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
Damage Functions

Water
Heat
Ultra Violet Radiation
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
Rain and Airflow Missing
### Moisture Transport in Porous Media

<table>
<thead>
<tr>
<th>Phase</th>
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Recall That Rain and Airflow Are Missing
Moisture Transport in Assemblies

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Laws of Thermodynamics
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

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
Example: Air leakage wetting of sheathing

Interior: 21 °C/40% RH
Exterior: -10 °C/85% RH
RSI 2.11 batt in stud space
RSI 1.40 insulated sheathing

Saturation = 100% RH

Cooling and condensation
From: Straube & Bumett, 2005
Water Molecules

Size Matters
Polar Molecule
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</table>
Vapor Diffusion Vapor Concentration
Convective Flow Air Pressure
Adsorbate Surface Diffusion Concentration
Liquid Capillary Flow Suction Pressure
Calculating capillary rise

\[ h = \frac{2 \sigma \cos \theta}{g \rho r} \]

Capillary rise versus diameter

![Graph showing capillary rise versus diameter](image)
Vapor     Diffusion     Vapor Concentration
Convective Flow  Air Pressure

Adsorbate     Surface Diffusion     Concentration

Liquid     Capillary Flow     Suction Pressure
          Osmosis     Solute Concentration
Capillarity + Salt = Osmosis

- Mineral salts carried in solution by capillary water
- When water evaporates from a surface the salts left behind form crystals in process called efflorescence
- When water evaporated beneath a surface the salts crystallize within the pore structure of the material in called sub-efflorescence
- The salt crystallization causes expansive forces that can exceed the cohesive strength of the material leading to spalling
Pressures

- Diffusion Vapor Pressure: 3 to 5 psi
- Capillary Pressure: 300 to 500 psi
- Osmosis Pressure: 3,000 to 5,000 psi
Combined Flows

Ambient relative humidity at which capillary condensation is predicted to occur by the Kelvin equation
From Strashe & Burnett, 2005

Pore Size (m) vs. Relative Humidity (%)
Size of water molecule
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 & Bunett, 2005
Typical predicted sorption isotherm according to Kelvin equation and modified BET theory
From Straube & Burnett, 2003
Average sorption isotherm for wood as a function of temperature
From Straube & Burnet, 2005

Moisture Content (w%)

Relative Humidity (%)

Equilibrium Moisture Content (EMC) %

Relative Humidity (RH) %
Kraft facing permeance as a function of humidity (Glass 2013)
Water Vapor Permeance of Sheathing Materials

Permeance (ngPa s m⁻²)

Mean Relative Humidity (%)

Dry Cup

Wet Cup

Pywood

CSB

Vapor permeability test results for wood-based products as a function of RH

[Numaan et al 2012]

From Straube & Burnett, 2015
Studs get much wider and thicker, but not much longer, when they pick up moisture.

Wood Fiber

Fibers get much thicker than longer when they pick up moisture.
Still More Combined Flows
Schematic drawing of the transient moisture transport process that is used to determine the liquid diffusivity of porous building materials. All four longitudinal surfaces of the test specimen are coated with water vapor resistant epoxy resin and one of the open-end surfaces is in contact with water while the other is open to the ambient air.

**Determining Liquid Diffusivity of Porous Building Materials**

From M.K. Kumaran, ASTM MNL 18-2nd Edition,
How Does Wetting Occur?

- “non-wettable” 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’

- “wettable” surface
- non-water repellant surface
- hygroscopic 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’
Building Science Corporation

Heat, Air and Moisture

May 16, 2016

Lstiburek

© buildingscience.com
<table>
<thead>
<tr>
<th>Material</th>
<th>Surface Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (20 C)</td>
<td>73 dynes/cm</td>
</tr>
<tr>
<td>Water (100 C)</td>
<td>59 dynes/cm</td>
</tr>
<tr>
<td>Epoxy</td>
<td>46 dynes/cm</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>31 dynes/cm</td>
</tr>
<tr>
<td>Soapy water</td>
<td>30 dynes/cm</td>
</tr>
<tr>
<td>Paraffin wax</td>
<td>25 dynes/cm</td>
</tr>
<tr>
<td>Silicone</td>
<td>24 dynes/cm</td>
</tr>
<tr>
<td>Teflon</td>
<td>18 dynes/cm</td>
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More Combined Flows
When Phases Change
Simple linearized energy-temperature relation for water
From Straube & Burnett, 2005
Figure 8.7. Outside vapour pressure, saturated vapour pressure and inside vapour pressure for Winnipeg.
Revisiting Convective Flow
Cladding Ventilation/Sheathing Ventilation

<table>
<thead>
<tr>
<th></th>
<th>Flow Rate</th>
<th>Gap</th>
<th>ACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Siding</td>
<td>0.1 cfm/sf</td>
<td>3/16&quot;</td>
<td>20</td>
</tr>
<tr>
<td>Vinyl Siding</td>
<td>0.5 cfm/sf</td>
<td>3/16&quot;</td>
<td>200</td>
</tr>
<tr>
<td>Brick Veneer</td>
<td>0.15 cfm/sf</td>
<td>3&quot;</td>
<td>10</td>
</tr>
<tr>
<td>Stucco (vented)</td>
<td>0.1 cfm/sf</td>
<td>3/8&quot;</td>
<td>10</td>
</tr>
<tr>
<td>Stucco (direct applied)</td>
<td>none</td>
<td>none</td>
<td>0</td>
</tr>
<tr>
<td>Sheathing flanking flow</td>
<td>0.05 cfm/sf</td>
<td>3/16&quot;</td>
<td>10</td>
</tr>
</tbody>
</table>
Interior Load – Exterior Load

- Interior gypsum board
- Metal studs are perforated permitting air to be drawn through wall cavity
- Interconnected hollow wall cavity constructed from metal studs with punched openings acting as an air duct
- Interior spaces are at a positive pressure relative to the exterior
Don’t Do Stupid Things
- 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 veneer 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.
Rain
Gravitational Flow
Surface Tension
Momentum
Convective Flow
Height
Surface Energy
Kinetic Energy
Air Pressure

Rain droplets can be carried through a wall by their own momentum

Rain entry by momentum can be prevented by designing wall systems with no straight through openings
Rainwater can flow around a surface as a result of surface tension.

Providing a kerf or drip edge will promote the formation of a water droplet and interrupt flow.

Rainwater can flow down surfaces and enter through openings and cavities.

Flashings direct gravity flow rainwater back toward the exterior.
When We Talk About Rain We Also Include Capillary Flow

Driven by air pressure differences, rain droplets are drawn through wall openings from the exterior to the interior.

By creating pressure equalization or pressure moderation between the exterior and cavity air, air pressure is diminished as a driving force for rain entry.
All We Have To Figure Out Is How Much Hits The Wall
All We Have To Figure Out Is How Much Hits The Wall
We Need Straube and Kuenzel
We use Straube/Kuenzel to determine how much rain water impinges on the wall.

We assume 30% bounces off
70% stays on the wall.

The 70% that stays on the wall is addressed by liquid conductivity (capillary flow) and vapor diffusion.

We assume 1% of the 70% penetrates to the back side of the cladding.

We further assume that 1% of the 1% gets past the water control layer into the sheathing.
Insulating glass unit

Seal (gasket)

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
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.
Interesting Complications
Rain Screen
Beer Screen?
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Diagram: Three rectangular blocks of varying colors and sizes, possibly representing different processes or categories in the context of heat, air, and moisture transfer.