Order of Magnitude
1 to 10
10 to 100
100 to 1000
1000 to 10000
First Order Effects, Second Order Effects....
Arrhenius Equation

For Every 10 Degree K Rise
Activation Energy Doubles

\[ k = Ae^{-E_a/(RT)} \]
Damage Functions
Water
Heat
Ultra-violet Radiation

Vapor Pressure and Relative Humidity
2T, 75°F  
1T  
RH = 50%  

1T  
RH = 100%

2T, 75°F  
1T  
RH = 50%  

1/2T  
RH = 75%

90°F  
50% RH  

75°F  
50% RH  

60°F  
50% RH  

45°F  
50% RH  

30°F  
50% RH
Laws of Thermodynamics

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
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

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 studspace
RSI 1.40 insulated sheathing

Cooling and condensation
From Straube & Burnett, 2005

Sorption Isotherms
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**
Average sorption isotherm for wood as a function of temperature
From Straube & Burnet, 2005
Moisture Transport in Porous Media

<table>
<thead>
<tr>
<th>Phase</th>
<th>Transport Process</th>
<th>Driving Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vapor</td>
<td>Diffusion</td>
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<tr>
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<td>Surface Diffusion</td>
<td>Concentration</td>
</tr>
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<td>Liquid</td>
<td>Capillary Flow</td>
<td>Suction Pressure</td>
</tr>
<tr>
<td></td>
<td>Osmosis</td>
<td>Solute Concentration</td>
</tr>
</tbody>
</table>
# Moisture Transport in Assemblies

<table>
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</thead>
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<td>Solute Concentration</td>
</tr>
<tr>
<td></td>
<td>Gravitational Flow</td>
<td>Height</td>
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<tr>
<td></td>
<td>Surface Tension</td>
<td>Surface Energy</td>
</tr>
<tr>
<td></td>
<td>Momentum</td>
<td>Kinetic Energy</td>
</tr>
<tr>
<td></td>
<td>Convective Flow</td>
<td>Air Pressure</td>
</tr>
</tbody>
</table>

**Vapor**

**Liquid**
Building Science Corporation

Joseph Lstiburek

University of Toronto
Physics
May 16, 2016

Lstiburek
© buildingscience.com
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- "non-wettable" surface
- water repellant surface
- hygroscopic 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"
Calculating capillary rise

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

Capillary rise versus diameter

![Graph showing capillary rise versus diameter](image)
Heat
Air
Moisture

HAM
Hygrothermal Analysis
Don’t Do Stupid Things
Figure 8.1: Outside vapour pressure, saturated vapour pressure and inside vapour pressure for Winnipeg.
The inside face of the roof sheathing forming the cavity is the first condensing surface.

- OSB or plywood nail base for shingles
- R-30 unfaced batt ceiling insulation compressed to fit within 2x6 rafters or spray cellulose or "naked" dry blown cellulose or fiberglass
- R-5 rigid insulation (vertical and horizontal joints offset from roof sheathing)

- Sealing
- Vinyl or aluminum siding
- Rigid insulation notched around roof rafters and sealed
- Unfaced batt insulation
- Gypsum board ceiling with semi-vapor permeable (latex) paint
- Caulking or sealant
- Gypsum board with semi-vapor permeable (latex) paint
- Vinyl or aluminum siding
Figure 1
Water Vapor Permeance of Hygroscopic Materials

Figure 2
Moisture Content vs. Relative Humidity

The amount of bound water in wood is determined by the relative humidity (RH) of the surrounding atmosphere; the amount of bound water changes little when the relative humidity changes. The moisture content of wood, where a balance is established at a given relative humidity, is its equilibrium moisture content (EMC). The solid line represents the curve for a white species, a typical species with fiber saturation point (FSP) around 30%, EMC for species with a high extractive content, such as mahogany, FSP is around 45%, and for those with low extractive content, such as teak, FSP may be as high as 55%. Although a precise curve cannot be drawn for each species, most will fall within the color band.
Rain Screen
Beer Screen?
Leaky air handling unit and supply ducts

Depressurized conditioned space inducing infiltration

Note: Colored shading depicts the building’s thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.
Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.
Figure 6.10
HVAC System as Designed
Figure 5.11
Untended Pressurization of Interstitial Cavity

Figure 5.12
Modified Pressure Relationship
Gravel protective cover
Top pour
Felt ply
Interply layers
Adhering layer
Deck, insulation or cover board
