Building Science

Adventures In Building Science

www.buildingscience.com
Environmental Separation
Definition of 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
Some Physics....
Arrhenius Equation
For Every 10 Degree K Rise
Reaction Rate Doubles

\[ k = A e^{-E_a/(RT)} \]
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
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
PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL
The Effect of Climate
The Perfect Wall
Water Control Layer
Air Control Layer
Vapor Control Layer
Thermal Control Layer
Cladding

Control layers

Structure
Configurations of the Perfect Wall
Brick veneer/stone veneer

Drained cavity

Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass

Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder

Concrete block

Metal channel or wood furring

Gypsum board

Latex paint or vapor semi-permeable textured wall finish

Vapor Profile
Brick veneer/stone veneer

Drained cavity

Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass

Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder

Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)

Uninsulated steel stud cavity

Gypsum board

Latex paint or vapor semi-permeable textured wall finish

Vapor Profile
Building Science Corporation

Brick veneer/stone veneer

Drained cavity

Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass

Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder

Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)

Insulated wood stud cavity

Gypsum board

Latex paint or vapor semi-permeable textured wall finish

Vapor Profile
The Water Molecule
Polar Molecule
Size Matters
Relative Humidity
Vapor Pressure
2T, 75°F

1T
RH = 50%

1T, 60°F

1T
RH = 100%

2T, 75°F

1T
RH = 50%

1 1/2T
RH = 75%
Heating

35°F
90% RH

70°F
30% RH
Sorption
Sorption isotherm for several building materials [Kumaran 2002]
From Straube & Burnett, 2005
BET Theory
BET Theory
Stephen Brunauer
Paul Emmett
Edward Teller
Typical predicted sorption isotherm according to Kelvin equation and modified BET theory
From Straube & Burnett, 2005
Change in the storage of moisture in a porous building material as the partial pressure of water vapor in the ambient air increases from zero to full saturation value at a given temperature.

**Sorption Curve**
Regimes of moisture storage in a hygroscopic porous material

From Straube & Burnett, 2005

A: Single-layer of adsorbed molecules
B: Multiple layers of adsorbed molecules
C: Interconnected layers (internal capillary condensation)
D: Free water in Pores, capillary suction
E: Supersaturated Regime
A - Single-layer of absorbed molecules
B - Multiple layers of absorbed molecules
C - Interconnected layers (internal capillary condensation)
D - Free water in pores, capillary suction
E - Supersaturated regime

Relationship between Dry Cup and Wet Cup
Adapted from Joy & Wilson, 1963
Water Vapor Permeance vs. Relative Humidity

- $\mu_1$ = Dry cup permeance
- $\mu_2$ = Wet cup permeance

Dry cup limits and Wet cup limits are indicated on the graph.
Water Vapor Permeance of Sheathing Materials

Mean Relative Humidity, %

Water Vapor Permeance, US perms

Dry Cup

Wet Cup

Plywood

OSB

72
Average sorption isotherm for wood as a function of temperature
From Straube & Burnett, 2005
Water Vapor Permeance of MemBrain™ Smart Vapor Retarder, Primed and Painted Gypsum Board, Unpainted Gypsum Board and Asphalt-Coated Kraft Paper

Mean Relative Humidity, %

Water Vapor Permeance, US perms

Unpainted Gypsum Board
MemBrain™ Smart Vapor Retarder
Primed & Painted Gypsum Board
Asphalt-Coated Kraft Paper
Water Vapor Permeance of WRB’s

Mean Relative Humidity, %

Water Vapor Permeance, US perms

Dry Cup

Wet Cup

Felt

ASK

Tyvek®

Typar®

WeatherSmart™

WeatherMate™

Plus
Air Flow and Vapor Diffusion
<table>
<thead>
<tr>
<th>Vapor</th>
<th>Diffusion</th>
<th>Convective Flow</th>
<th>Vapor Concentration</th>
<th>Air Pressure</th>
</tr>
</thead>
</table>
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
4x8 sheet of gypsum board
Interior at 70°F and 40% RH

½ quart of water

AIR LEAKAGE

4x8 sheet of gypsum board
with a 1in² hole

Interior at 70°F and 40% RH

30 quarts of water
4x8 sheet of gypsum board
Interior at 75°F and 50% RH

3/4 quart of water

Exterior at 74°F dewpoint

4x8 sheet of gypsum board with a 1in² hole
Interior at 75°F and 50% RH

7 quarts of water
Rain
Hydrostatic pressure

Hydrostatic pressure
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
Rain Screen
Beer Screen?
Drain the Rain on the Plane
If You Want to Save Cash…Flash
Don’t Be a Dope…Slope
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
Baffle to deflect raindrops hitting face of cup due to momentum ("kinetic energy")

Pressure in cup is same as pressure outside on face of baffle

Momentum driving force converted to gravity—water drains away

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

Cup can still drain water to exterior

Entire wind pressure taken here
Insulating glass unit

Seal (gasket)

Seal (tape)

Setting block (typically two per unit)

Hole providing drainage and pressurization

Frame

Rough opening
Outer seal sees water but not pressure; no pressure difference across this seal, therefore no rain entry.

Pressure in chamber is same as pressure outside on face of assembly.

Air enters and pressurizes chamber.

Key seal is interior seal as it takes maximum wind load but it does not see water.

Entire wind pressure taken here.

Pressure chamber.
Pressure moderated chamber

Interior air seal

Beveled wood siding

Adhesive-backed sill flashing

Housewrap

Sheathing
Intent of sealant is to limit this lateral flow of water between sheathing and building wrap.
Wind pressurizes chamber between inner and outer seal.

Sealant backer rod

Inner seal

Sealant backer rod

Outer seal

Vent tube
Sealant backer rod
Inner seal
Pressure chamber
Baffle
Inner, protected seal

Outer, exposed seal

Drain and vent opening
Open Joints vs Closed Joints
Open Joints vs Closed Joints
Limits of Pressure Equalization
Pressure Equalization Needs to be Perfect
Pressure Equalization Reduces Drying
Prevention of Wetting Is Not As Important As Drying
Assume Things Get Wet…Design Them to Dry
Ventilated Claddings Promote Drying
Capillarity
William Thomson
William Thomson – Lord Kelvin
Kelvin Equation

\[\ln \frac{p}{p_0} = \frac{2\gamma V_m}{rRT}\]
Calculating capillary rise

\[ h = \frac{2 \sigma \cos \theta}{g \rho r} \]
Capillary rise versus diameter
Figure 1c. Gypsum, hydrated from plaster of paris and water, porosity 30 per cent.

Figure 1b. Brick, sintered clay, porosity 40 per cent.
Capillary break on exterior foundation wall

Capillary break under slab

Capillary break on top of footing
Siding Laps
FILM OF WATER ON SURFACE OF SIDING

WATER FILM DRAWS UP BETWEEN LAPS OF SIDING BY CAPILLARY SUCTION

BUILDING PAPER

SHEATHING
Plywood/OSB sheathing

Water control layer

\[\frac{3}{8}\text{"} \text{ spacer strip}\]
Phases of Water
Monolayers flow along surface following concentration gradient
Kelvin Equation Again….

\[ \ln \frac{p}{p_0} = \frac{2\gamma V_m}{rRT} \]