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Building Science

Air-Vapor Moisture Physics

presented by www.buildingscience.com

Moisture and Buildings

- Moisture is involved in almost all building envelope performance problems
  - In-service .... Durability
- Examples:
  - rot,
  - corrosion,
  - mould (IAQ)
  - termites, (!),
  - staining
  - etc.

Moisture Damage

- Damage caused by
  - Very high humidity for a long time
  - Wet (100%RH) for a shorter time
- Time required depends
  - on material
  - Temperature
- Temperature
  - Accelerates slows or stops process

Moisture Control

- Moisture-related Problems
  1. **Moisture** must be available
  2. There must be a route or **path**
  3. There must be a **force** to cause movement
  4. The material must be **susceptible** to damage
- Theory:
  – eliminate any one for complete control
- Practice:
  – control as many as possible

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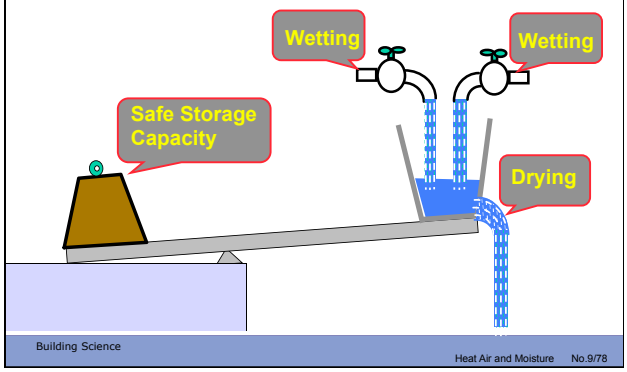
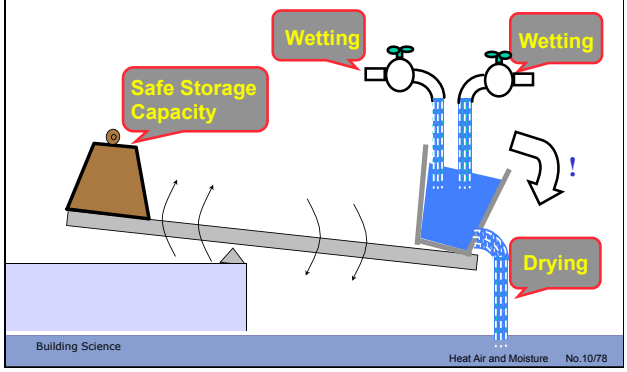
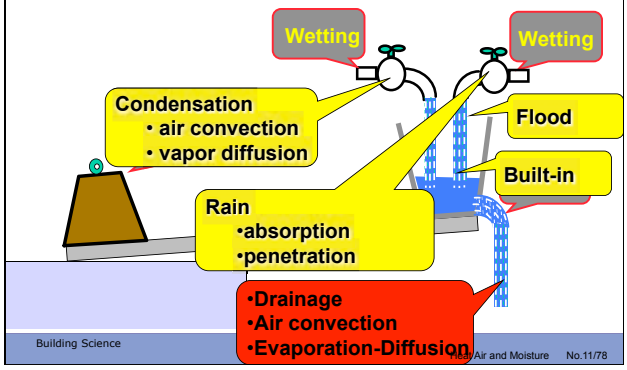
Moisture Balance



Moisture Balance: Accumulation

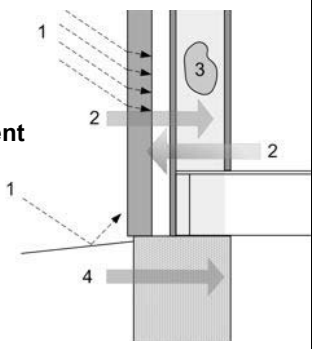


Moisture Balance



Wall + Roof Wetting
Sources/ Mechanisms

1. **Rain**
   – absorption
   – penetration
   – splash and drips
2. **Water Vapor Movement**
   – Diffusion
   – Convection (air leaks)
3. **Built in**
4. **Ground**
   – Capillary (wicking)
   – Gravity
   – Diffusion



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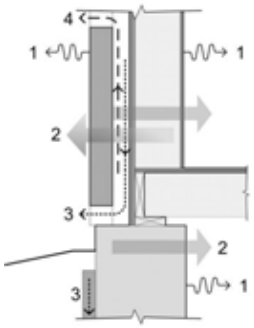
Wall + Roof Drying
Sinks and Mechanisms

1. **Surface Evaporation**
   - Wicking to surface
2. **Vapor Movement**
   i) Diffusion
   ii) Convection
3. **Drainage**
4. **Intentional Convection** = Ventilation Drying



Note above and below grade

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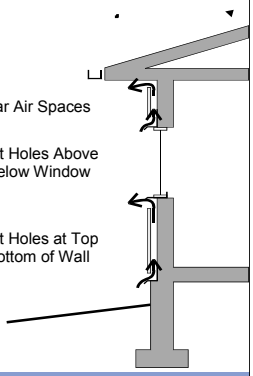
Ventilation Drying

- **Ventilation provides drying to the exterior**
- Can be important for:
  1. **vapor impermeable cladding**
     - metal panels
     - most roofing
  2. **systems which retain rainwater**
     - Improves survivability of small rain leaks and condensation



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Storage

- Bridges gap in time between wetting and drying
- How much moisture for how long before damage
- *Safe* storage: safe against what?
  - mold, rot, freeze-thaw, corrosion
- Basic mechanisms
  - Absorbed into materials= capillary pores (*bound liquid*)
  - Adsorbed to materials = sorption (*vapor*)
  - pools and puddles (*free liquid*)

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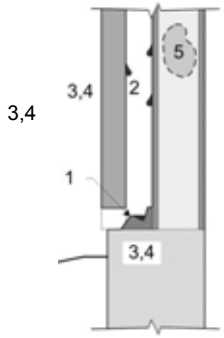
Moisture Storage in Assemblies

