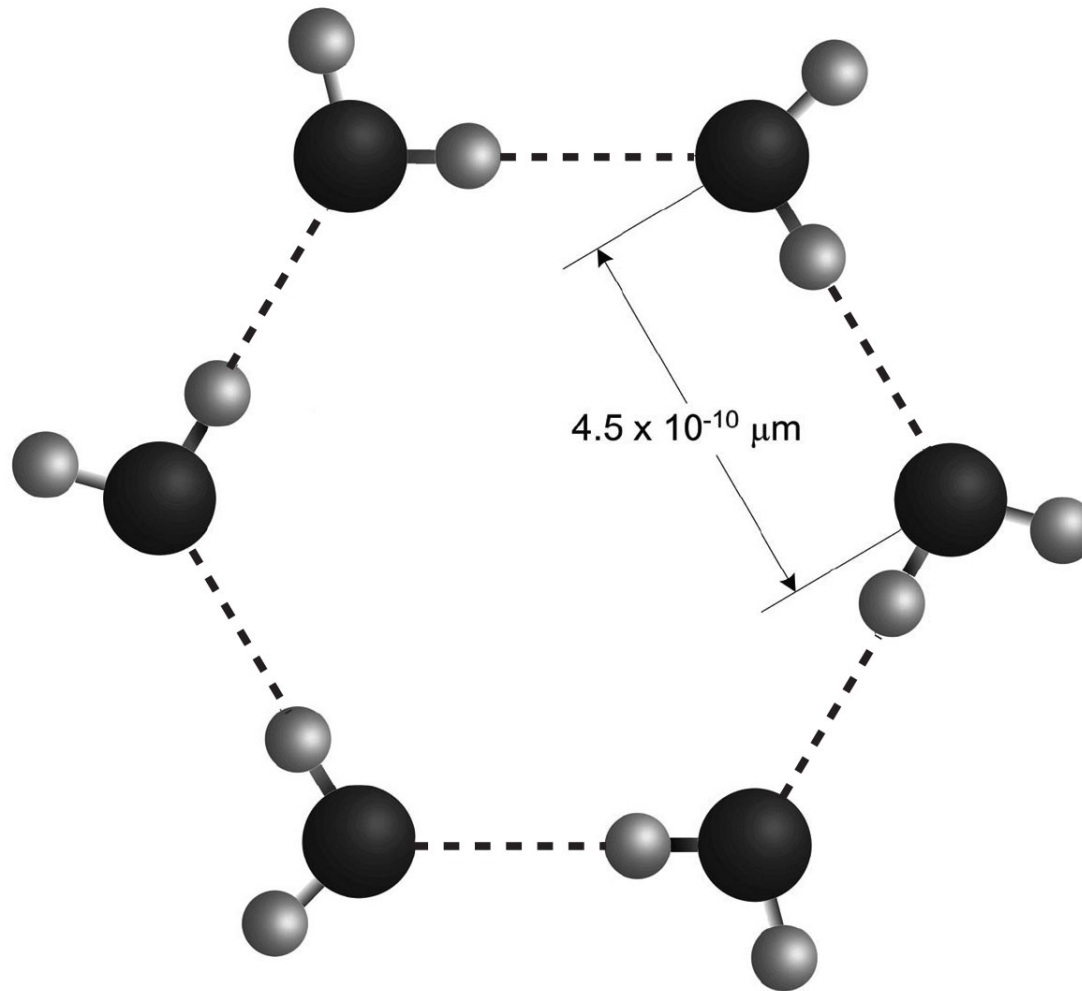
30°F
50% RH











Damage Functions

Damage Functions

Water

Heat

Ultra Violet Radiation

Damage Functions

Water

Heat

Ultra Violet Radiation

Oxidization (Ozone)

Fatigue (Creep)

The Three Biggest Problems In Buildings Are Water, Water and Water...

