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Building Science

Adventures In Building Science

www.buildingscience.com

"It isn't what we don't know that gives us trouble, it's what we know that ain't so"

Will Rogers

"There are known knowns. These are things we know. There are known unknowns. There are things that we know we don't know. But there are also unknown unknowns. There are things we don't know we don't know.

Donald Rumsfeld

Order of Magnitude

Order of Magnitude

1 to 10

10 to 100

100 to 1000

1000 to 10000

First Order Effects, Second Order Effects….

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

Zeroth Law – Equal Systems
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
Air Flow Is From A Higher Pressure to a Lower Pressure
Gravity Acts Down

Moisture Flow Is From Warm To Cold
Moisture Flow Is From More To Less

Moisture Flow Is From Warm To Cold
Moisture Flow Is From More To Less

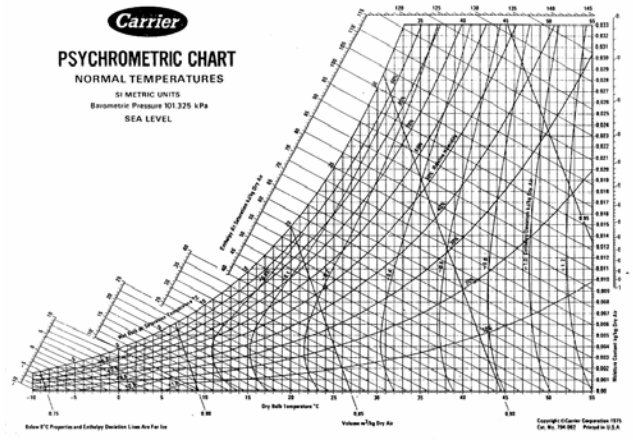
Thermal Gradient – Thermal Diffusion
Concentration Gradient – Molecular Diffusion

Moisture Flow Is From Warm To Cold
Moisture Flow Is From More To Less

Thermal Gradient – Thermal Diffusion
Concentration Gradient – Molecular Diffusion

Vapor Diffusion

Thermodynamic Potential



Damage Functions

Damage Functions
Water
Heat
Ultra Violet Radiation

Damage Functions
Water
Heat
Ultra Violet Radiation
Oxidization (Ozone)
Fatigue (Creep)

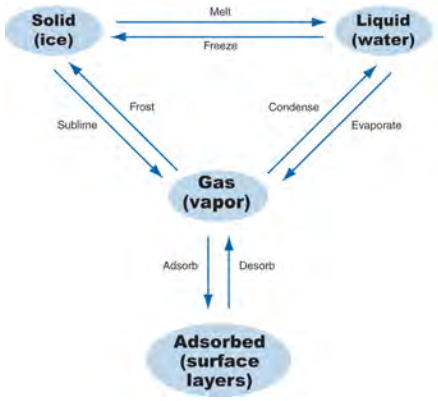
The Three Biggest Problems In Buildings Are
Water, Water and Water…

80 Percent of all Construction Problems are Related to Water

Heat
Air
Moisture

HAM

Hygrothermal Analysis

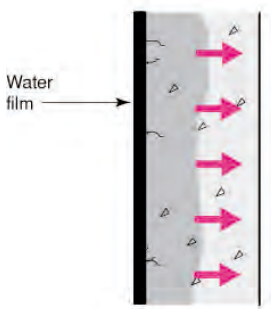


Moisture Transport in Porous Media

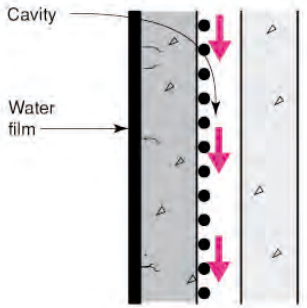
Phase	Transport Process	Driving Potential
Vapor	Diffusion	Vapor Concentration
Adsorbate	Surface Diffusion	Concentration
Liquid	Capillary Flow	Suction Pressure
	Osmosis	Solute Concentration

Moisture Transport in Assemblies

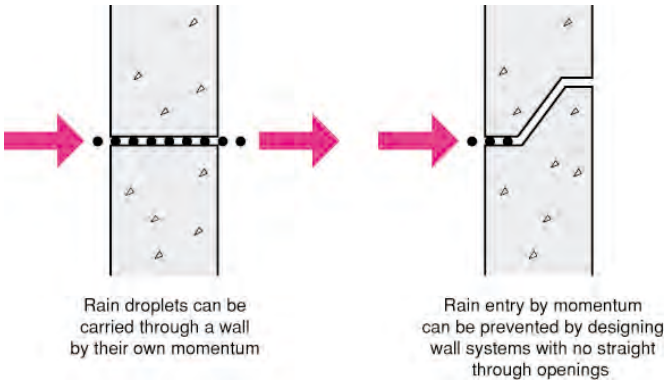
Phase	Transport Process	Driving Potential
Vapor	Diffusion	Vapor Concentration
	Convective Flow	Air Pressure
Adsorbate	Surface Diffusion	Concentration
Liquid	Capillary Flow	Suction Pressure
	Osmosis	Solute Concentration
	Gravitational Flow	Height
	Surface Tension	Surface Energy
	Momentum	Kinetic Energy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



Capillary suction draws water into porous material and tiny cracks



Cavity acts as capillary break and receptor for capillary water interrupting flow



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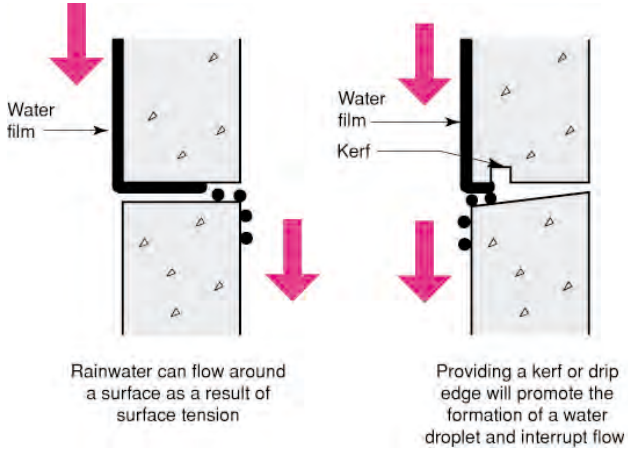

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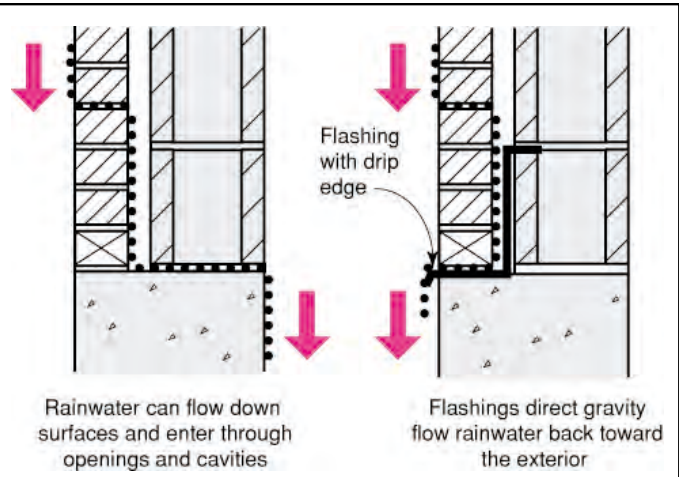

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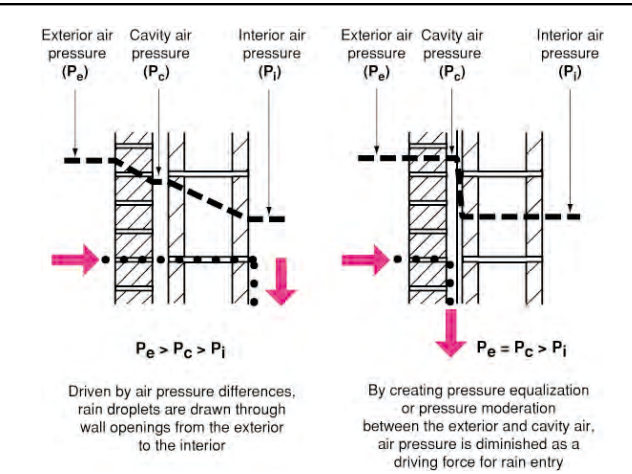

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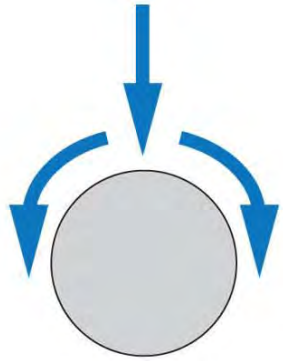

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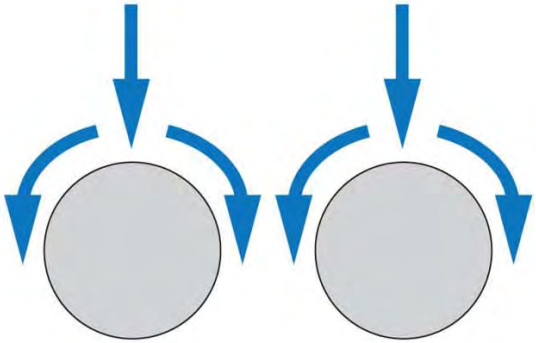

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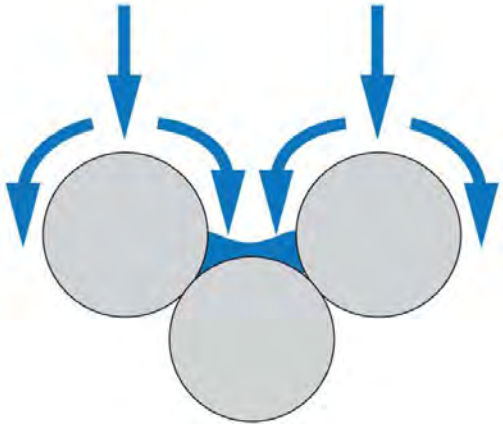

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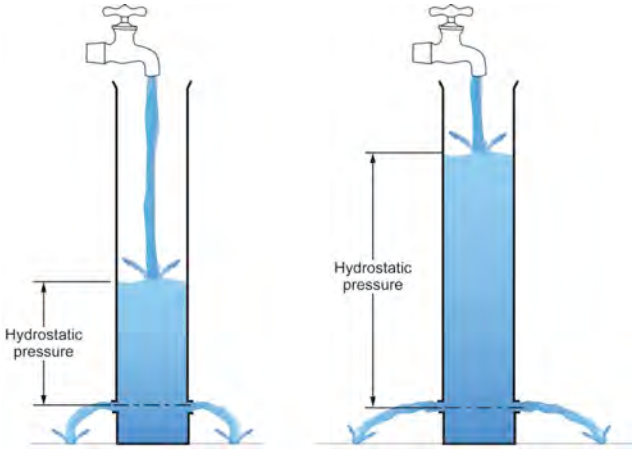

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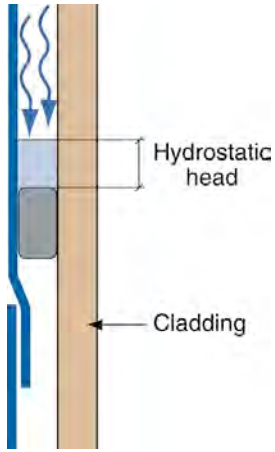

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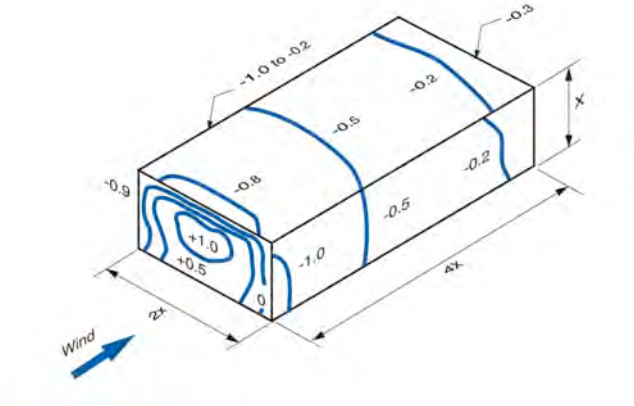

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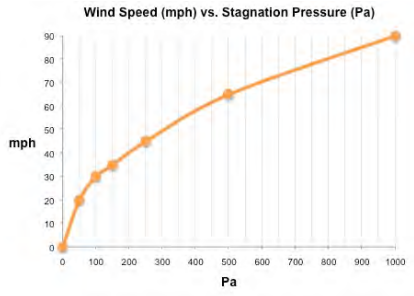
Pascals		mph
50	Pa =	20 mph
100	Pa =	30 mph
150	Pa =	35 mph
250	Pa =	45 mph
500	Pa =	65 mph
1,000	Pa =	90 mph