1. Trapped / undrained
2. Surface tension
   - Liquid or solid
3. Adsorbed
4. Absorbed
5. Vapor
   - small



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Design Choices

- Either avoid wetting
- Or, provide enough drying to accommodate wetting
- Depending on the storage provided

The balance has shifted over time

- *Amount* of storage has changed over last 100 yrs
  - e.g. steel stud, vs wood stud vs concrete block
  - 1: 10 : 100+
- Wetting is usually less
- Drying is often much less

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Design Solutions

- *Balance* wetting, drying, and storage
- Practical Rules
  - Provide a continuous plane of rain control including each enclosure detail
  - Provide continuous air barriers and insulation to control condensation problems
  - Allow drying of built-in and accidental moisture – beware drying retarders

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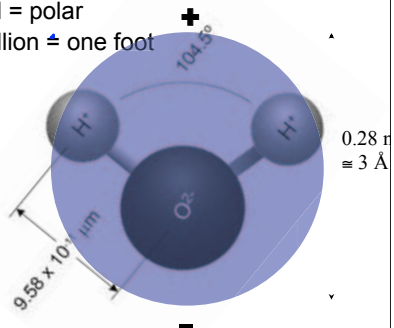
The Water Molecule

- Asymmetrical = polar
- Small: one billion ≐ one foot



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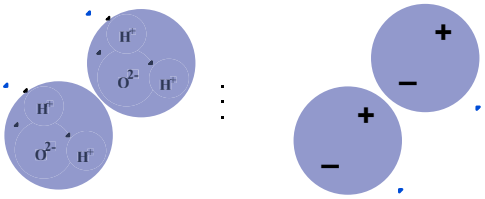
The Polar Molecule

- Hydrogen end is “more” positive
- Oxygen end is “more” negative



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Surface Tension: Wettable

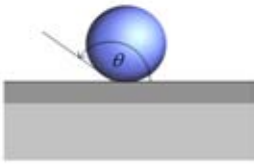
Water attracted to surface more than self

$\theta < 90°$

normal material: “wettable”

Water attracted to self more than surface

$\theta > 90°$



hydrophobically treated: “non-wettable”

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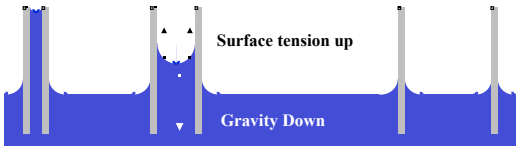
Capillary Pressures

- Result of surface tension = attraction to surfaces
  - pressure varies with pore size
  - e.g., height rise in a glass tube



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Surface Tension

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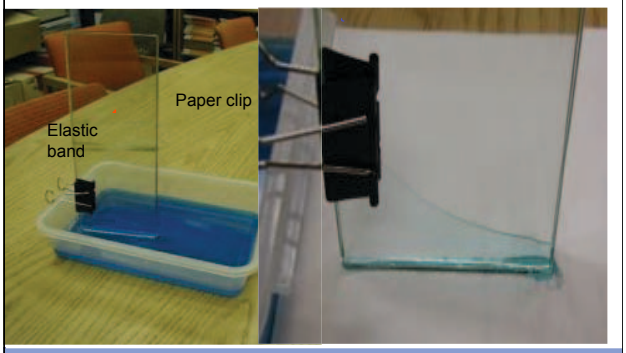
Capillary rise between glass sheets



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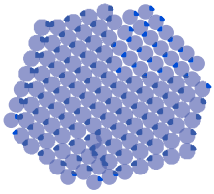
Water: Liquid vs Vapor

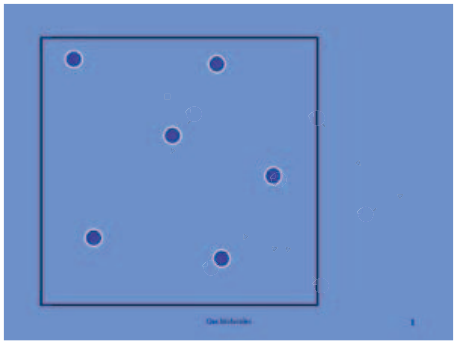
- Vapor is a single molecule
- Liquid is molecular clumps, 60 or more
- Tyvek vs asphalt