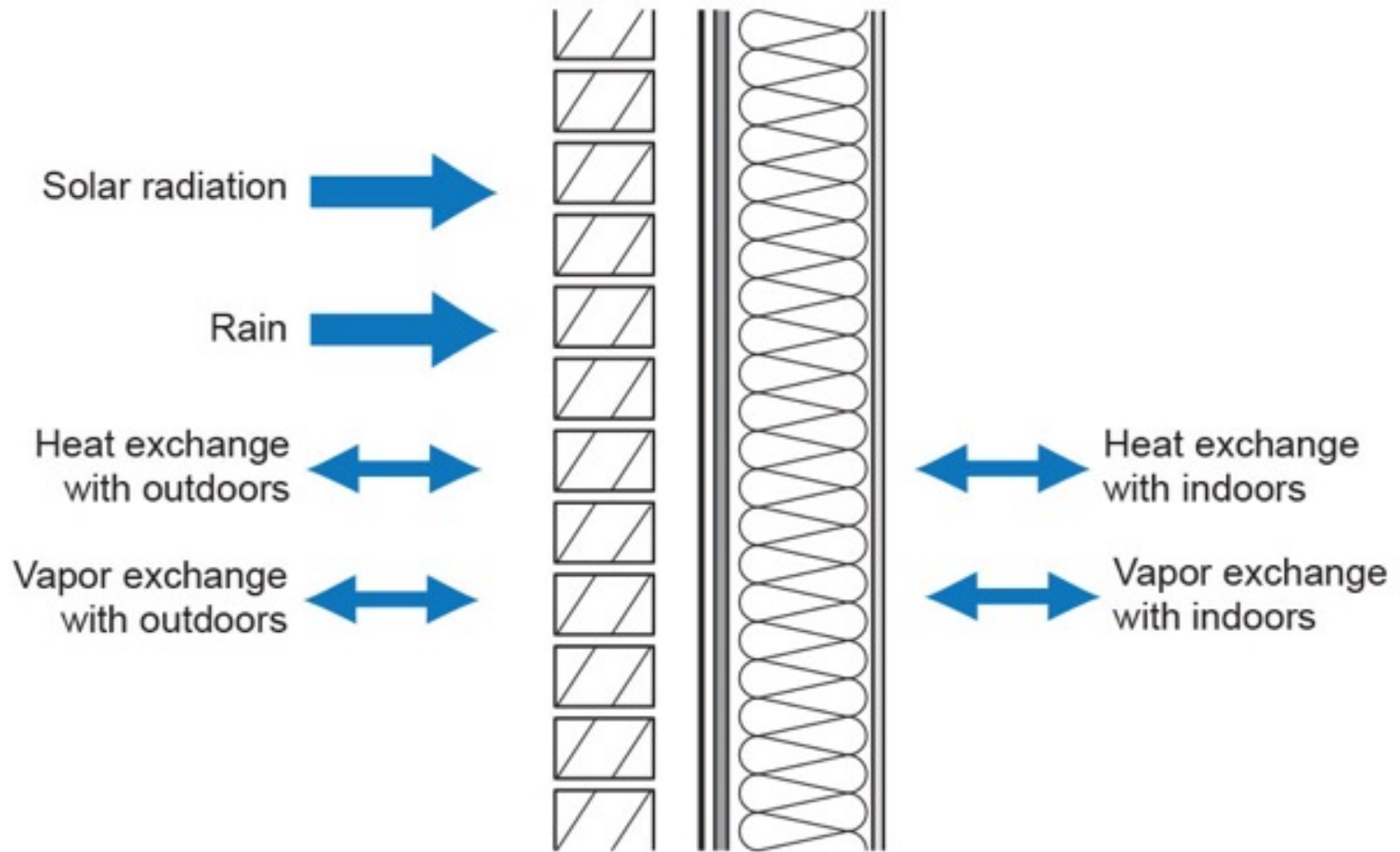
Heat

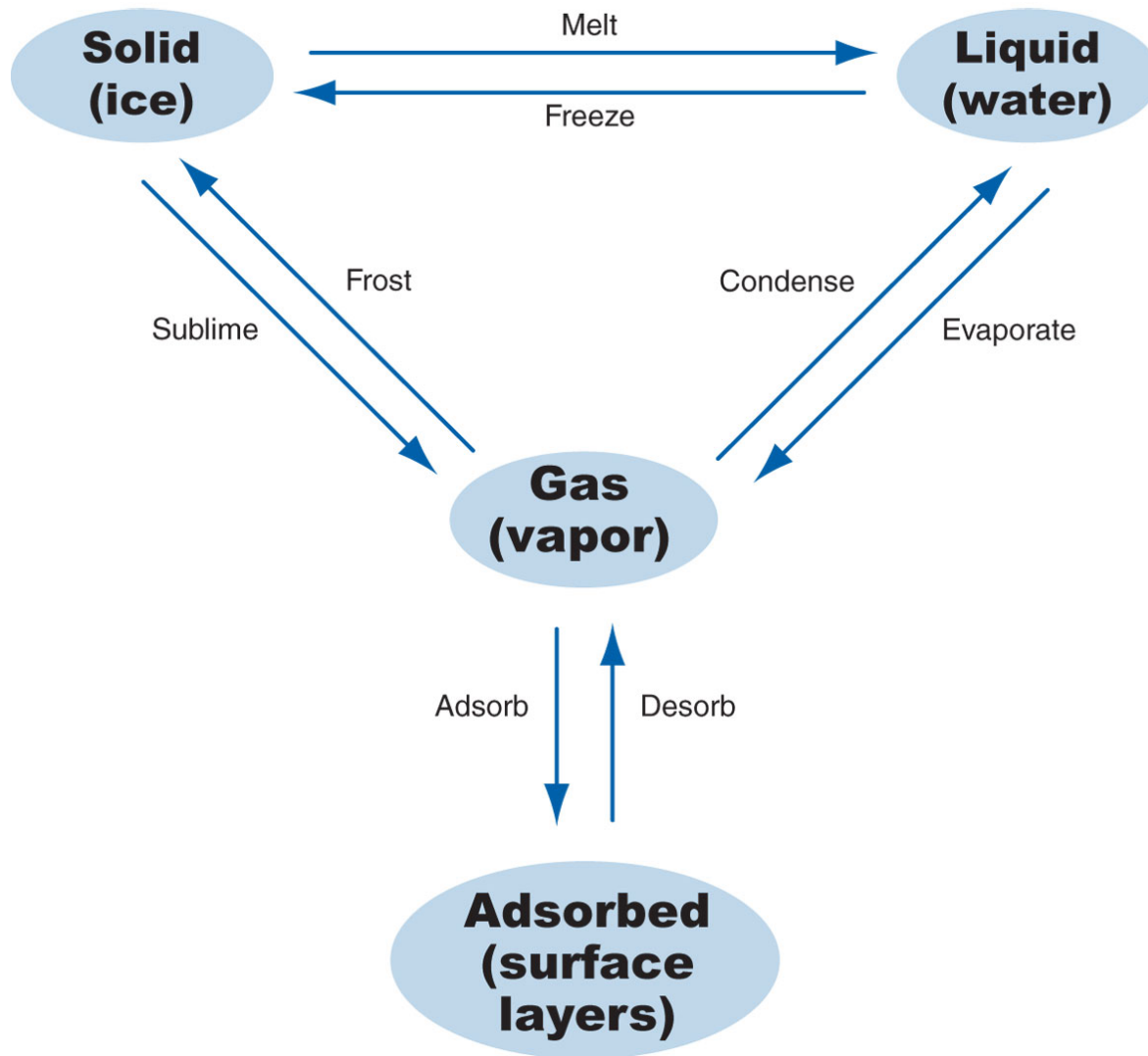
Air

Moisture

HAM

Hygrothermal Analysis





Moisture Transport in Porous Media

| Phase | Transport Process | Driving Potential |
|-----------|-------------------|----------------------|
| Vapor | Diffusion | Vapor Concentration |
| Adsorbate | Surface Diffusion | Concentration |
| Liquid | Capillary Flow | Suction Pressure |
| | Osmosis | Solute Concentration |

Moisture Transport in Assemblies

| Phase | Transport Process | Driving Potential |
|------------------|--------------------|----------------------|
| Vapor | Diffusion | Vapor Concentration |
| | Convective Flow | Air Pressure |
| ----- | | |
| Adsorbate | Surface Diffusion | Concentration |
| ----- | | |
| Liquid | Capillary Flow | Suction Pressure |
| | Osmosis | Solute Concentration |
| | Gravitational Flow | Height |
| | Surface Tension | Surface Energy |
| | Momentum | Kinetic Energy |
| | Convective Flow | Air Pressure |

Water Control Layer

Air Control Layer

Vapor Control Layer

Thermal Control Layer