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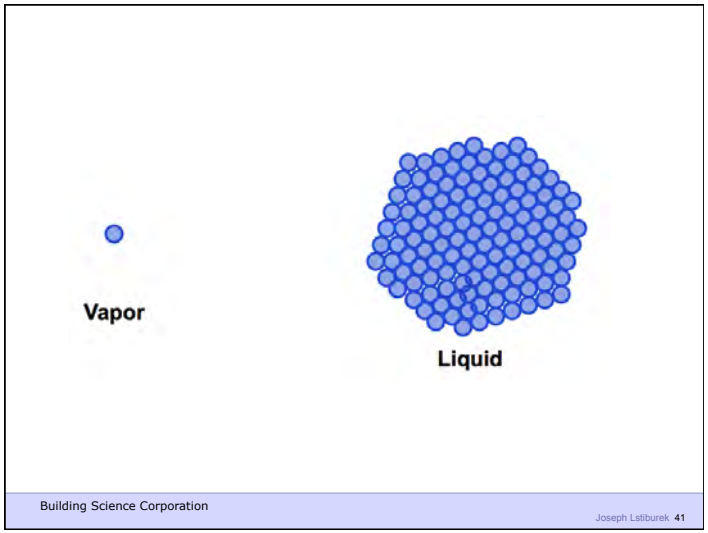
Vapor
Liquid
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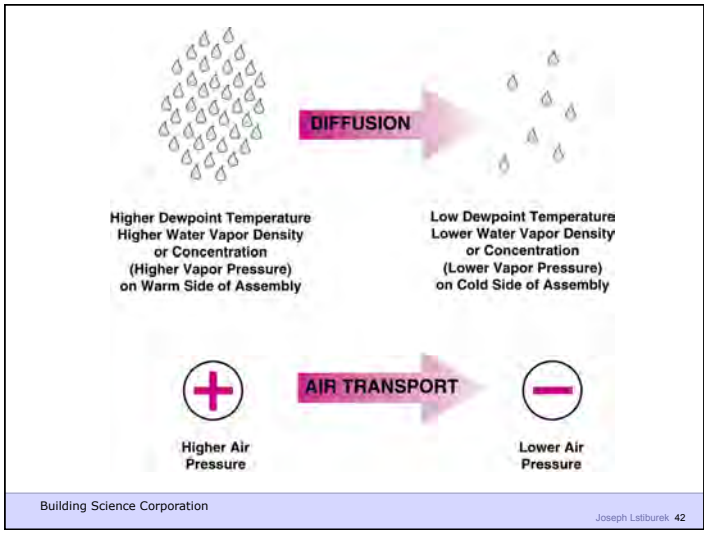
DIFFUSION
Higher Dewpoint Temperature
Higher Water Vapor Density
or Concentration
(Higher Vapor Pressure)
on Warm Side of Assembly
Low Dewpoint Temperature
Lower Water Vapor Density
or Concentration
(Lower Vapor Pressure)
on Cold Side of Assembly
AIR TRANSPORT
Higher Air
Pressure
Lower Air
Pressure
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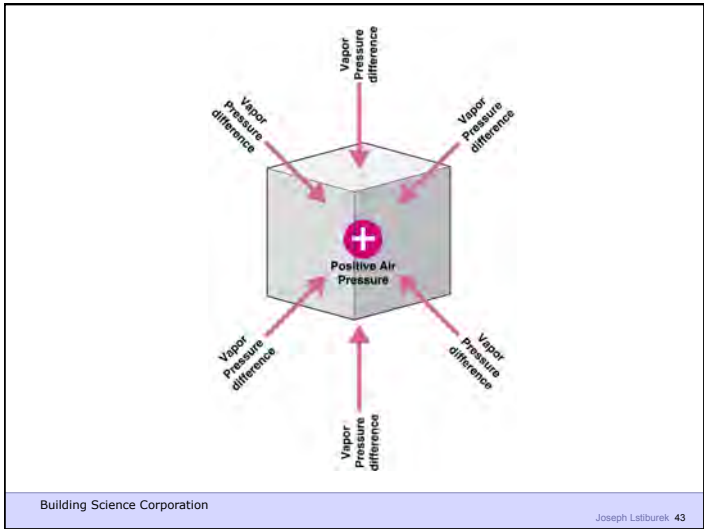
Vapor Pressure difference
Positive Air Pressure
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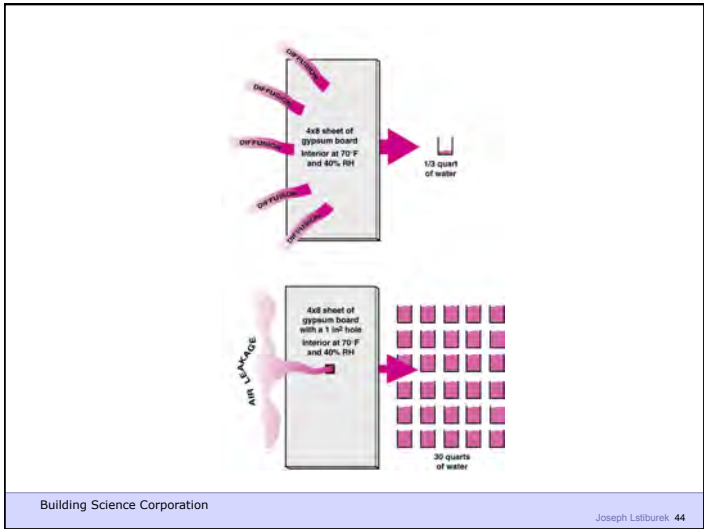
DIFFUSION
4x8 sheet of gypsum board Interior at 70°F and 40% RH
1/3 quart of water
AIR LEAKAGE
4x8 sheet of gypsum board with a 1 in² hole Interior at 70°F and 40% RH
30 quarts of water
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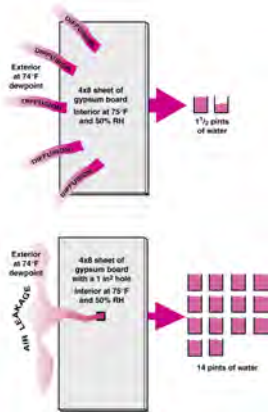

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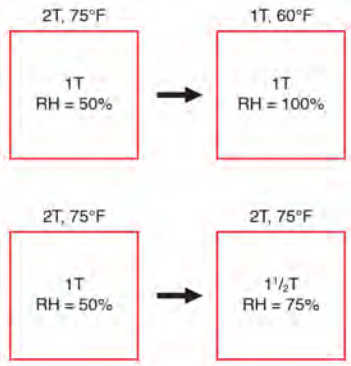

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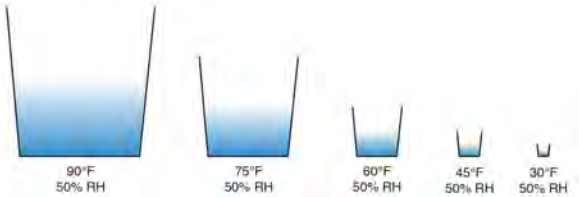

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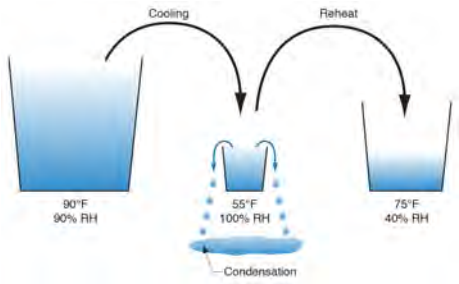

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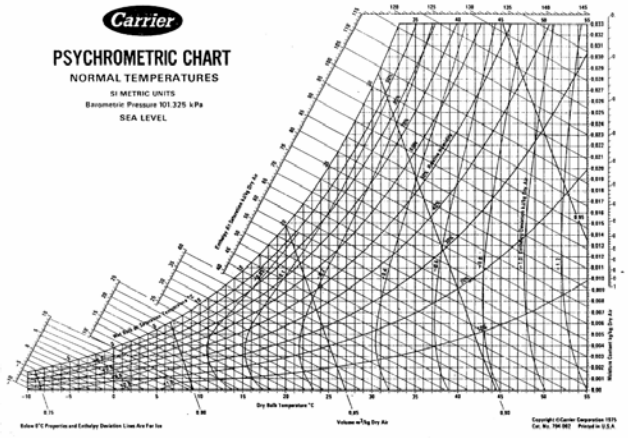

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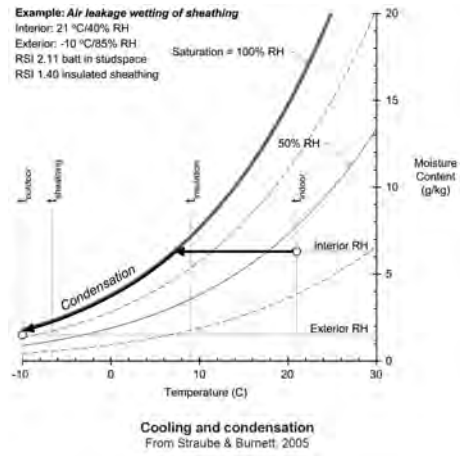

Cooling and condensation
From Straube & Burnett, 2005

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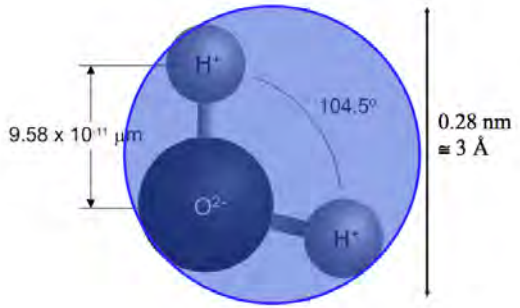

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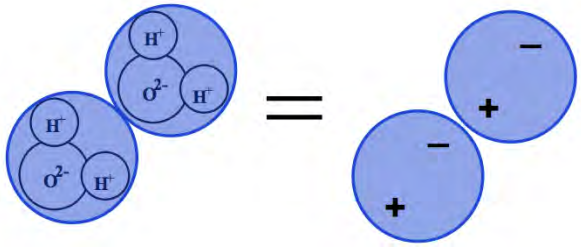

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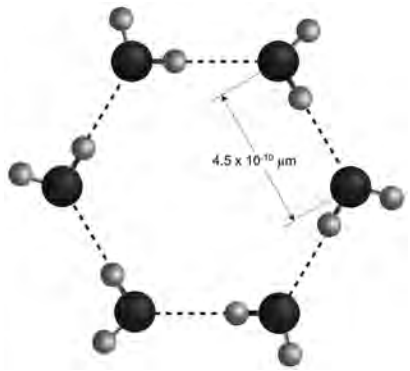

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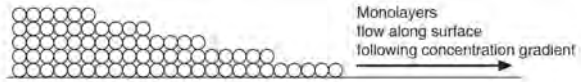

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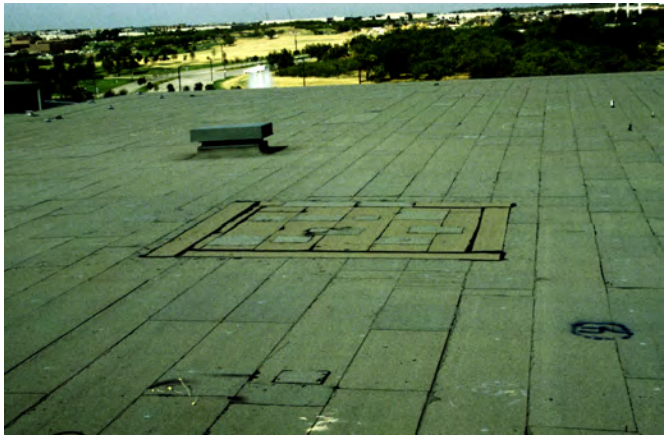

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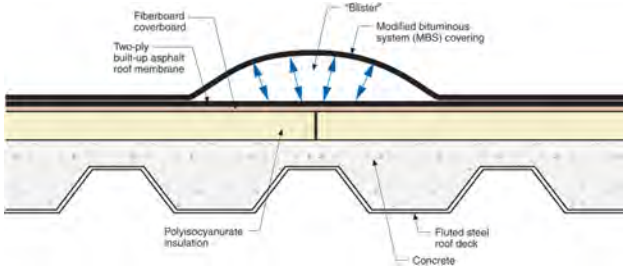

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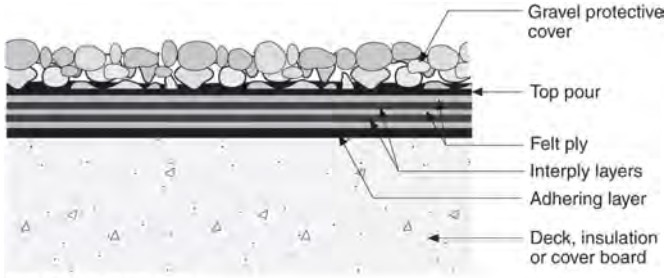

From Baker, M.; Roofs, 1980

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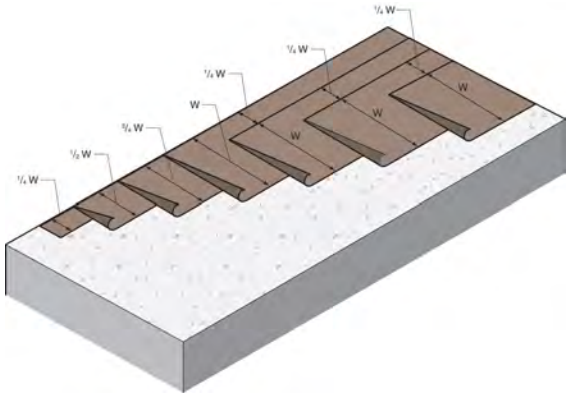

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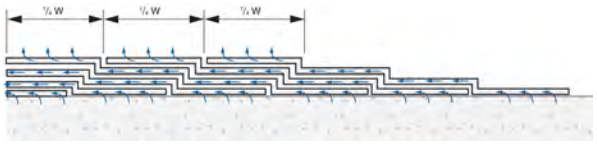

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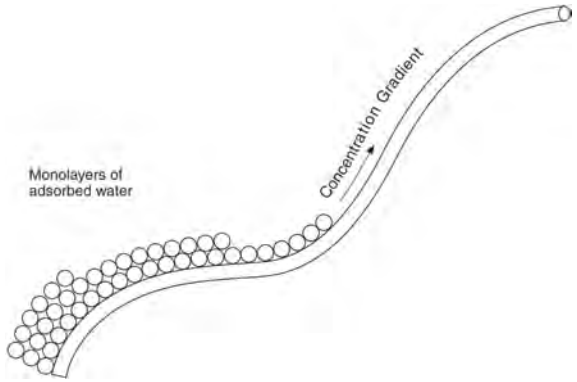

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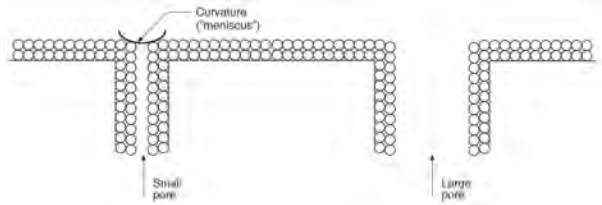

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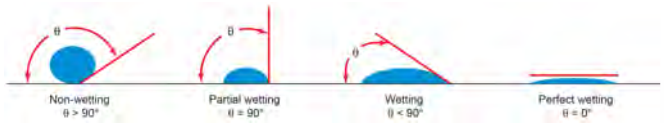
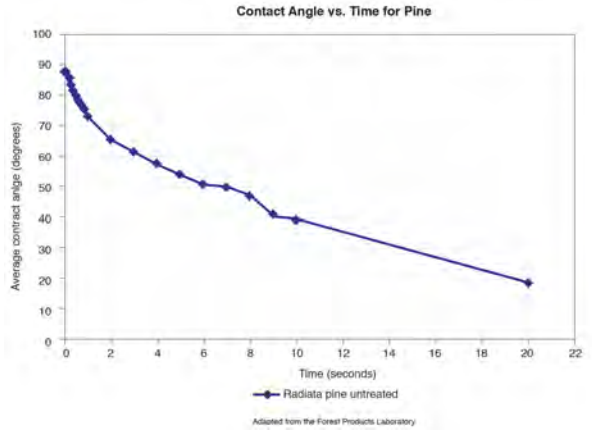
- "non-wetable" surface
- water repellant surface
- hygrophobic surface
- water more attracted to itself than to surface
- surface energy of water greater than surface energy of surface
- water "beads up"
- "greasy" surface
- high contact angle "θ"