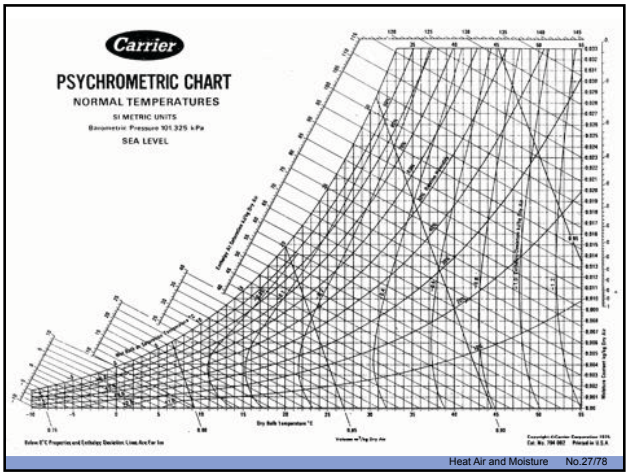
Vapor



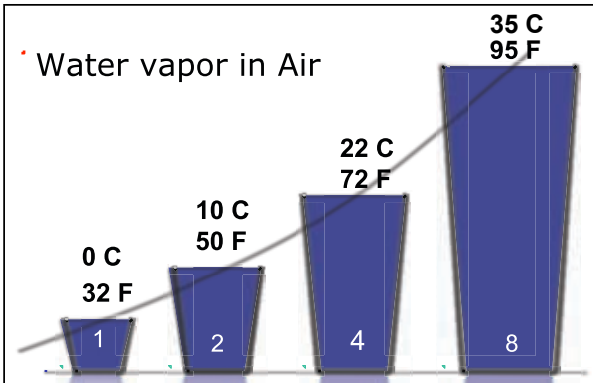
Liquid

Vapor Pressure: water as a gas

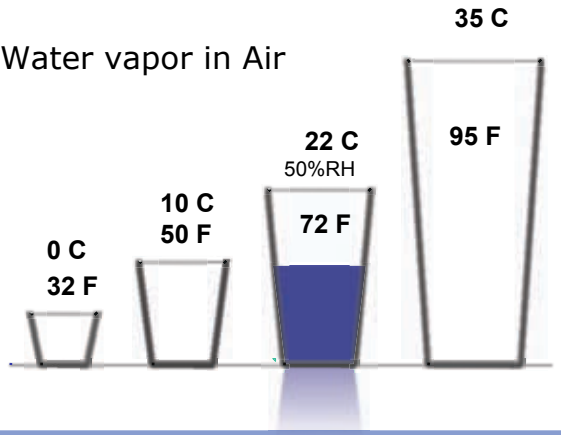




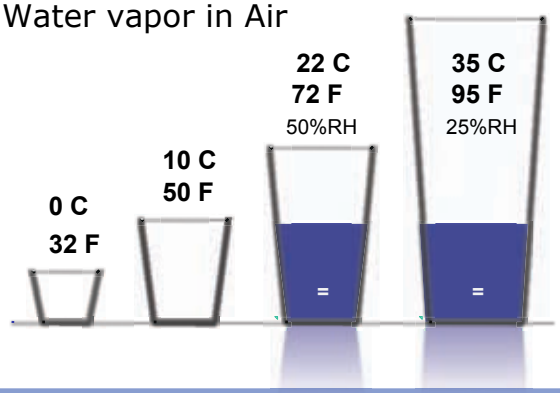
Water vapor in Air

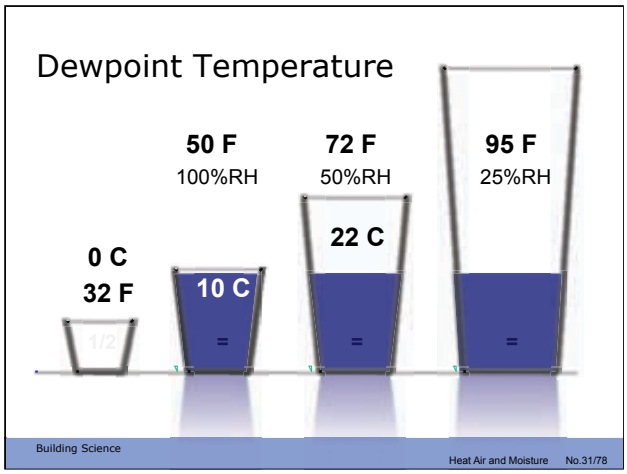


Water vapor in Air



Water vapor in Air




Dewpoint Temperature
50 F
100%RH
72 F
50%RH
95 F
25%RH
0 C
32 F
10 C
22 C
1/2
=
=
=
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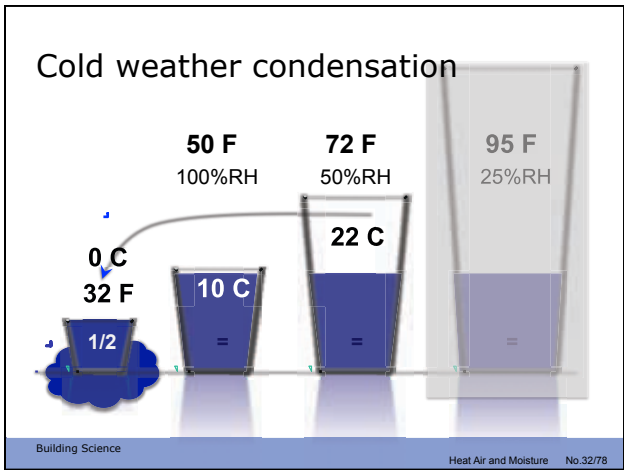
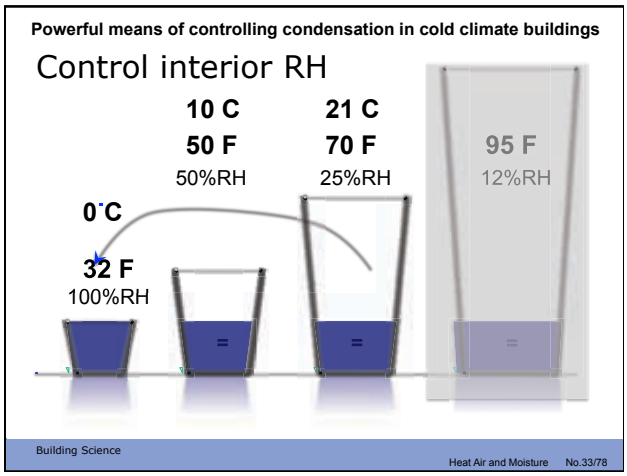
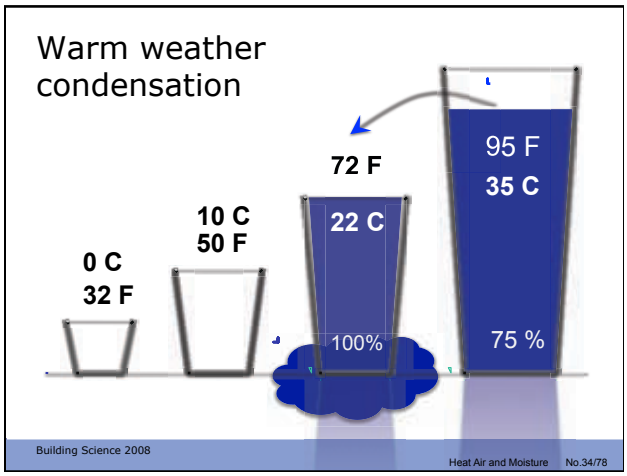
No.31/78


