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
Thermodynamics
Zeroth Law – A=B and B=C therefore A=C
First Law - Conservation of Energy
Second Law - Entropy
Third Law – Absolute Zero
2\textsuperscript{nd} Law of Thermodynamics
In an isolated system, a process can occur only if it increases the total entropy of the system

Rudolf Clausius
There Is No Such Thing As A Free Thermodynamic Lunch
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
Hygrothermal Analysis
Solar radiation

Rain

Heat exchange with outdoors

Vapor exchange with outdoors

Heat exchange with indoors

Vapor exchange with indoors
Firmness, Commodity and Delight

“These are properly designed, when due regard is had to the country and climate in which they are erected. For the method of building which is suited to Egypt would be very improper in Spain, and that in use in Pontus would be absurd at Rome: so in other parts of the world a style suitable to one climate, would be very unsuitable to another”

Marcus Vitruvius Pollio (c.90-20 B.C.E.)
Arrhenius Equation
For Every 10 Degree K Rise
Activation Energy Doubles

\[ k = A e^{-E_a/(RT)} \]
Damage Functions
Water
Heat
Ultra-violet Radiation
The Three Biggest Problems In Buildings Are Water, Water and Water…
Solid (ice) → Melt → Liquid (water)

Solid (ice) → Freeze → Liquid (water)

Solid (ice) → Sublime → Gas (vapor)

Liquid (water) → Condense → Gas (vapor)

Liquid (water) → Evaporate → Gas (vapor)

Gas (vapor) → Adsorb → Adsorbed (surface layers)

Gas (vapor) → Desorb → Adsorbed (surface layers)
### 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>
<td>Vapor Concentration</td>
</tr>
<tr>
<td>Adsorbate</td>
<td>Surface Diffusion</td>
<td>Concentration</td>
</tr>
<tr>
<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>
<thead>
<tr>
<th>Phase</th>
<th>Transport Process</th>
<th>Driving Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vapor</td>
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<td>Vapor Concentration</td>
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<tr>
<td></td>
<td>Convective Flow</td>
<td>Air Pressure</td>
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<td>Adsorbate</td>
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<tr>
<td></td>
<td>Osmosis</td>
<td>Solute Concentration</td>
</tr>
<tr>
<td></td>
<td>Gravitational Flow</td>
<td>Height</td>
</tr>
<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>
Microclimates and Materials Science
Calculating capillary rise

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

Where:
- \( h \) is the capillary rise height.
- \( \sigma \) is the surface tension of the liquid.
- \( \theta \) is the contact angle.
- \( g \) is the acceleration due to gravity.
- \( \rho \) is the density of the liquid.
- \( r \) is the radius of the capillary tube.

The diagram illustrates the forces at play, including the capillary pressure \( P_{\text{cap}} \), the ambient pressure, and the gravitational forces acting on the liquid column.
Capillary rise versus diameter
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

From Hutcheon & Handegord, 1983
Monolayers of adsorbed water increase with increasing RH
Monolayers flow along surface following concentration gradient
Environmental Loads
Rain Exposure Zone
Hygro-thermal Regions
Interior Climate Class
Water Control Layer
Air Control Layer
Vapor Control Layer
Thermal Control Layer
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)
Insulated wood stud cavity
Gypsum board
Latex paint or vapor semi-permeable textured wall finish

Vapor Profile
Commercial Enclosure: Simple Layers

- Structure
- Rain/Air/Vapor
- Insulation
- Finish
Stucco
Bond Break
Dramix Matt
Slab
Sealant
Dramix Matt
Water Management
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

Cup can still drain water to exterior

Entire wind pressure taken here
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
Outer seal sees water but not pressure; no pressure difference across this seal, therefore no rain entry.

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

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

Air enters and pressurizes chamber.

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
Sealant backer rod

Inner seal

Wind pressurizes chamber between inner and outer seal

Sealant backer rod

Outer seal

Vent tube
Inner, protected seal

Outer, exposed seal

Drain and vent opening
<table>
<thead>
<tr>
<th>Pascals</th>
<th>mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 Pa</td>
<td>20 mph</td>
</tr>
<tr>
<td>100 Pa</td>
<td>30 mph</td>
</tr>
<tr>
<td>150 Pa</td>
<td>35 mph</td>
</tr>
<tr>
<td>250 Pa</td>
<td>45 mph</td>
</tr>
<tr>
<td>500 Pa</td>
<td>65 mph</td>
</tr>
<tr>
<td>1,000 Pa</td>
<td>90 mph</td>
</tr>
</tbody>
</table>

Wind Speed (mph) vs. Stagnation Pressure (Pa)
Rain Screen
Beer Screen?
All We Have To Figure Out Is How Much Hits The Wall
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.
Rain penetrating water control layer

Rain penetrating cladding

Incident rain

Rain “bounce”
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

1/3 quart of water

4x8 sheet of gypsum board with a 1 in² hole
Interior at 70°F and 40% RH

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

1 1/2 pints of water

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

14 pints of water
PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL
Don’t Do Stupid Things
Exterior sheathing

Dewpoint (50% RH, 70°F)

Location of condensation and frost

70°F

0°F

Outside

Inside
Simple linearized energy-temperature relation for water
From Straube & Burnett, 2005
The inside face of the exterior sheathing is the condensing surface of interest.

- Wood-based siding
- Building paper
- Exterior sheathing
- R-19 cavity insulation in wood frame wall
- Gypsum board with any paint or wall covering

The graph shows the monthly temperature variation with the potential for condensation. The dew point temperature is indicated at specific relative humidity levels (50%, 35%, and 20%) and is compared to the mean monthly outdoor temperature. The shaded area represents the potential for condensation.
The inside face of the insulating sheathing is the condensing surface of interest.

- Wood-based siding
- R-7.5 rigid insulation
- R-13 cavity insulation in wood frame wall
- Gypsum board with any paint or wall covering

Mean monthly outdoor temperature

Insulation/sheathing interface temperature (R-7.5 sheathing, R-13 cavity insulation as shown in adjacent drawing)

Potential for condensation

Dew point temp. at 35% R.H., 70°F

Month:
- APR
- MAY
- JUN
- JUL
- AUG
- SEP
- OCT
- NOV
- DEC
- JAN
- FEB
- MAR
- APR
- MAY
Figure 8-7. Outside vapour pressure, saturated vapour pressure and inside vapour pressure for Winnipeg.
Outside

Roof sheathing

Condensation and frost accumulating on underside of roof sheathing

Attic

Attic insulation

Inside

Dewpoint