- "wetable" surface
- non-water repellant surface
- hygroscobic surface
- water more attracted to surface than itself
- surface energy of surface greater than surface energy of water
- water "spreads out"
- "non-greasy" surface
- low contact angle "θ"





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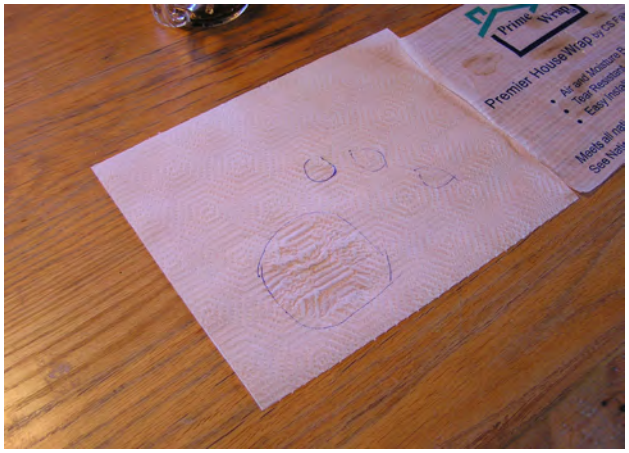

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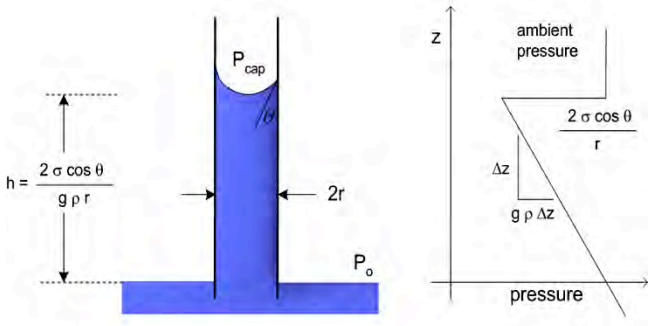
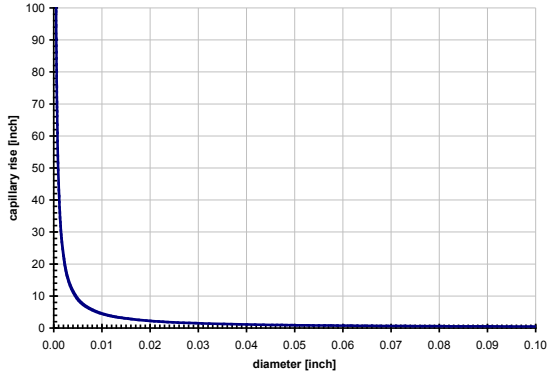
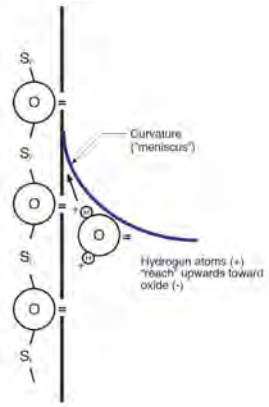
	Surface Energy
Water (20 C)	73 dynes/cm
Water (100 C)	59 dynes/cm
Epoxy	46 dynes/cm
Polyethylene	31 dynes/cm
Soapy water	30 dynes/cm
Paraffin wax	25 dynes/cm
Silicone	24 dynes/cm
Teflon	18 dynes/cm

Calculating capillary rise



Capillary rise versus diameter





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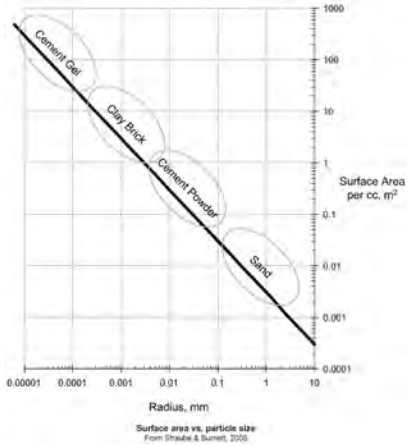

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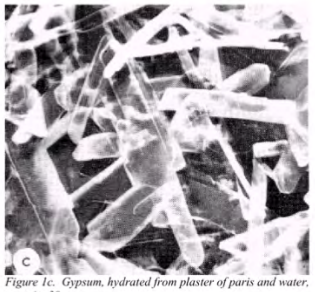

Figure 1c. Gypsum, hydrated from plaster of paris and water, porosity 30 per cent.

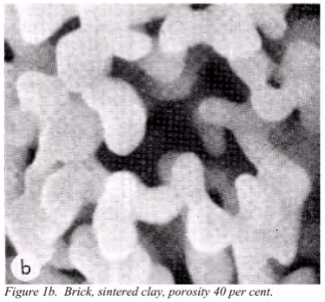

Figure 1b. Brick, sintered clay, porosity 40 per cent.

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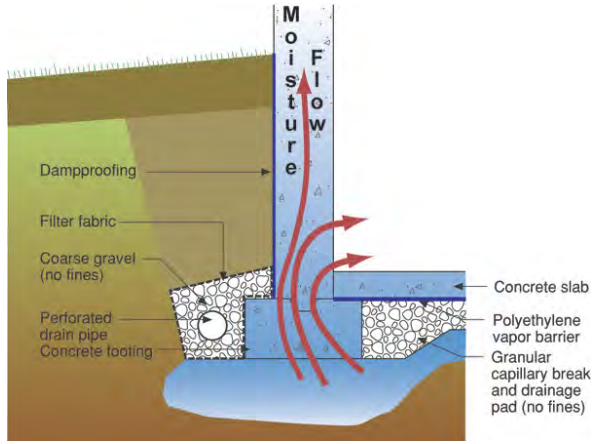

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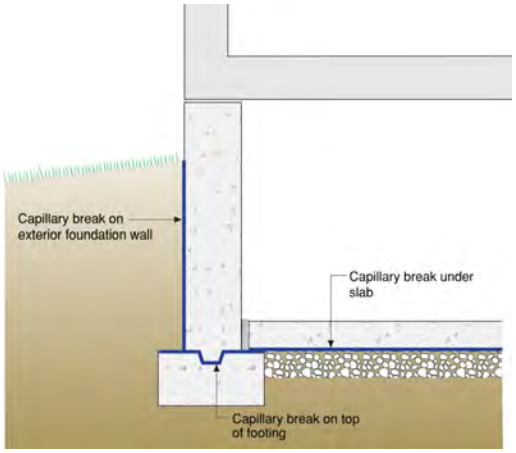
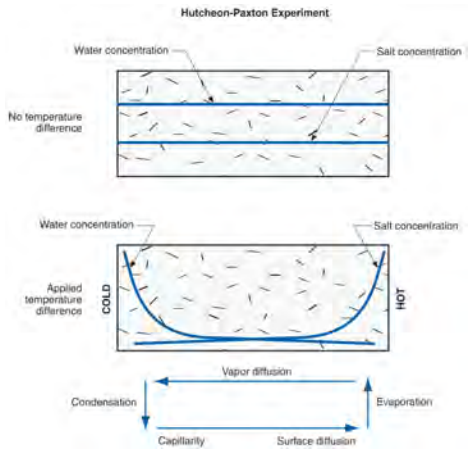
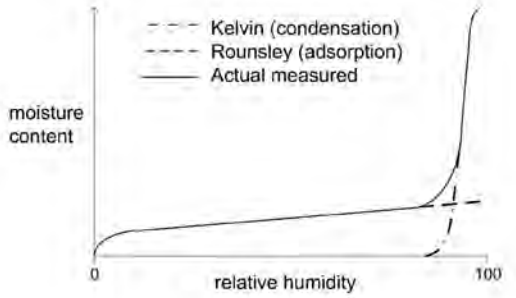
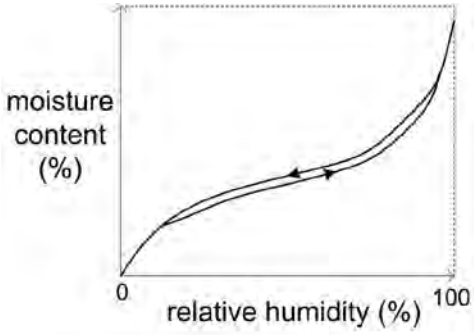


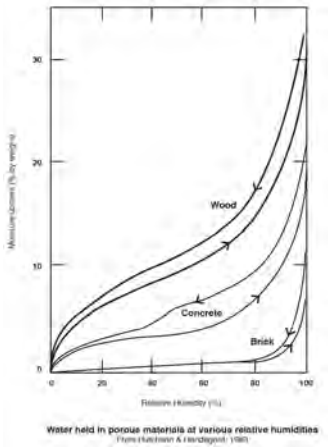




Typical predicted sorption isotherm according to Kelvin equation and modified BET theory
From Straube & Burnett, 2005



Typical sorption isotherm of a hygroscopic material
From Straube & Burnett, 2005



Water held in porous materials at various relative humidities

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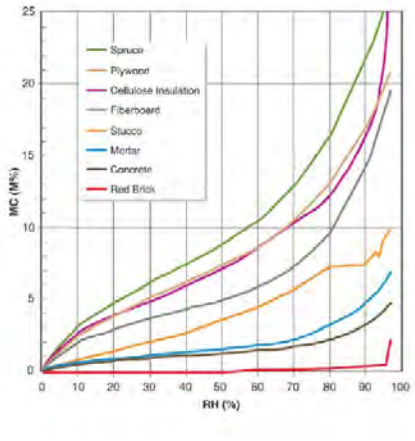

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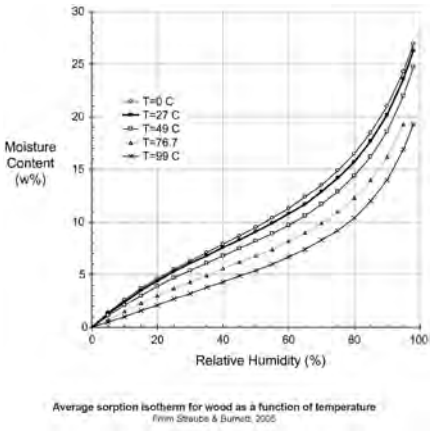

Average sorption isotherm for wood as a function of temperature

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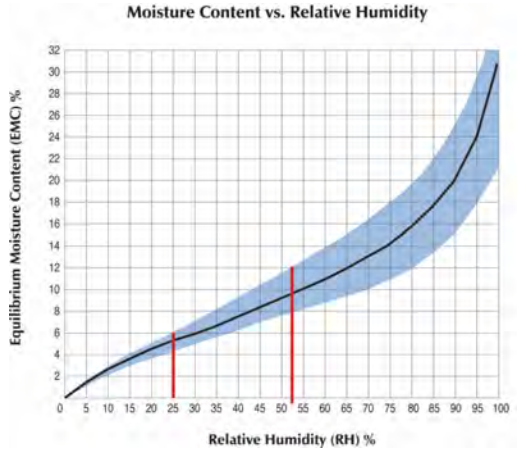

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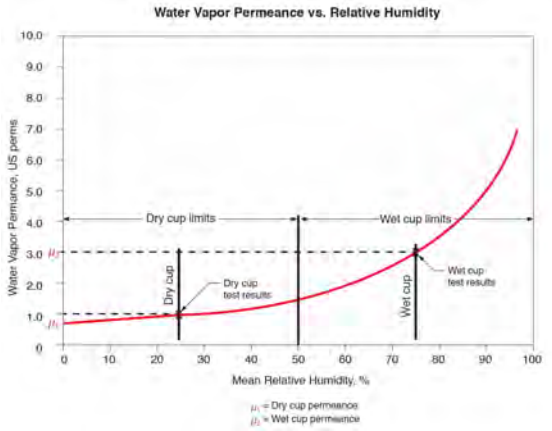

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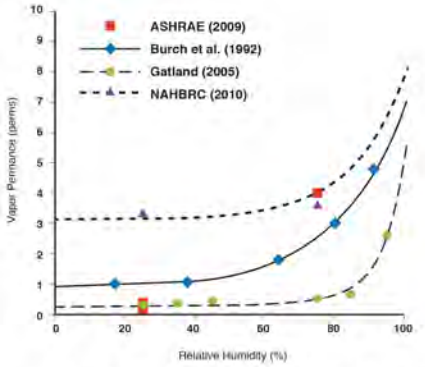

Kraft facing permeance as a function of humidity (Glass 2013)