Cold weather condensation
50 F
100%RH
72 F
50%RH
95 F
25%RH
0 C
32 F
10 C
22 C
1/2
=
=
=
Building Science
Heat Air and Moisture
No.32/78


Powerful means of controlling condensation in cold climate buildings
Control interior RH
10 C
50 F
50%RH
21 C
70 F
25%RH
95 F
12%RH
0 C
32 F
100%RH
=
=
=
Building Science
Heat Air and Moisture
No.33/78


Warm weather condensation
72 F
95 F
35 C
10 C
50 F
22 C
0 C
32 F
100%
75 %
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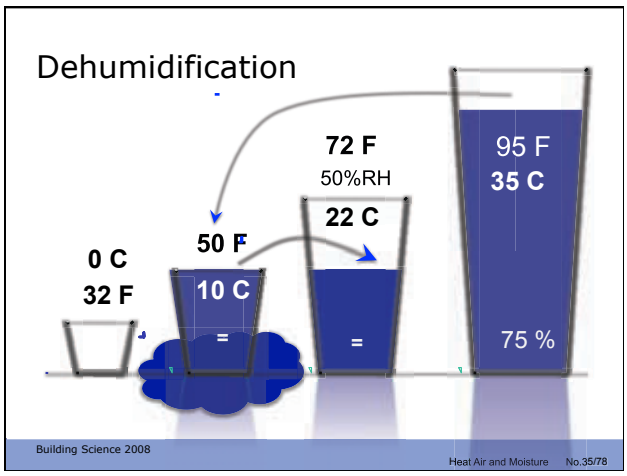
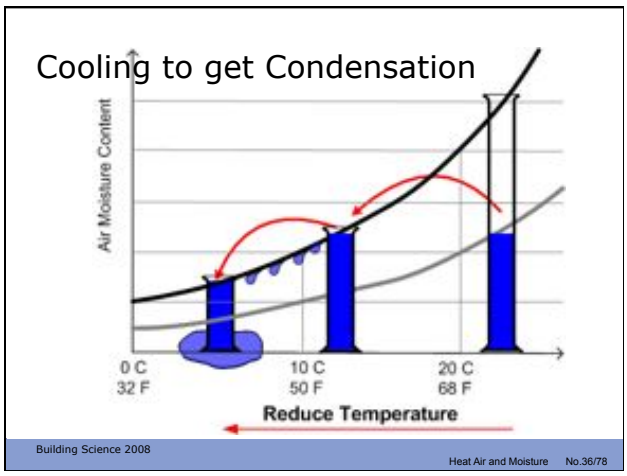
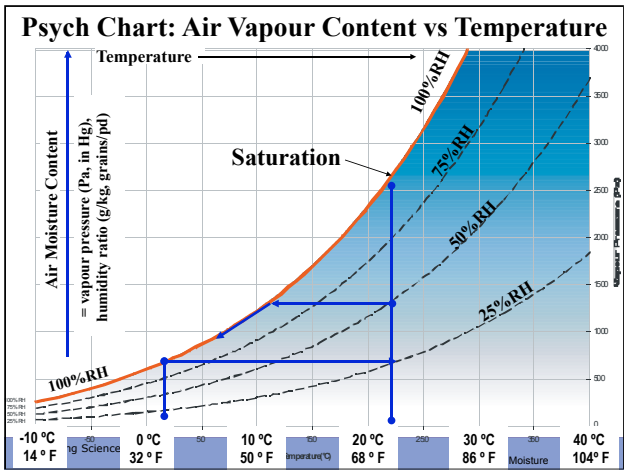
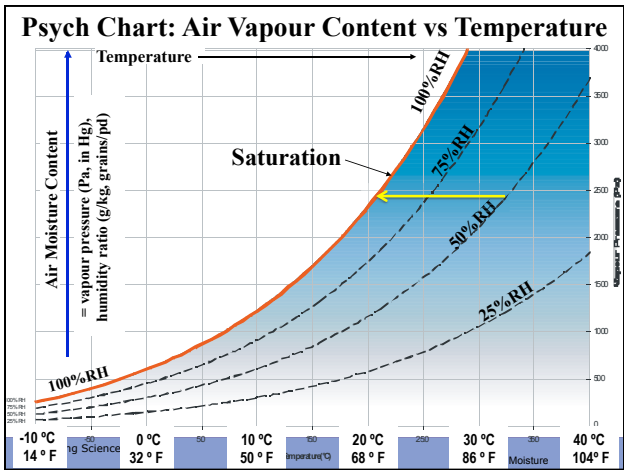
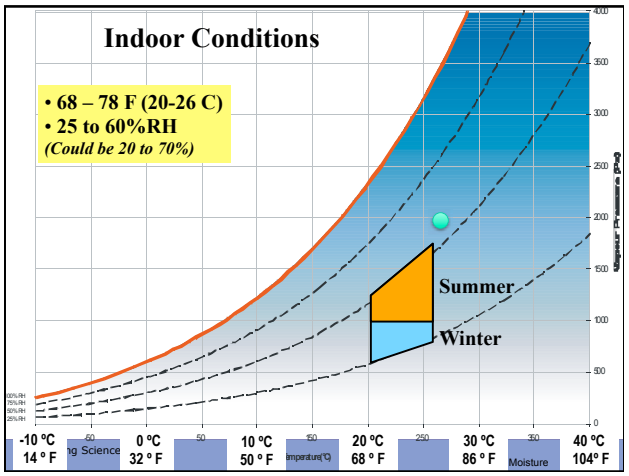
Heat Air and Moisture
No.34/78

