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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.

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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

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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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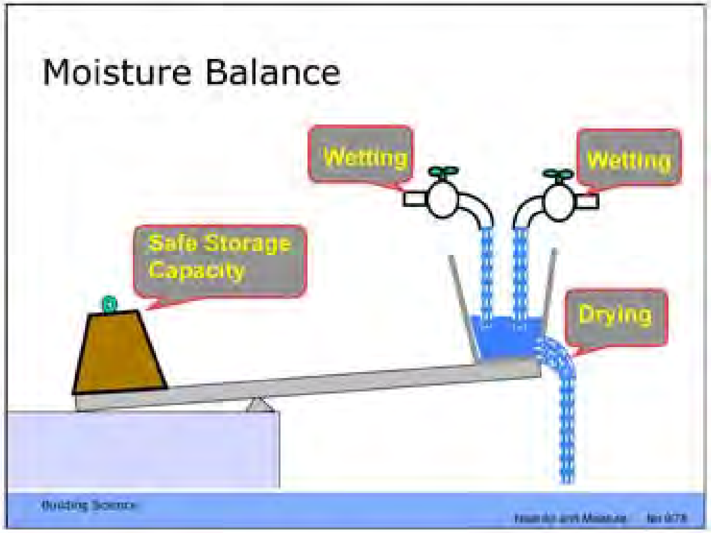
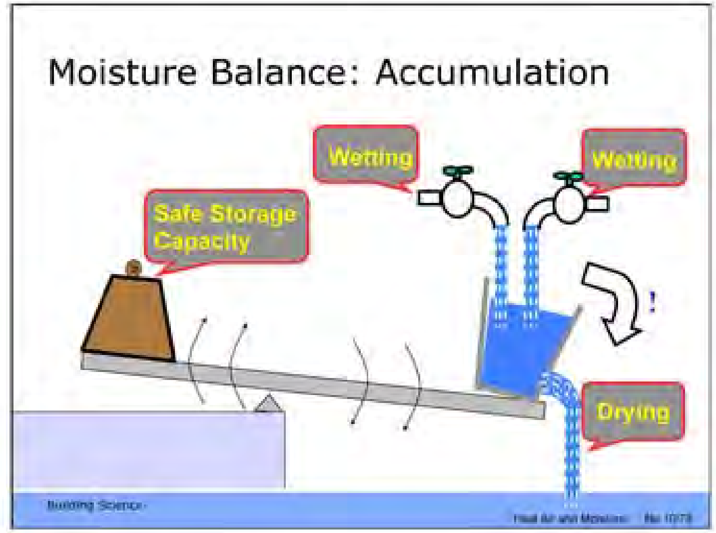
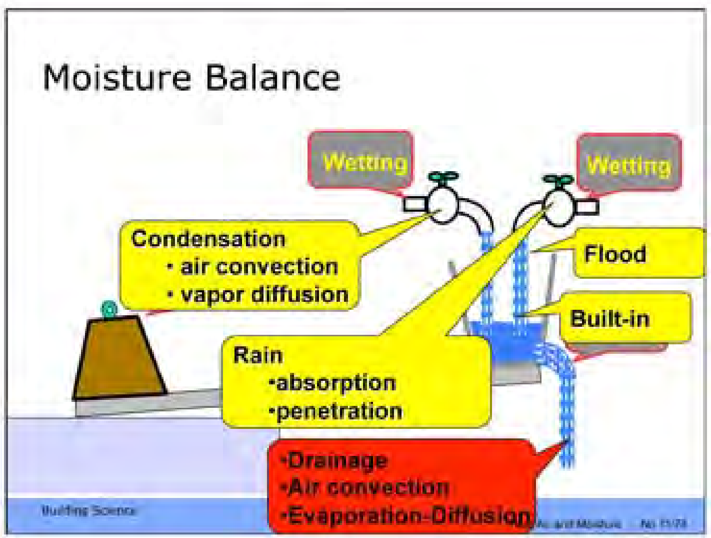

Moisture Balance
Wetting
Wetting
Safe Storage Capacity
Drying
Building Science


Moisture Balance: Accumulation
Wetting
Wetting
Safe Storage Capacity
!
Drying
Building Science


Moisture Balance
Wetting
Wetting
Condensation
• air convection
• vapor diffusion
Flood
Built-in
Rain
•absorption
•penetration
•Drainage
•Air convection
•Evaporation-Diffusion
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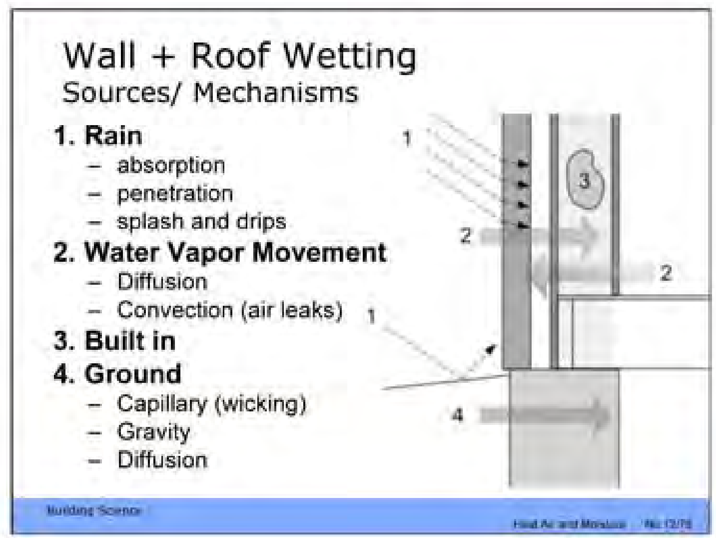
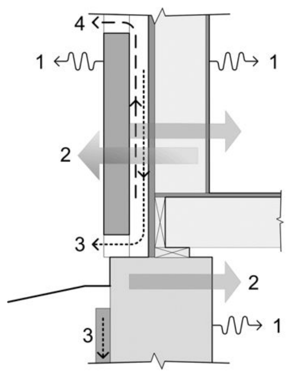