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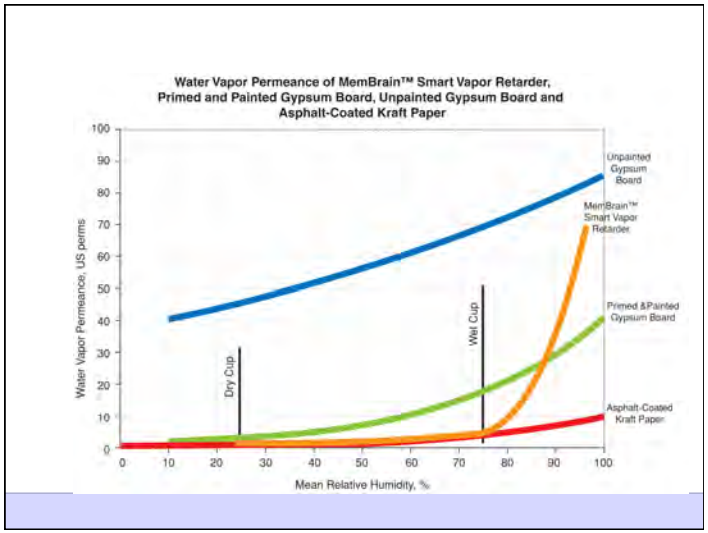
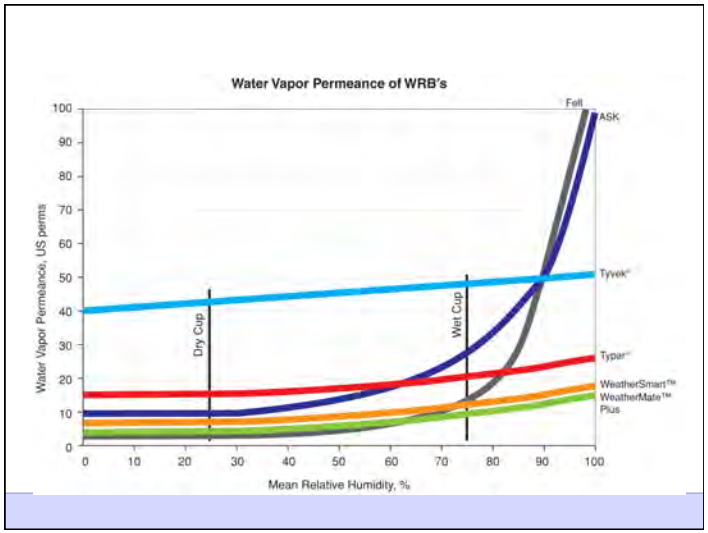
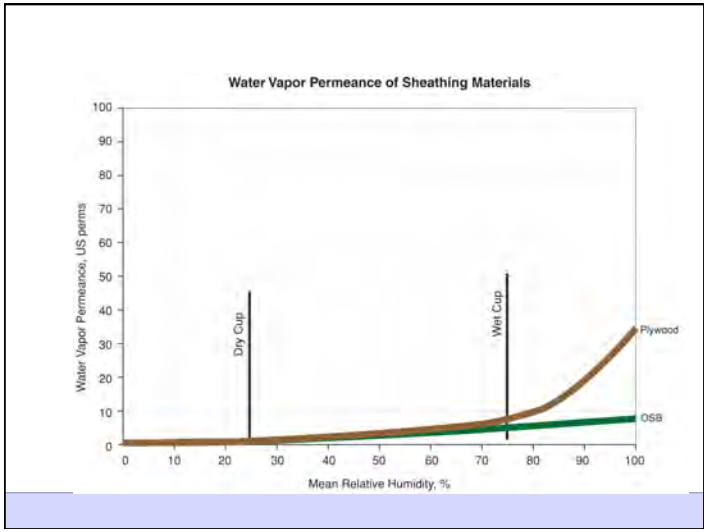
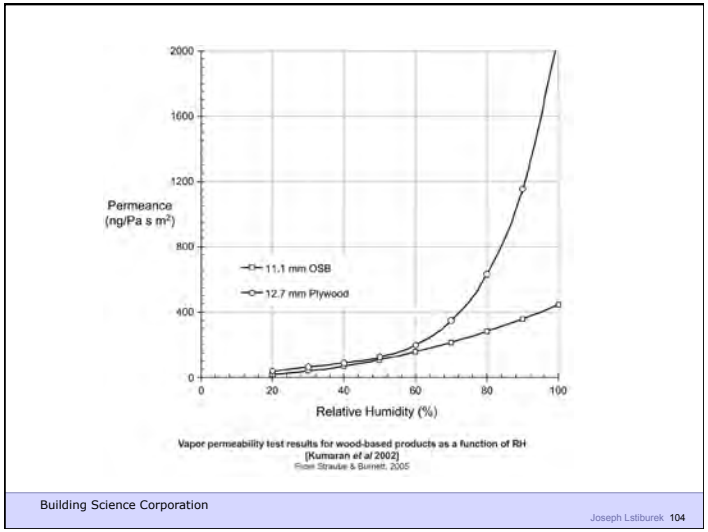

Water Vapor Permeance of MemBrain™ Smart Vapor Retarder, Primed and Painted Gypsum Board, Unpainted Gypsum Board and Asphalt-Coated Kraft Paper
Water Vapor Permeance, US perms
Mean Relative Humidity, %
Dry Cup
Wet Cup
Unpainted Gypsum Board
MemBrain™ Smart Vapor Retarder
Primed &Painted Gypsum Board
Asphalt-Coated Kraft Paper


Water Vapor Permeance of WRB's
Water Vapor Permeance, US perms
Mean Relative Humidity, %
Dry Cup
Wet Cup
Fell
ASK
Tyvek®
Typar®
WeatherSmart™
WeatherMate™ Plus


Water Vapor Permeance of Sheathing Materials
Water Vapor Permeance, US perms
Mean Relative Humidity, %
Dry Cup
Wet Cup
Plywood
OSB


Permeance (ng/Pa s m²)
Relative Humidity (%)
11.1 mm OSB
12.7 mm Plywood
Vapor permeability test results for wood-based products as a function of RH
[Kumaran et al 2002]
From Straube & Burnett, 2005
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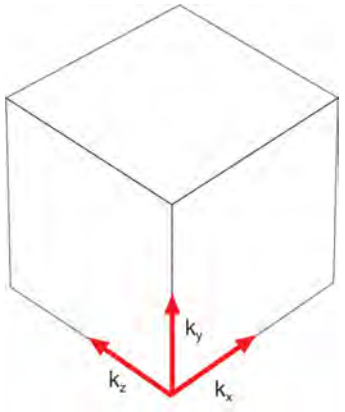

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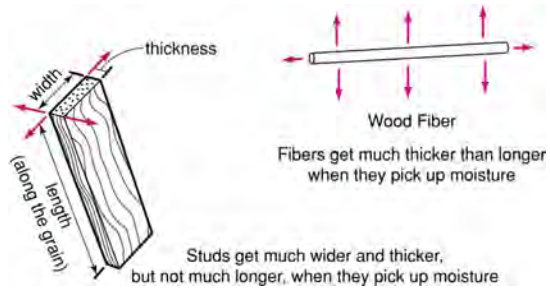

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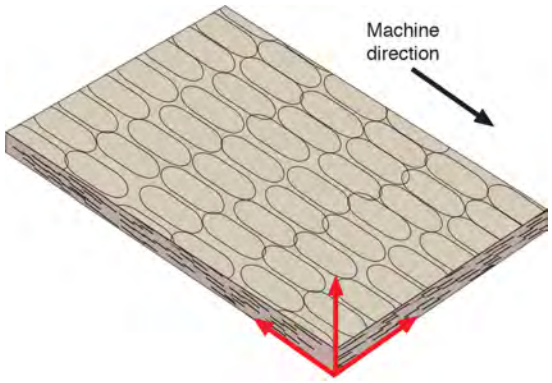

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$$J_B = -k \cdot grad\ \Phi_B$$

$$J_{Bx} = -k_x \cdot (\frac{d}{dx})\ \Phi_{Bx}$$

$$k_x = k_y = k_z$$

$$J_V = -\mu \cdot grad\ p$$

$$J_{Vx} = -\mu_x \frac{dp}{dx}$$

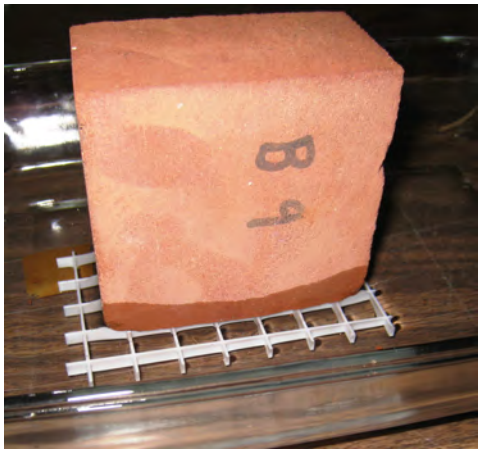
$$W = \mu A \Theta \frac{(P_1 - P_2)}{l}$$

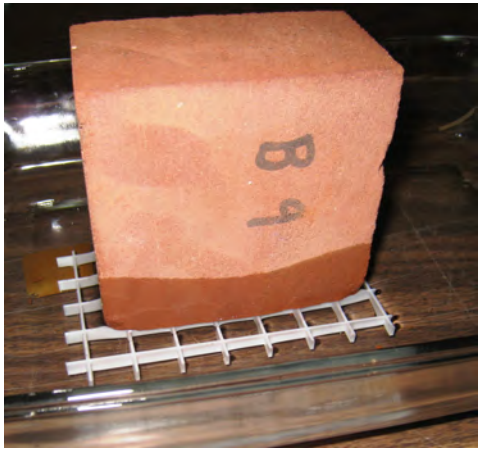
$$W = \mu A \Theta \frac{(P_1 - P_2)}{l}$$

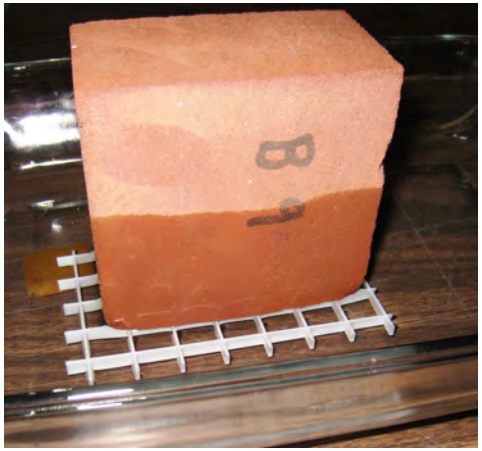
$W = total\ mass\ of\ vapor\ transmitted$
$A = cross\ sectional\ area$
Θ = ***time during which flow occurs***
$(P_1 - P_2)$ = ***vapor pressure difference***
l = ***length of flow path***
$\bar{\mu} = average\ permeability$

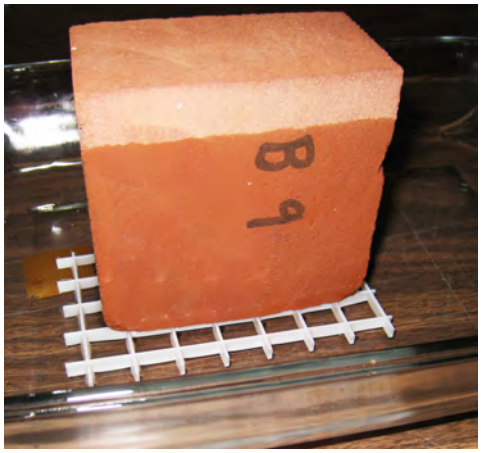
$$M = \frac{\bar{\mu}}{l} \qquad W = MA\Theta(P_1 - P_2)$$

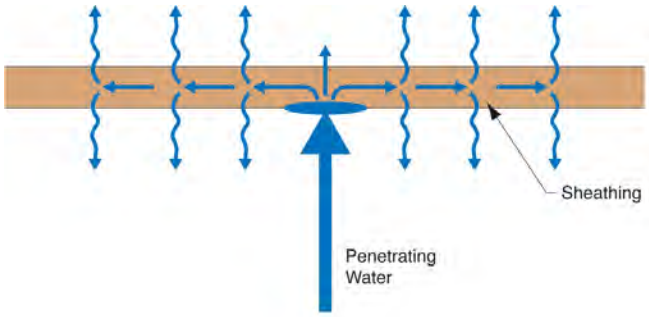
$$J_c = -D_c \cdot grad\ c$$

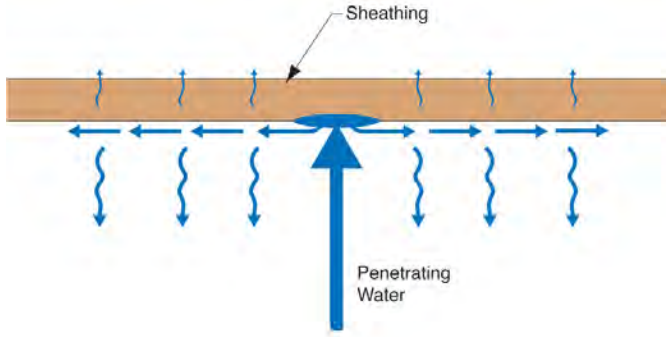







B 9


Sheathing
Penetrating
Water


Sheathing
Penetrating
Water

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Joseph Lstiburek 123

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Joseph Lstiburek 124


LOWER N-2


Tyvek
omeWrap

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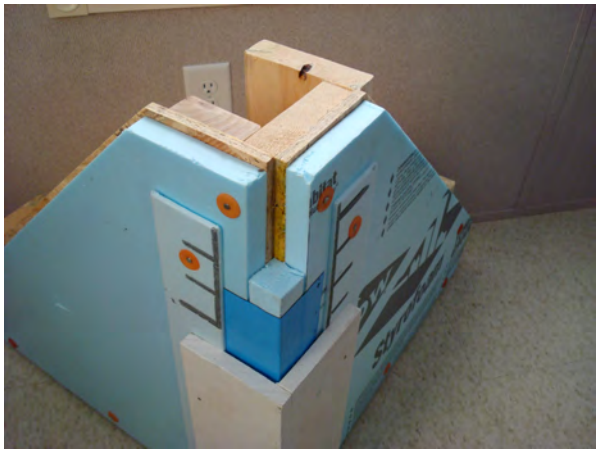

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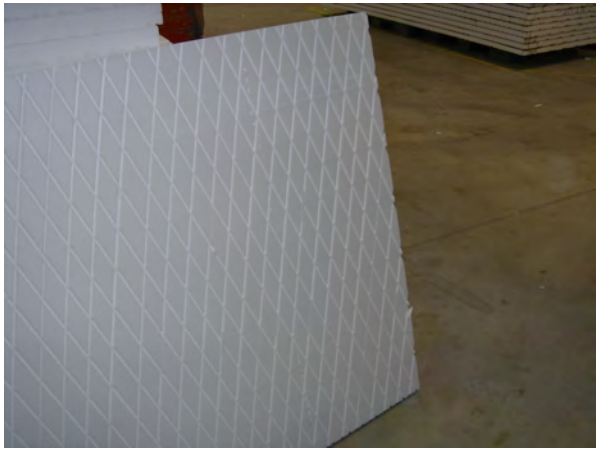

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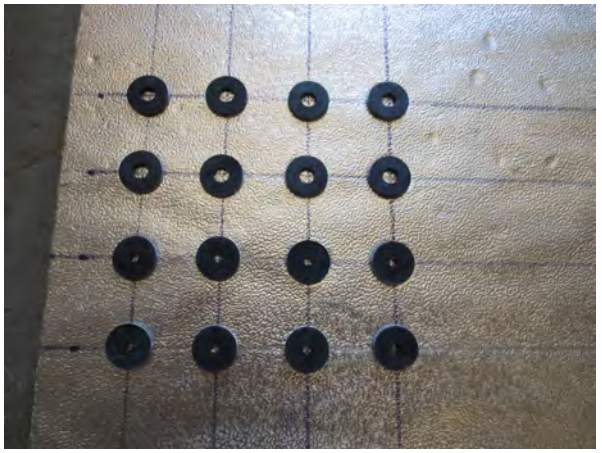
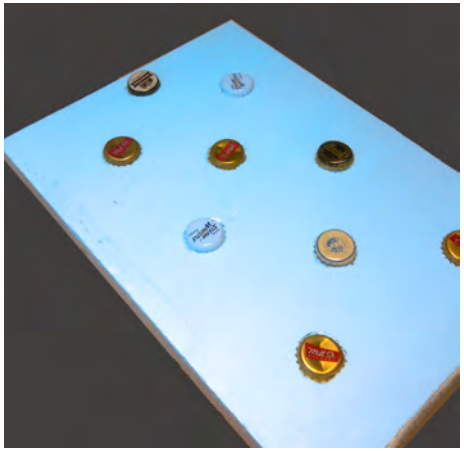
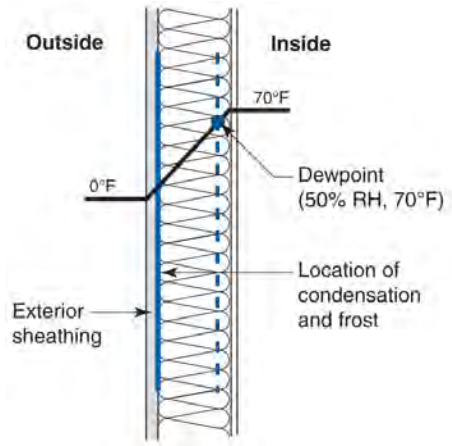
Rain Screen



Beer Screen?