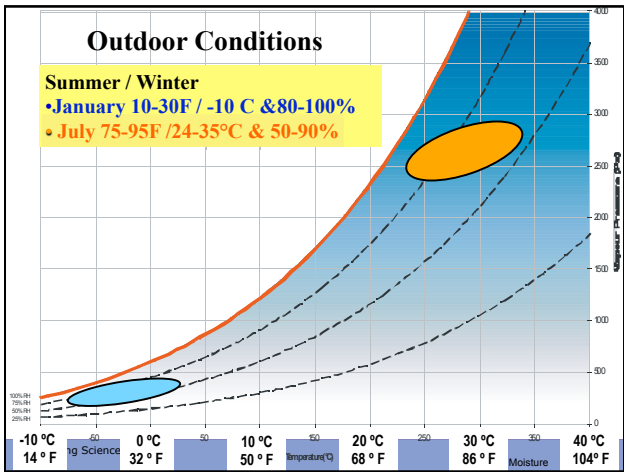

Dehumidification
72 F
50%RH
95 F
35 C
22 C
50 F
0 C
32 F
10 C
=
=
75 %
Building Science 2008
Heat Air and Moisture
No.35/78

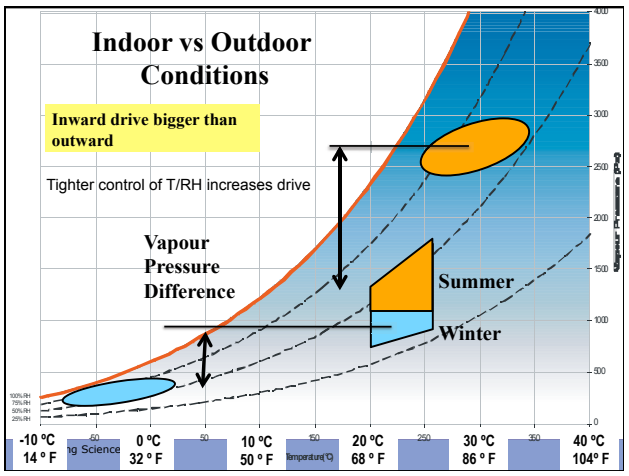

Cooling to get Condensation
Air Moisture Content
0 C
32 F
10 C
50 F
20 C
68 F
Reduce Temperature
Building Science 2008
Heat Air and Moisture
No.36/78

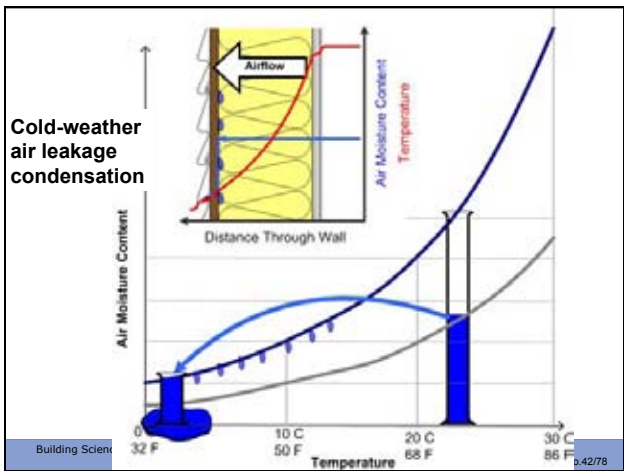

Psych Chart: Air Vapour Content vs Temperature
Temperature
Air Moisture Content
= vapour pressure (Pa, in Hg), humidity ratio (g/kg, grains/pd)
Saturation
100%RH
75%RH
50%RH
25%RH
100%RH
-10 °C 14 ° F
0 °C 32 ° F
10 °C 50 ° F
20 °C 68 ° F
30 °C 86 ° F
40 °C 104° F
Moisture


Psych Chart: Air Vapour Content vs Temperature
Temperature
Air Moisture Content
= vapour pressure (Pa, in Hg), humidity ratio (g/kg, grains/pd)
Saturation
100%RH
75%RH
50%RH
25%RH
100%RH
-10 °C 14 ° F
0 °C 32 ° F
10 °C 50 ° F
20 °C 68 ° F
30 °C 86 ° F
40 °C 104° F
Moisture


Indoor Conditions
• 68 – 78 F (20-26 C)
• 25 to 60%RH
(Could be 20 to 70%)
Summer
Winter
-10 °C 14 ° F
0 °C 32 ° F
10 °C 50 ° F
20 °C 68 ° F
30 °C 86 ° F
40 °C 104° F
Moisture

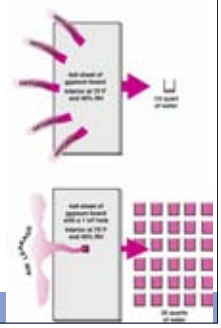

Outdoor Conditions
Summer / Winter
•January 10-30F / -10 C &80-100%
• July 75-95F /24-35°C & 50-90%
-10 °C 14 ° F
0 °C 32 ° F
10 °C 50 ° F
20 °C 68 ° F
30 °C 86 ° F
40 °C 104° F
Moisture

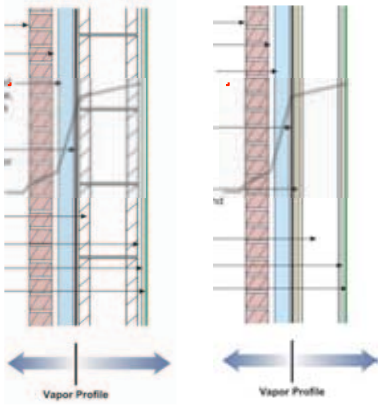

Indoor vs Outdoor Conditions
Inward drive bigger than outward
Tighter control of T/RH increases drive
Vapour Pressure Difference
Summer
Winter
-10 °C 14 ° F
0 °C 32 ° F
10 °C 50 ° F
20 °C 68 ° F
30 °C 86 ° F
40 °C 104° F
Moisture