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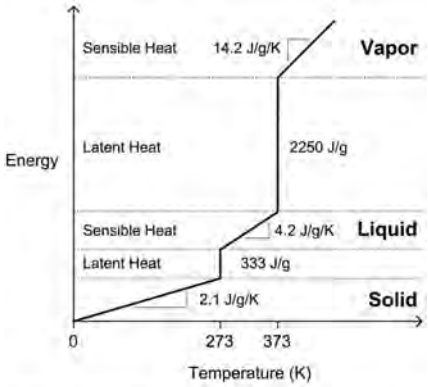

Simple linearized energy-temperature relation for water
From Straube & Burnett, 2005

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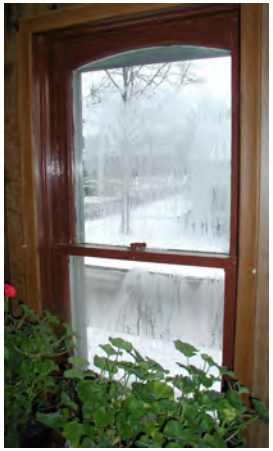

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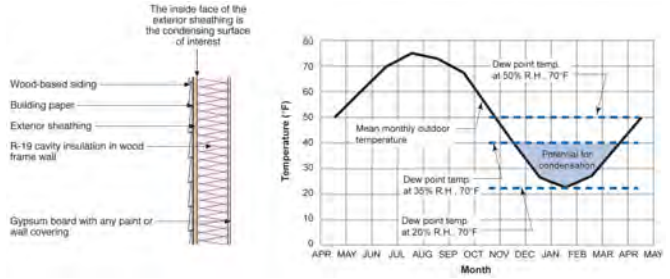
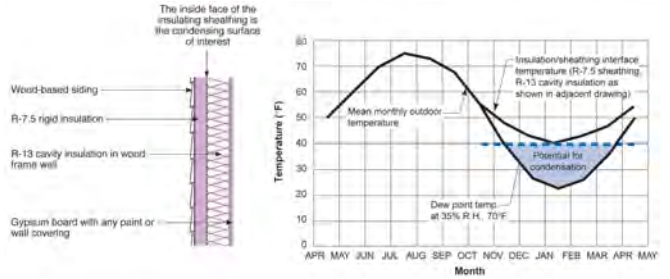




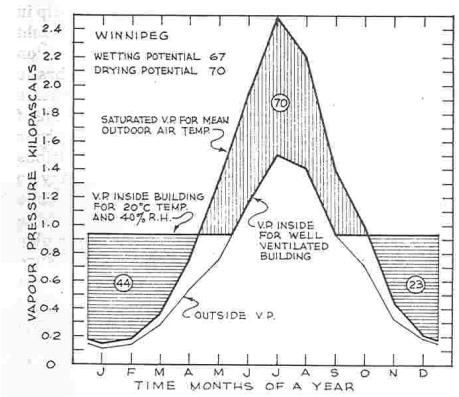
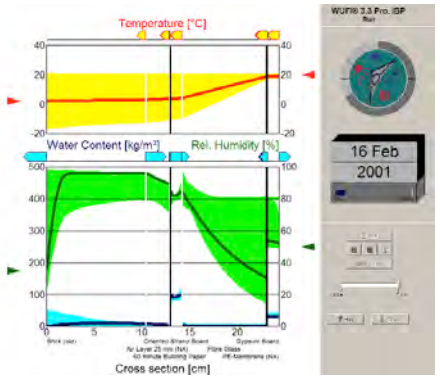
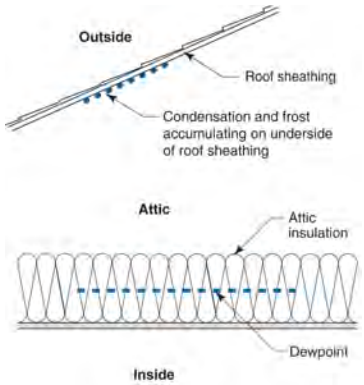


Figure 8-7. Outside vapour pressure, saturated vapour pressure and inside vapour pressure for Winnipeg.





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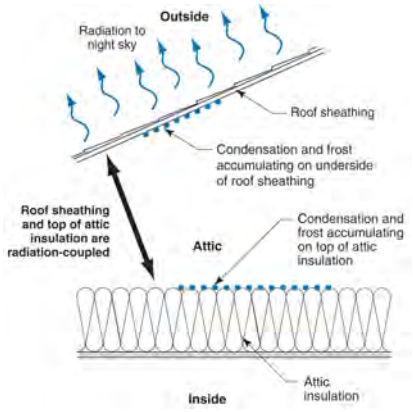

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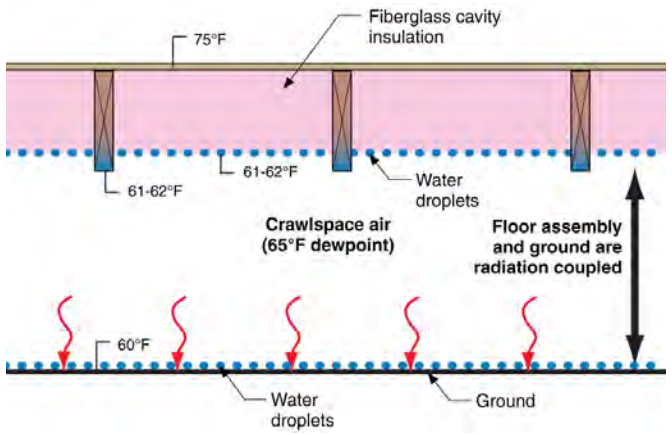
Building Science Corporation
Joseph Lstiburek 148

Building Science Corporation Joseph Lstiburek 149



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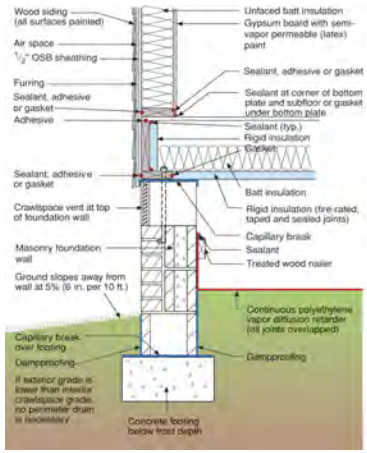

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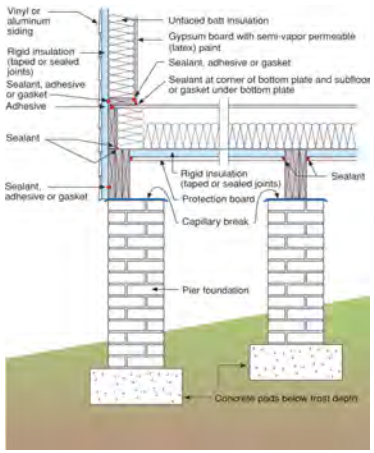

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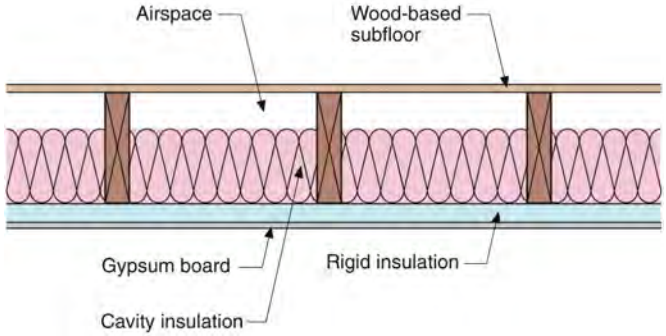

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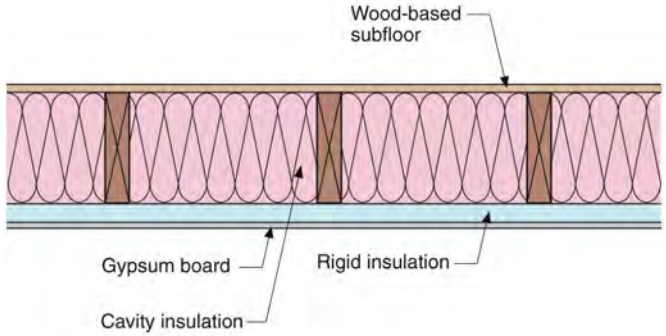

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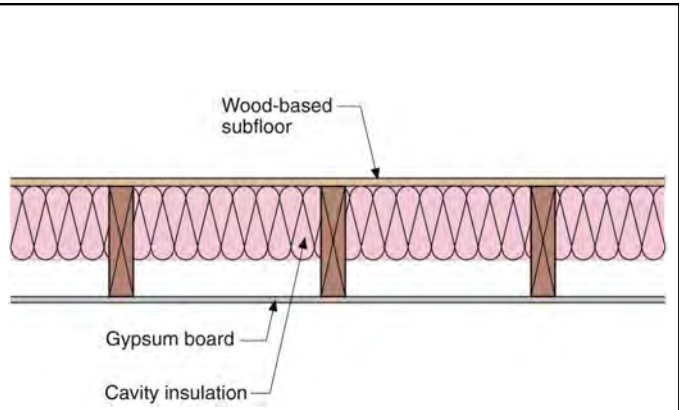

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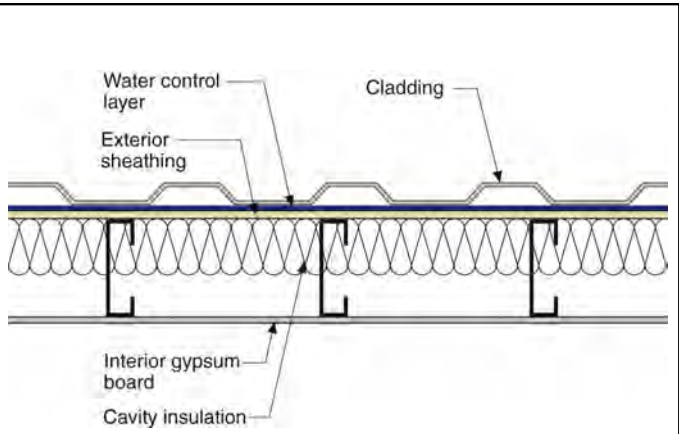
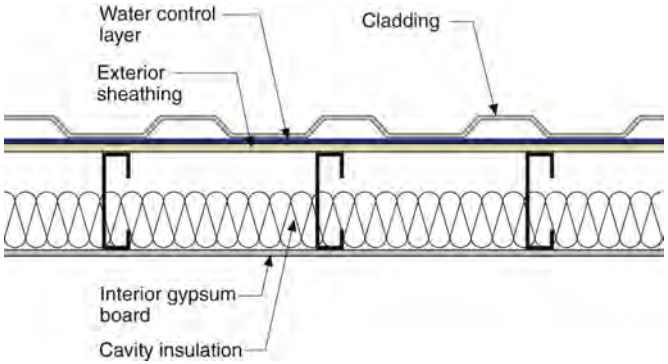
Joseph Lstiburek 155



Building Science Corporation
Joseph Lstiburek 156



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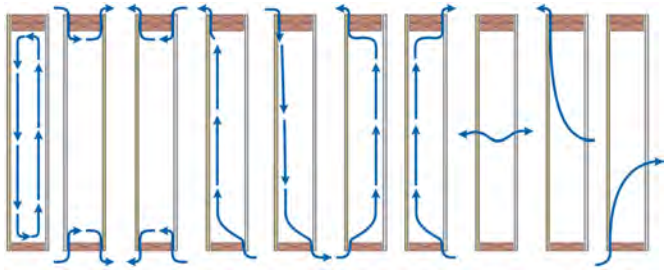
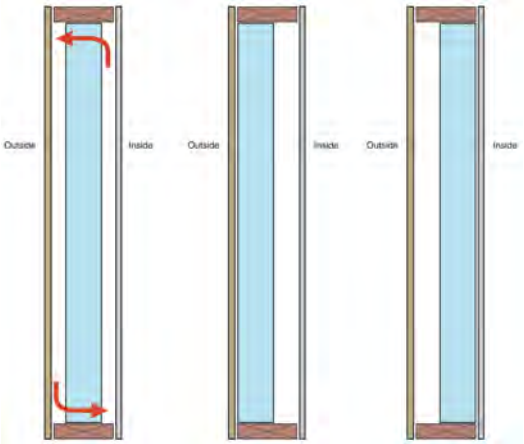


Building Science Corporation Joseph Lstiburek 158



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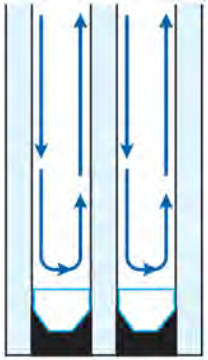

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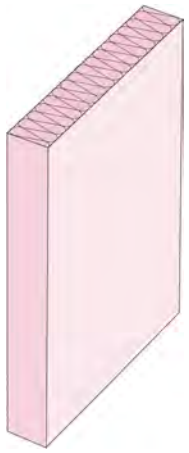

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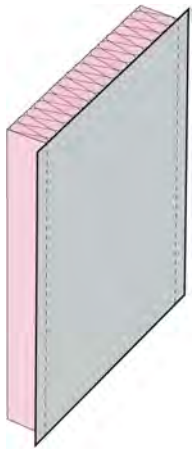