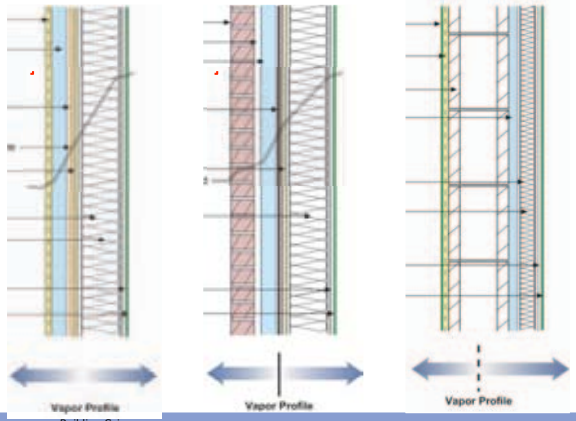

Cold-weather air leakage condensation
Airflow
Air Moisture Content
Temperature
Distance Through Wall
Air Moisture Content
32 F
10 C 50 F
20 C 68 F
30 C 86 F
Temperature

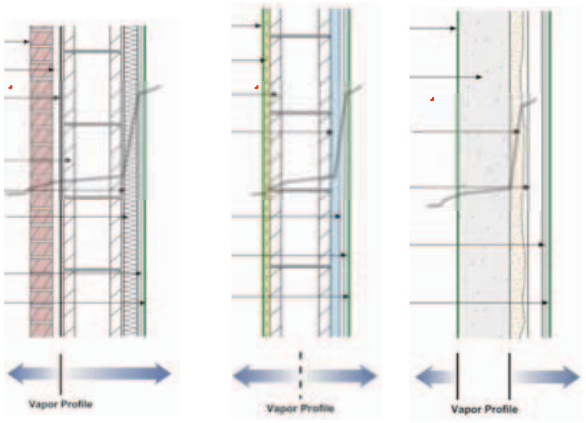
Air leakage

- Much more vapor can be carried on back of air flow than diffusion
- Condensation only happens if air flows towards cold surface

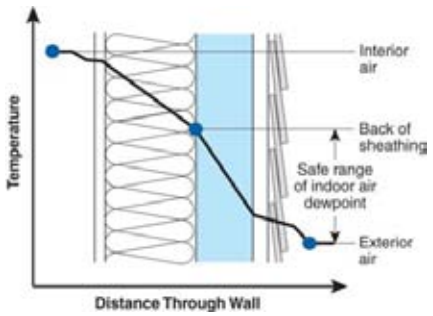




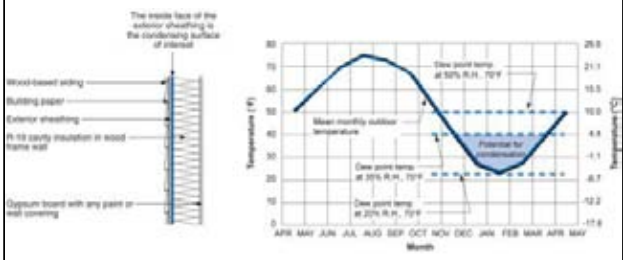




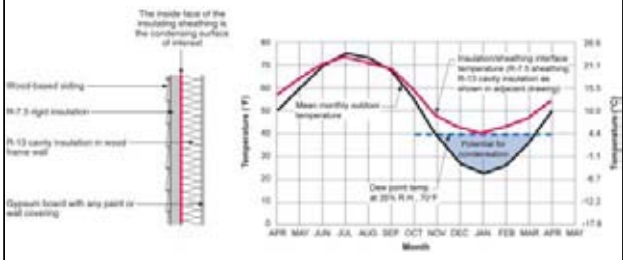
$T_{back\ of\ sheathing} = T_{interior} - (T_{interior}-T_{exterior})\ R_{batt}/R_{total}$