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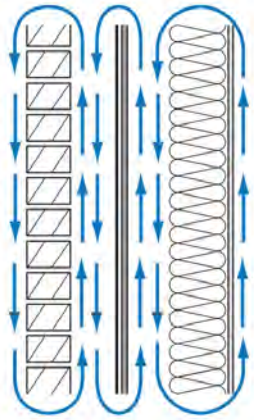

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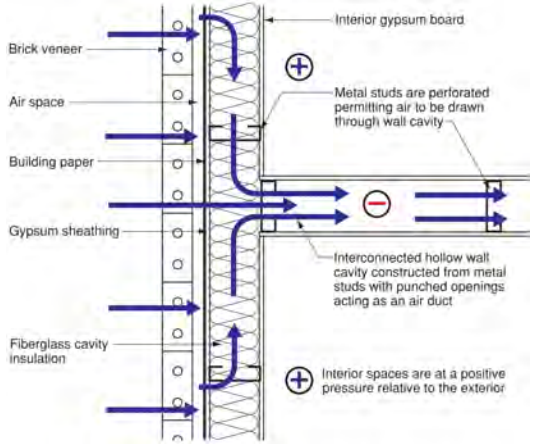

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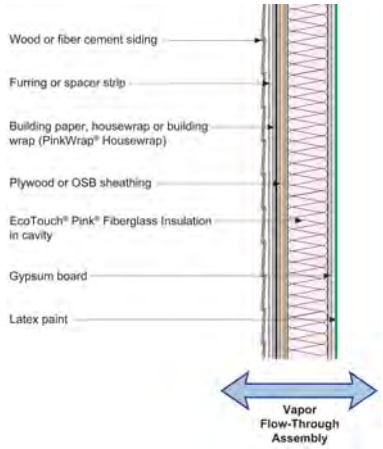

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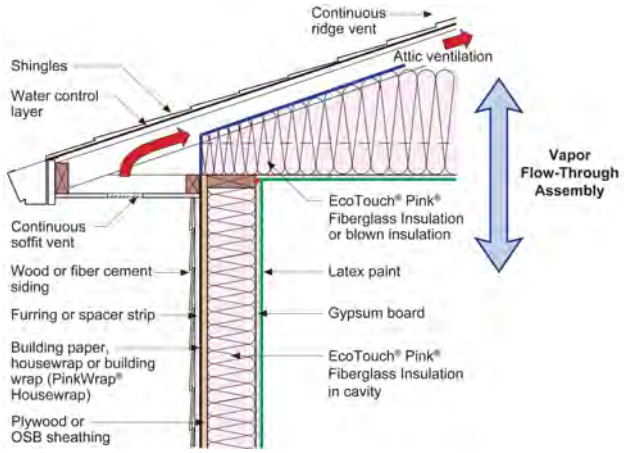

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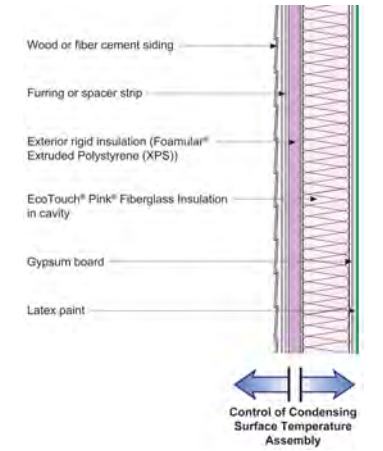

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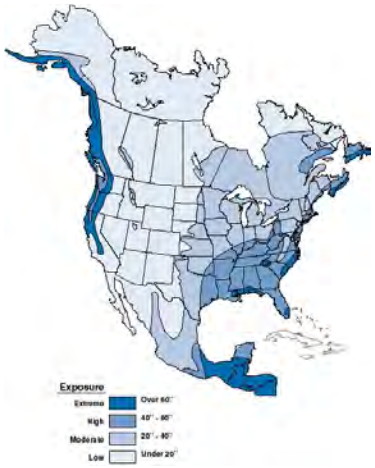
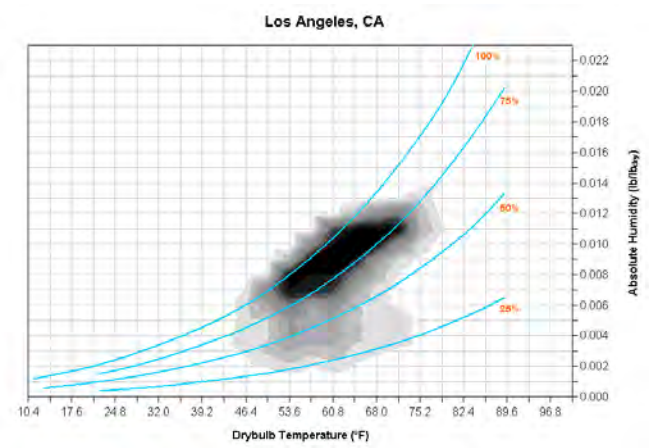
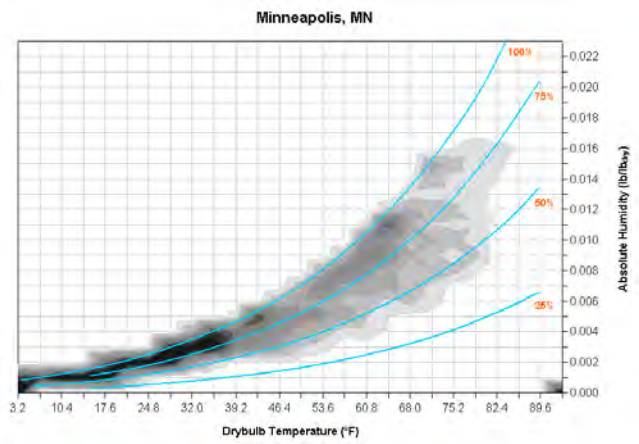
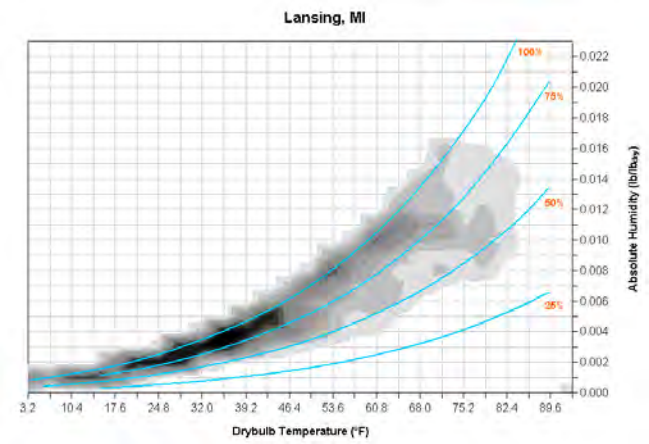
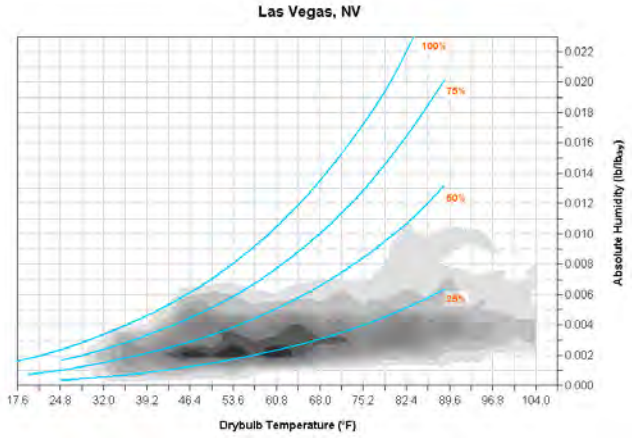
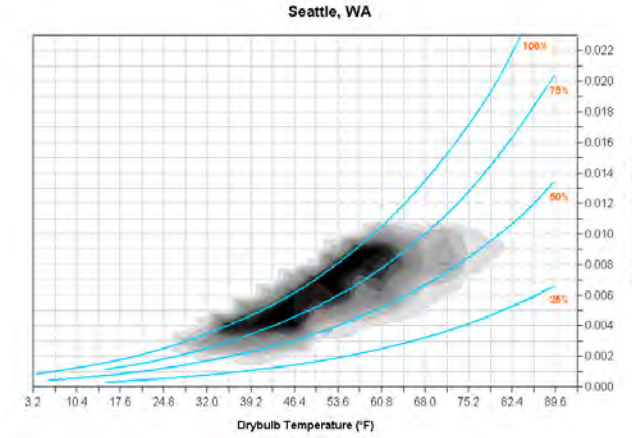

Exposure
Extreme
High
Moderate
Low
Over 60°
40° - 60°
20° - 40°
Under 20°


Los Angeles, CA
100%
75%
50%
25%
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Absolute Humidity (lb/lbdry)
10.4 17.6 24.8 32.0 39.2 46.4 53.6 60.8 68.0 75.2 82.4 89.6 96.8
Drybulb Temperature (°F)

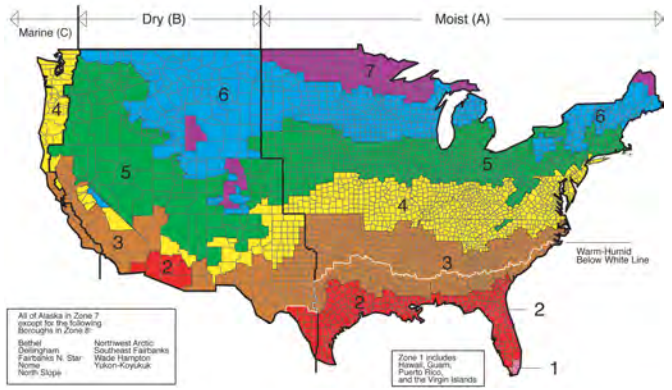

Minneapolis, MN
100%
75%
50%
25%
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Absolute Humidity (lb/lbdry)
3.2 10.4 17.6 24.8 32.0 39.2 46.4 53.6 60.8 68.0 75.2 82.4 89.6
Drybulb Temperature (°F)

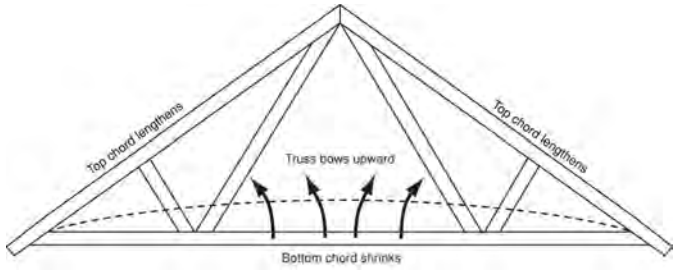

Lansing, MI
100%
75%
50%
25%
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Absolute Humidity (lb/lbdry)
3.2 10.4 17.6 24.8 32.0 39.2 46.4 53.6 60.8 68.0 75.2 82.4 89.6
Drybulb Temperature (°F)

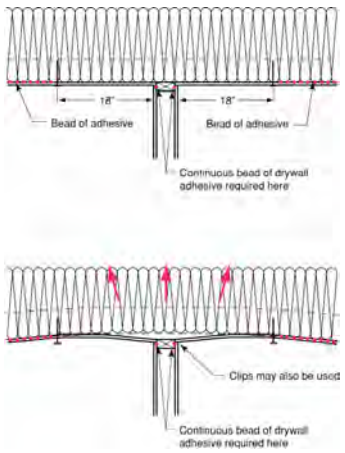


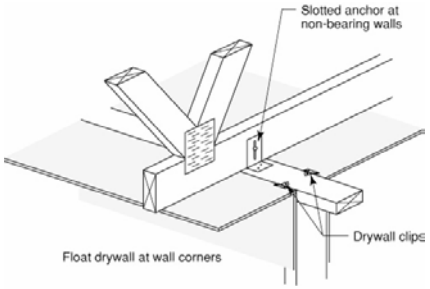


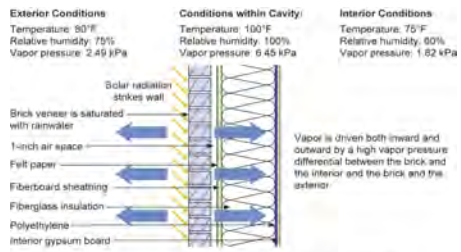
Don’t Do Stupid Things


Marine (C)
Dry (B)
Moist (A)
1
2
3
4
5
6
7
Warm-Humid
Below White Line
All of Alaska in Zone 7
except for the following
Boroughs in Zone 8:
Bethel
Dellingham
Fairbanks N. Star
Nome
North Slope
Northwest Arctic
Southeast Fairbanks
Wade Hampton
Yukon-Koyukuk
Zone 1 includes
Hawaii, Guam,
Puerto Rico,
and the Virgin Islands

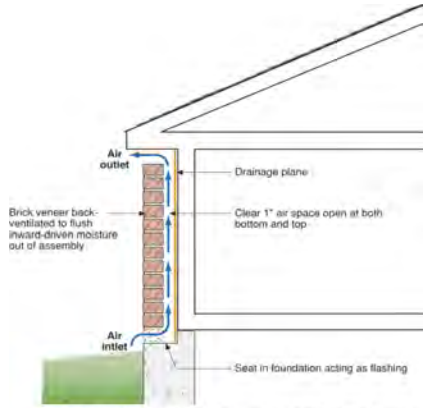

Top chord lengthens
Truss bows upward
Top chord lengthens
Bottom chord shrinks


16"
16"
Bead of adhesive
Bead of adhesive
Continuous bead of drywall adhesive required here
Clips may also be used
Continuous bead of drywall adhesive required here

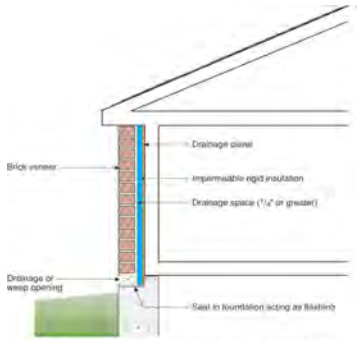

Slotted anchor at non-bearing walls
Drywall clips
Float drywall at wall corners



- It is not a good idea to install a vapor barrier (polyethylene) on the inside of an air conditioned assembly. Vinyl wall coverings and foil-backed batt cavity insulation should also be avoided.
- Vapor permeable exterior sheathings, housewraps or building papers should not be used with absorptive claddings such as brick veneers unless a ventilated cavity is provided in conjunction with high inward drying potentials (i.e. no interior polyethylene vapor barriers).
- Failure will occur when brick is installed over a frame wall constructed with felt paper, fiberboard sheathing and an interior polyethylene vapor barrier. Kraft-faced fiberglass batts should be used in place of unfaced batts and a polyethylene vapor barrier. OSB, plywood or foam sheathing should be used in place of the fiberboard sheathing.
- Similar problems occur with stucco.