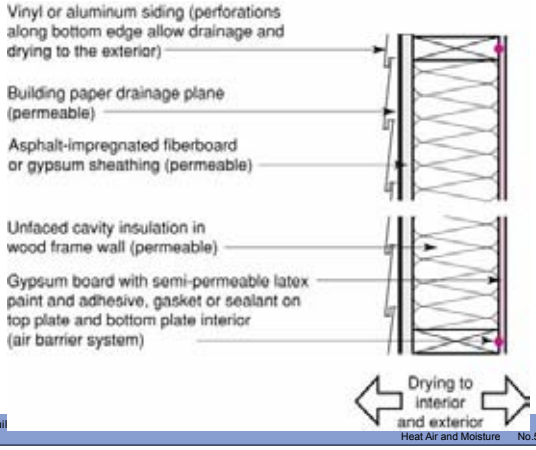


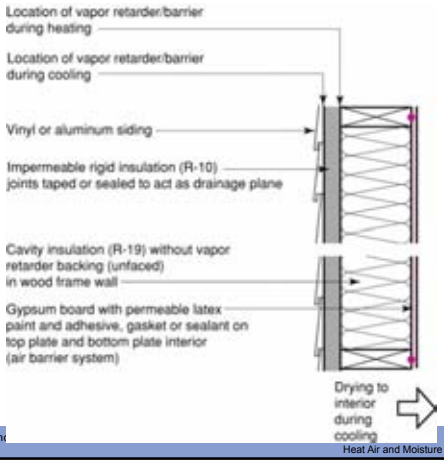
No exterior sheathing

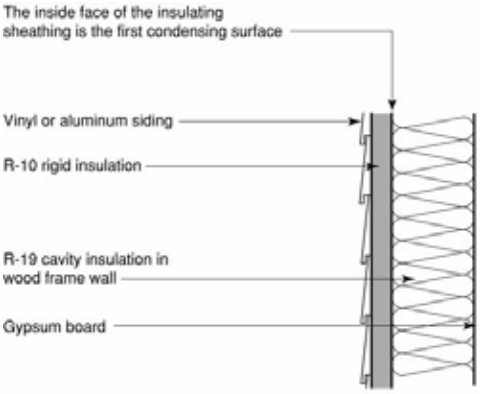


With exterior insulation



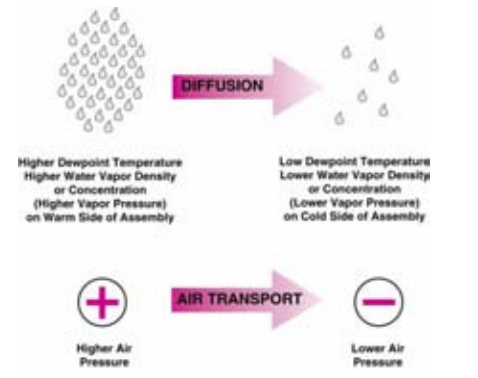


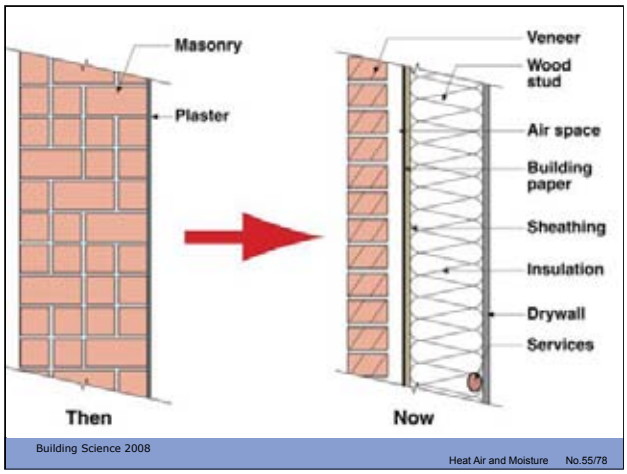


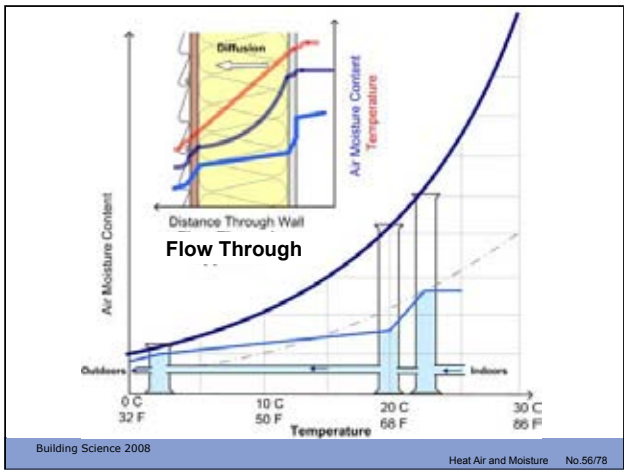


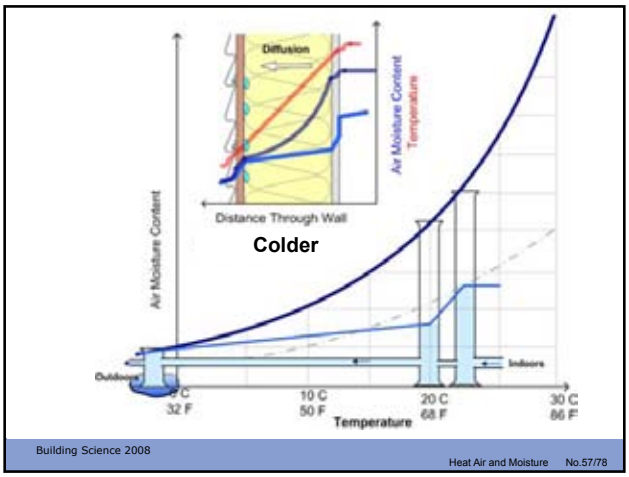
Water Vapour Transport

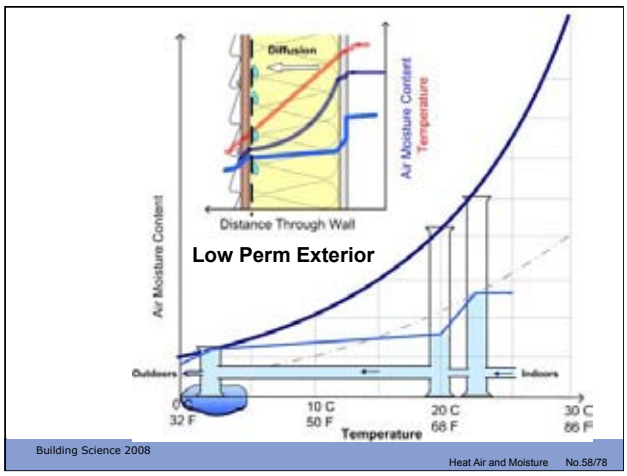
- Vapour Diffusion (like heat conduction)
  - more to less vapor
  - No air flow
  - Flow through tiny pores
- Air Convection (like heat convection)
  - more to less air pressure
  - flow through visible cracks and holes
  - vapour is just along for the ride