- To effectively uncouple a brick veneer from a wall system by using back ventilation, a clear cavity must be provided along with both air inlets at the bottom and air outlets at the top.



- To effectively uncouple a brick veneer from a wall system by using a condensing surface, the drainage plane must also be a vapor barrier or a vapor impermeable layer (i.e. rigid insulation) must be installed between the drainage plane and the brick veneer. Alternatively, the rigid insulation can be configured to act as both the drainage plane and vapor impermeable layer.
- When a condensing surface is used to uncouple a brick veneer from a wall system, a ventilated air space is no longer necessary — i.e. the presence of mortar droppings is no longer an issue. Additionally, the width of the drainage space is almost irrelevant.

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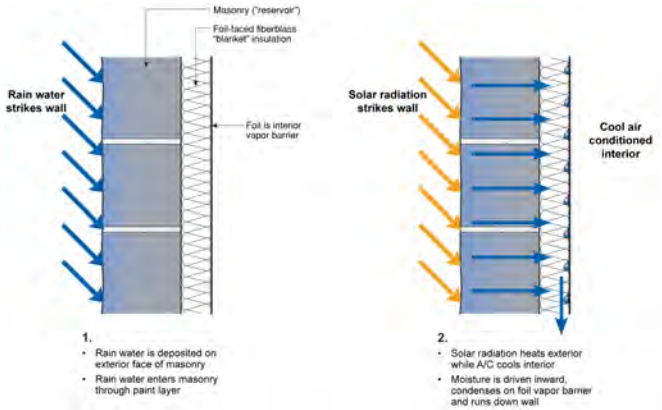

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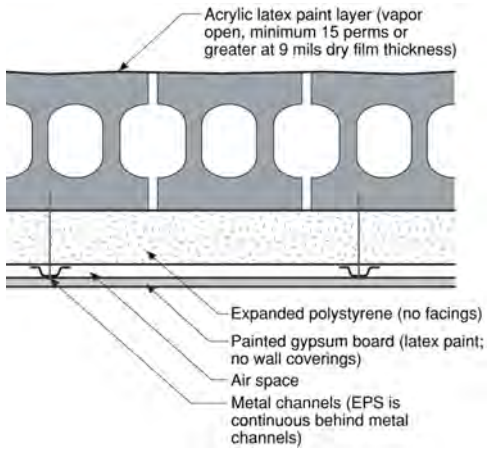

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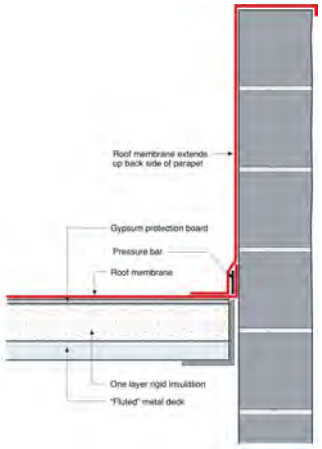

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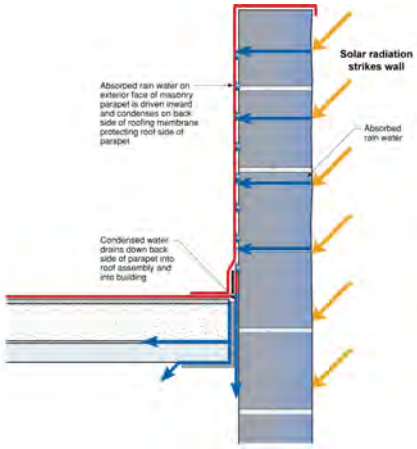

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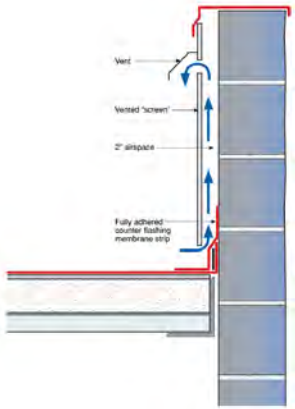

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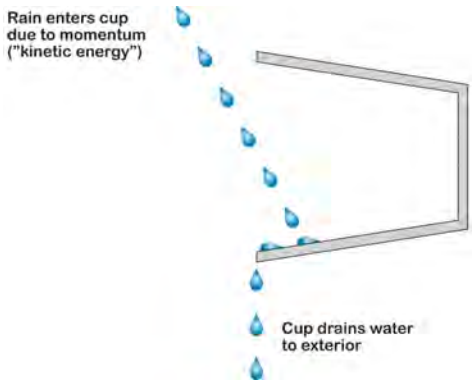

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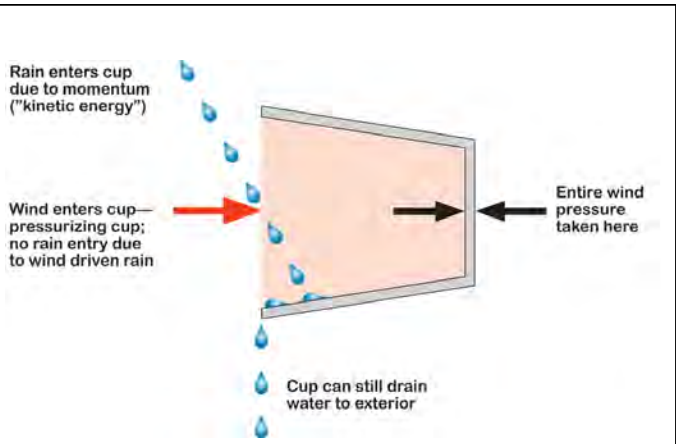
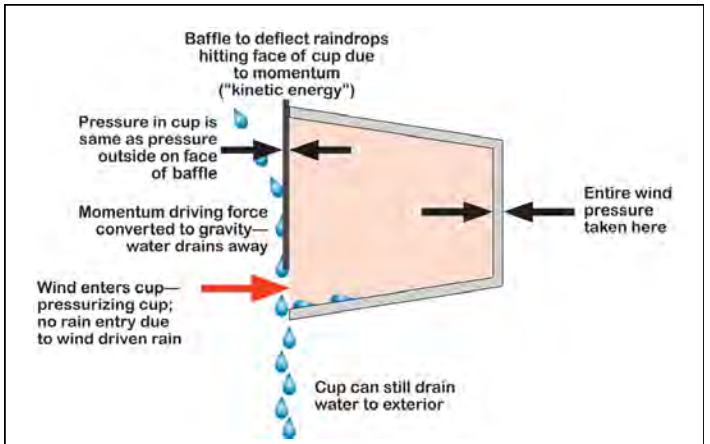
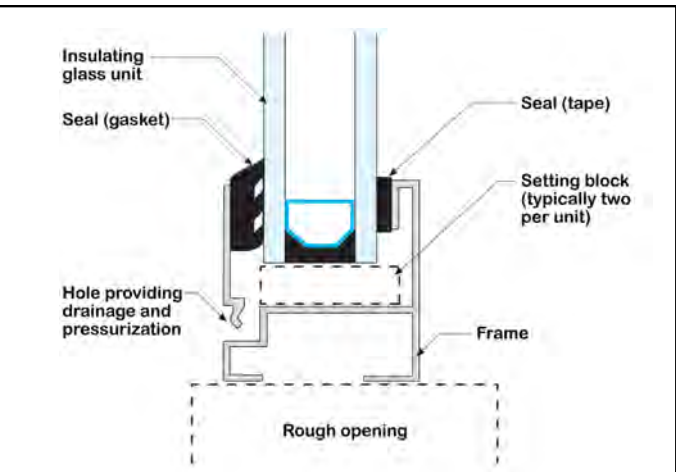


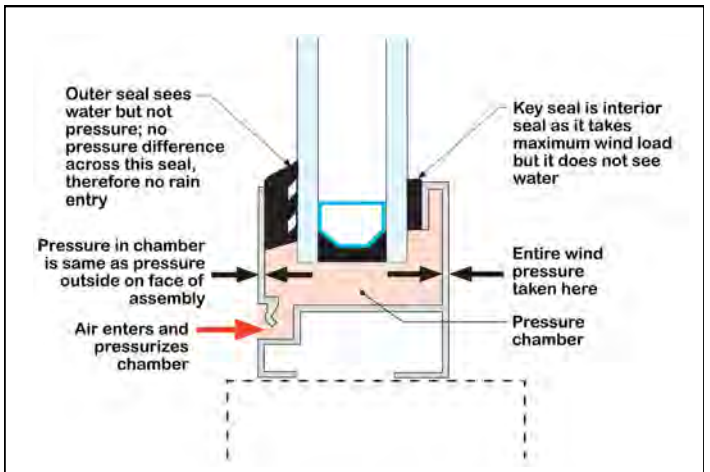
Building Science Corporation 2011 Joseph Lstiburek 201



Building Science Corporation 2011 Joseph Lstiburek 202



Building Science Corporation Joseph Lstiburek 203



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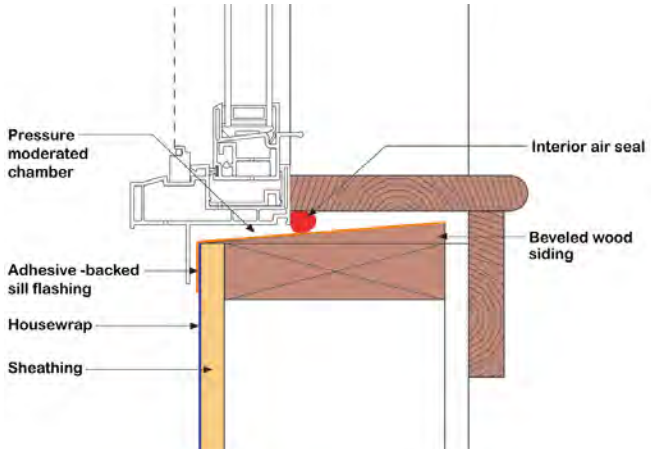

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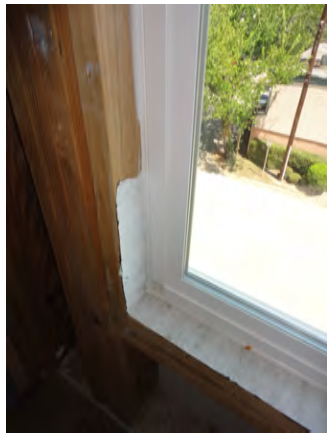

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Building Science Corporation
Joseph Lstiburek 207

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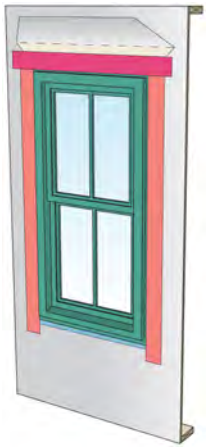
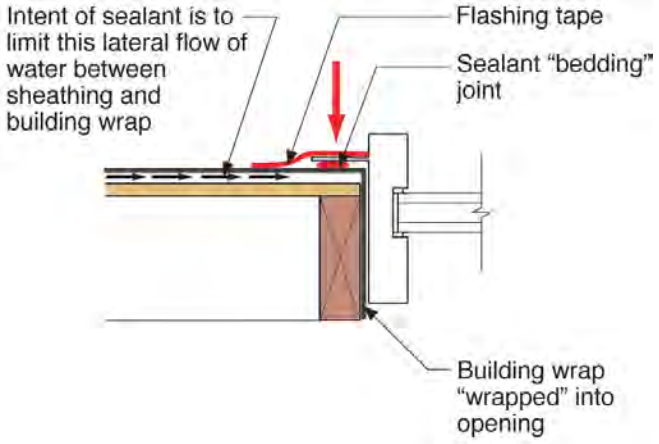
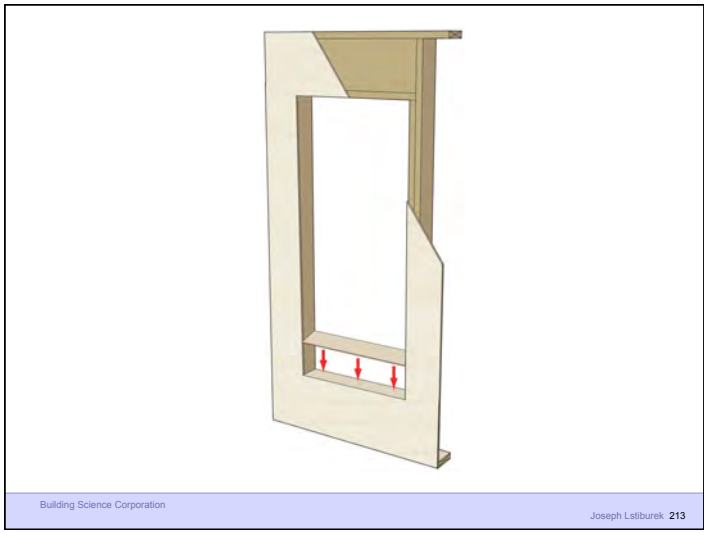



Intent of sealant is to limit this lateral flow of water between sheathing and building wrap
Flashing tape
Sealant "bedding" joint
Building wrap "wrapped" into opening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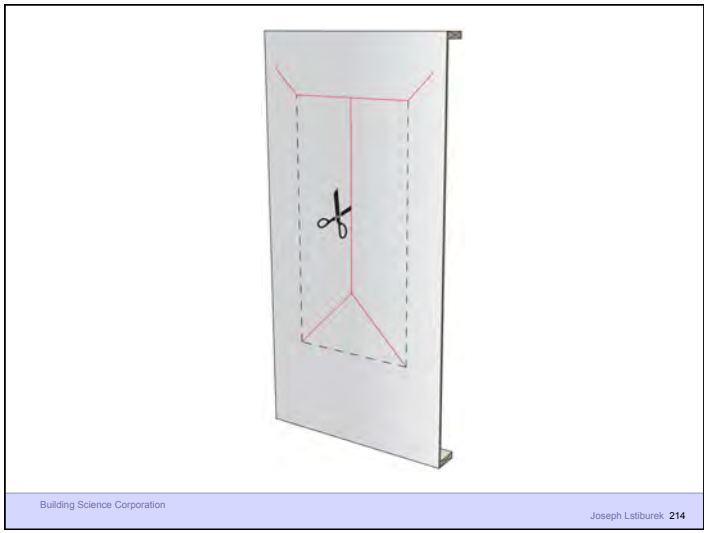
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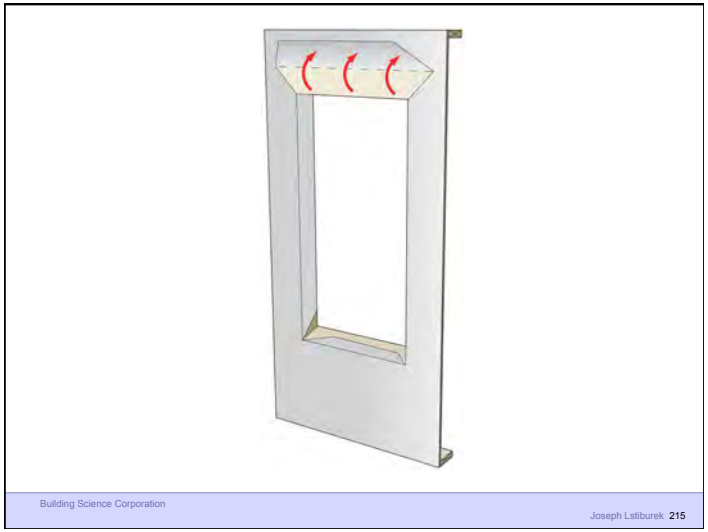
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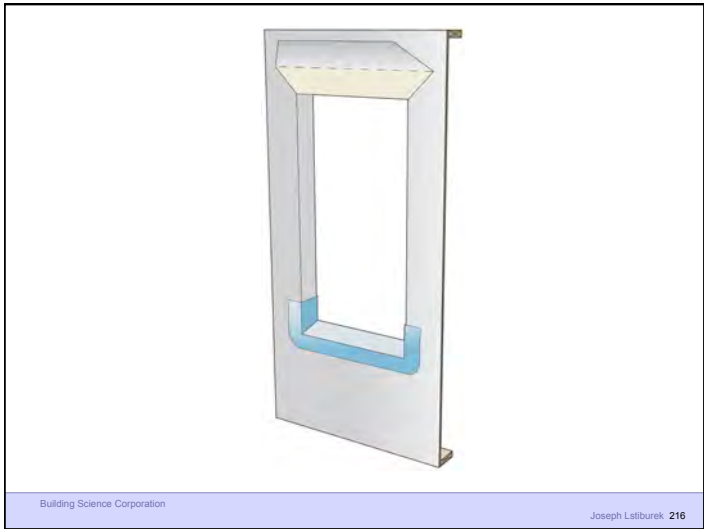
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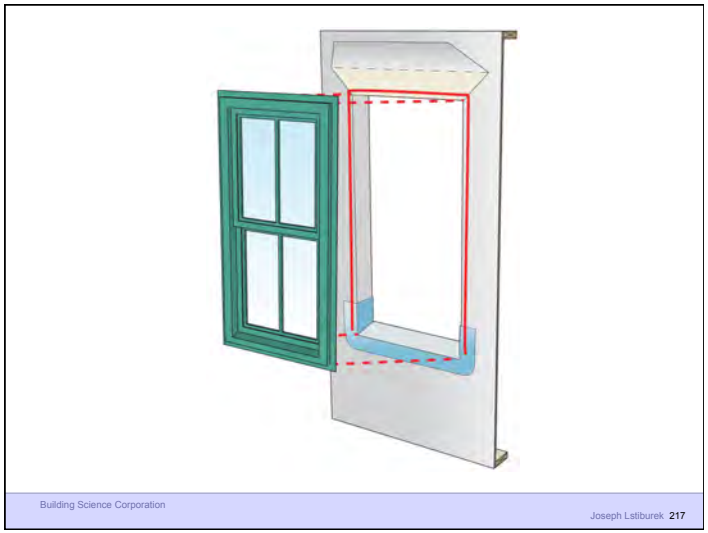
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Building Science Corporation
Joseph Lstiburek 221

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Joseph Lstiburek 222

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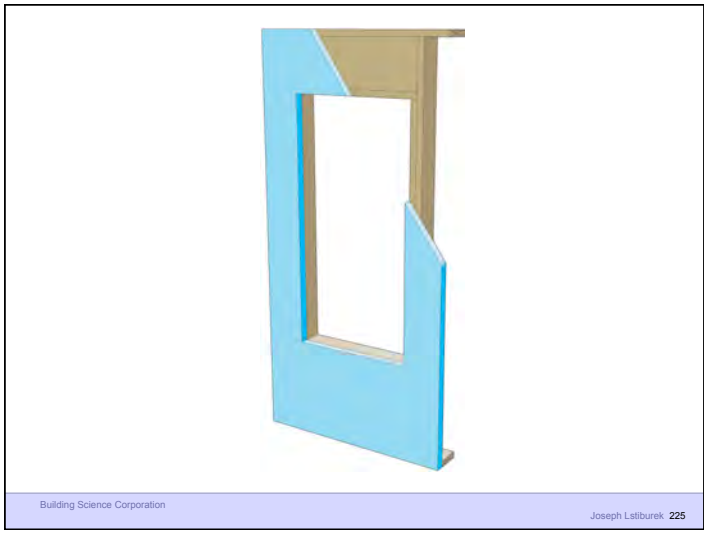
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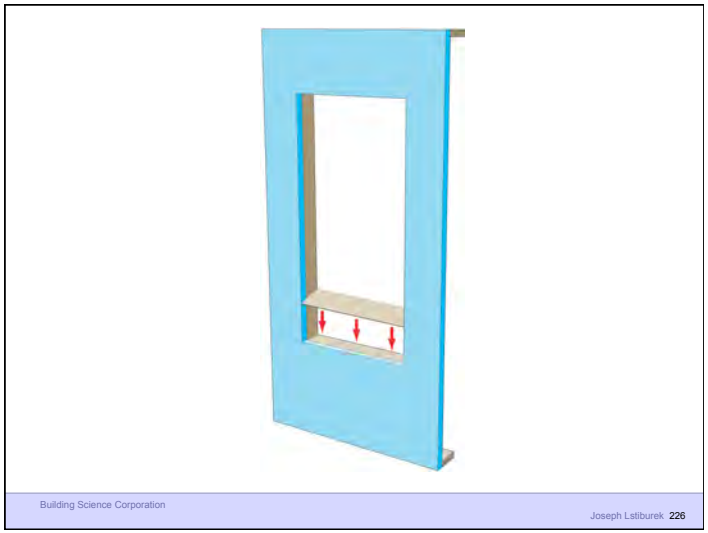
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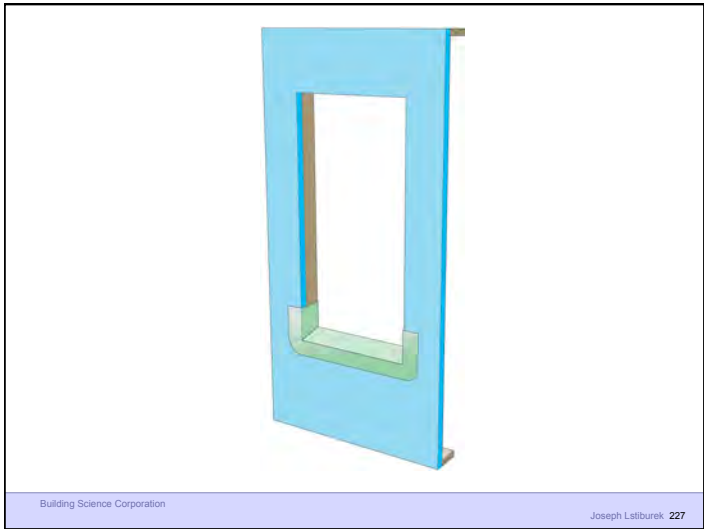
Building Science Corporation
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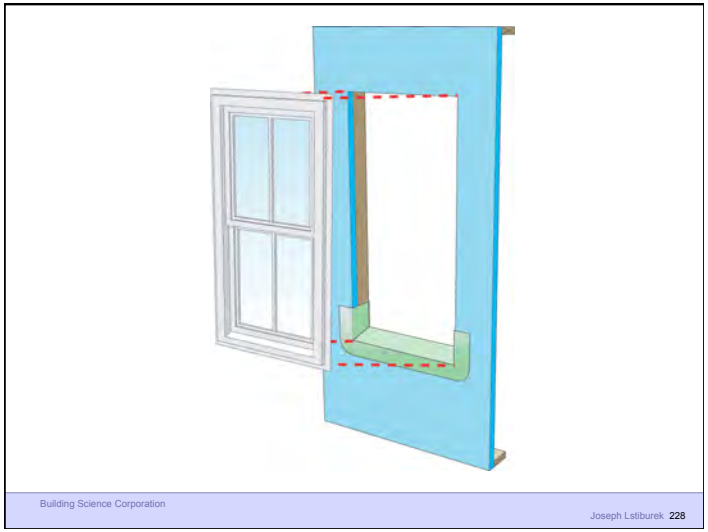
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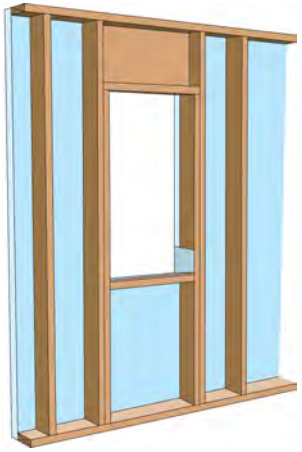

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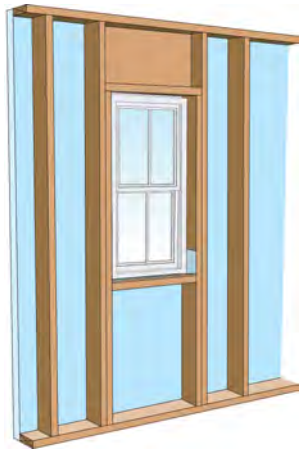

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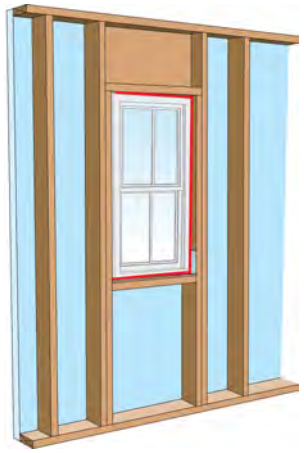
Joseph Lstiburek 233



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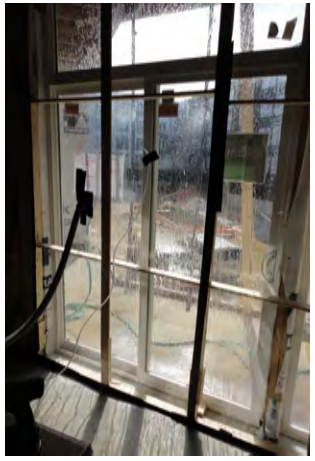

Building Science Corporation
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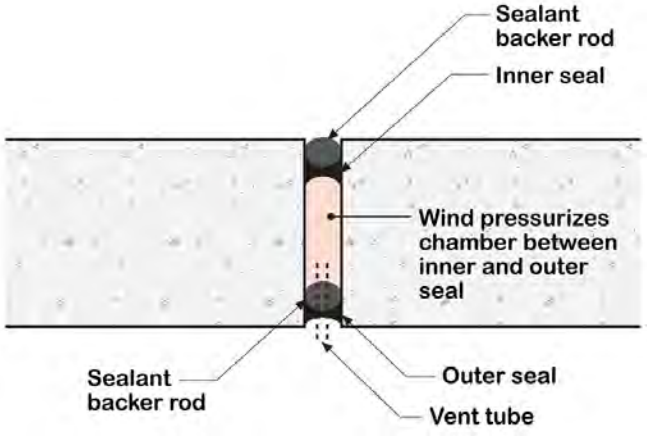

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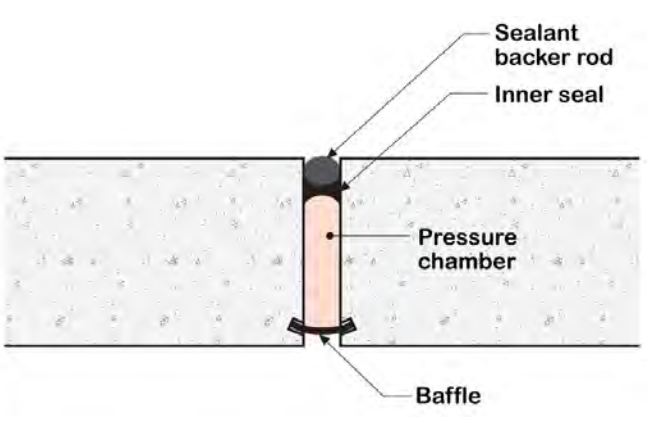

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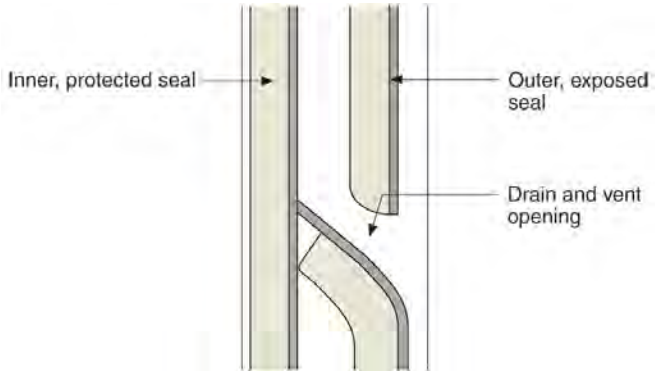
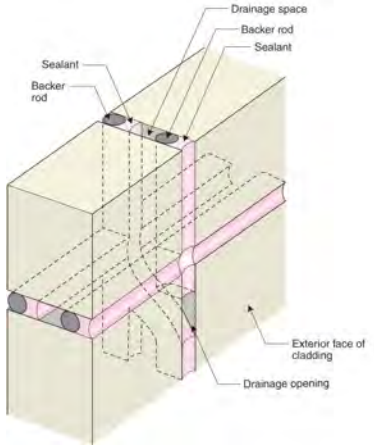


Building Science Corporation Joseph Lstiburek 239



Building Science Corporation Joseph Lstiburek 240

Building Science Corporation Joseph Lstiburek 241

Building Science Corporation Joseph Lstiburek 242

Building Science Corporation Joseph Lstiburek 243

Building Science Corporation Joseph Lstiburek 244