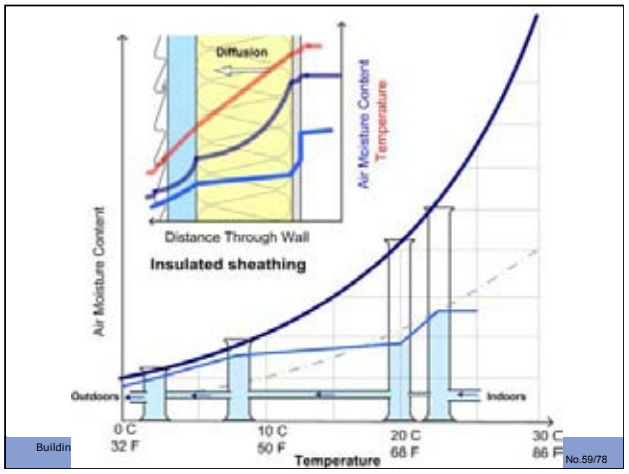


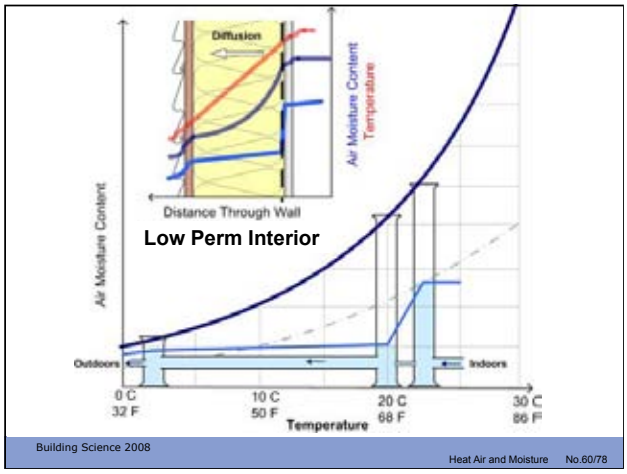

Masonry
Plaster
Veneer
Wood stud
Air space
Building paper
Sheathing
Insulation
Drywall
Services
Then
Now
Building Science 2008
Heat Air and Moisture No.55/78

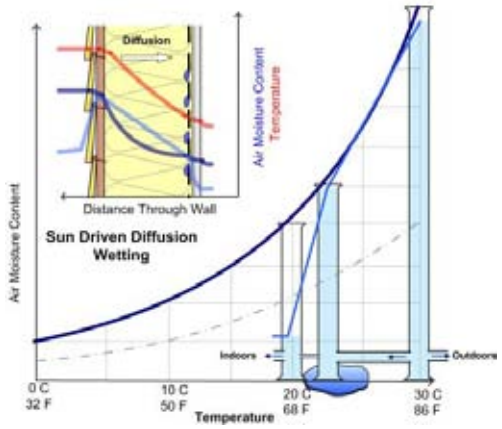

Diffusion
Air Moisture Content
Temperature
Distance Through Wall
Flow Through
Air Moisture Content
Outdoors
Indoors
0 C 32 F
10 C 50 F
20 C 68 F
30 C 86 F
Temperature
Building Science 2008
Heat Air and Moisture No.56/78


Diffusion
Air Moisture Content
Temperature
Distance Through Wall
Colder
Air Moisture Content
Outdoors
Indoors
0 C 32 F
10 C 50 F
20 C 68 F
30 C 86 F
Temperature
Building Science 2008
Heat Air and Moisture No.57/78


Diffusion
Air Moisture Content
Temperature
Distance Through Wall
Low Perm Exterior
Air Moisture Content
Outdoors
Indoors
0 C 32 F
10 C 50 F
20 C 68 F
30 C 86 F
Temperature
Building Science 2008
Heat Air and Moisture No.58/78


Diffusion
Air Moisture Content
Temperature
Distance Through Wall
Insulated sheathing
Air Moisture Content
Outdoors
Indoors
0 C 32 F
10 C 50 F
20 C 68 F
30 C 86 F
Temperature
Buildin
No.59/78


Diffusion
Air Moisture Content
Temperature
Distance Through Wall
Low Perm Interior
Air Moisture Content
Outdoors
Indoors
0 C 32 F
10 C 50 F
20 C 68 F
30 C 86 F
Temperature
Building Science 2008
Heat Air and Moisture No.60/78



Conclusions

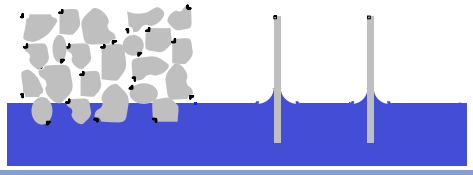
- Air can store much more water vapor as temperature increases
- Water vapor moves in two modes
  - Diffusion (vapor control)
  - Air Leakage (air control)
- Vapor control is less important
- Air control requires all holes sealed

Liquid Transport: Capillary Flow

- Surface tension drives water uptake
- Flow rate depends on size of opening
  - Small pores – high suction, low flow
  - Large pores – low suction, high flow

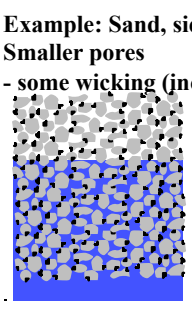
Capillary Flow

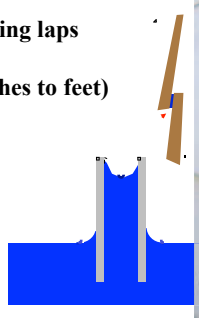
- Solution: use gaps
- Large pores - no suction (no “wicking”)
- Eg. : Crushed stone, air gaps
- Gravity flow allows drainage

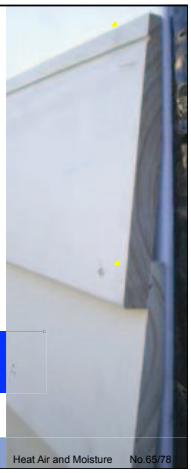


Capillary Flow

Example: Sand, siding laps
Smaller pores
- some wicking (inches to feet)







Capillary Flow- concrete sucks

Example: Clay or silt
Wicking (dozens - hundreds of ft)