Wall + Roof Wetting
Sources/ Mechanisms
1. Rain
– absorption
– penetration
– splash and drips
2. Water Vapor Movement
– Diffusion
– Convection (air leaks)
3. Built in
4. Ground
– Capillary (wicking)
– Gravity
– Diffusion
1
2
3
2
1
4
Building Science

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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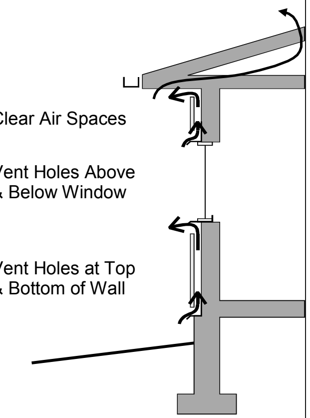
Ventilation Drying

- **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

Clear Air Spaces

Vent Holes Above & Below Window

Vent Holes at Top & Bottom of Wall



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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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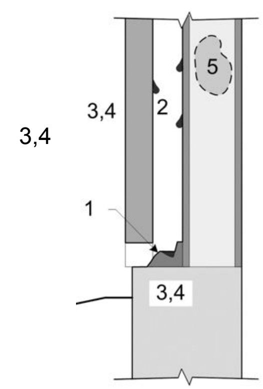
Moisture Storage in Assemblies

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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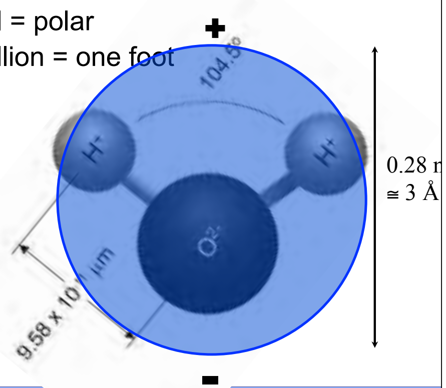
The Water Molecule

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



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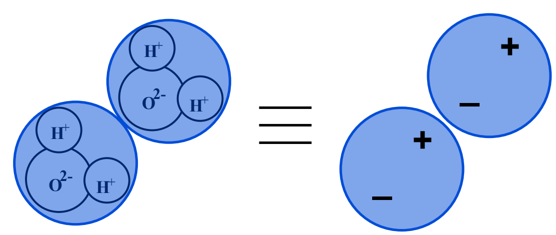
The Polar Molecule

- Hydrogen end is "more" positive
- Oxygen end is "more" negative



Building Science 2008 Heat Air and Moisture No.20/78

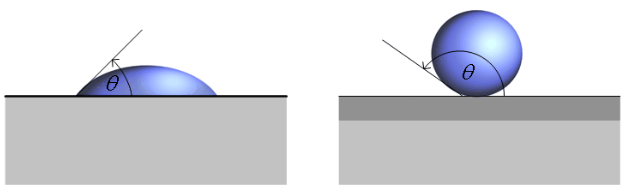
Surface Tension: Wettable

Water attracted to surface more than self

$\theta < 90^{o}$

Water attracted to self more than surface

$\theta > 90^{o}$



normal material: “wettable”

hydrophobically treated: “non-wettable”

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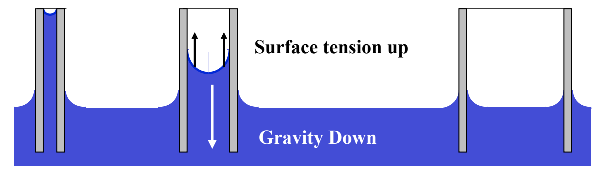
Heat Air and Moisture No.21/78

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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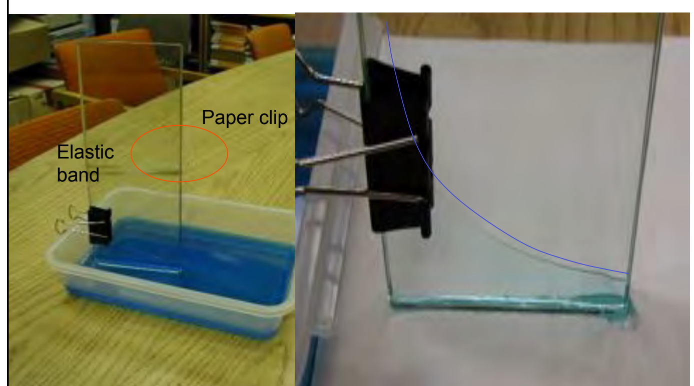
Heat Air and Moisture No.23/78

Capillary rise between glass sheets



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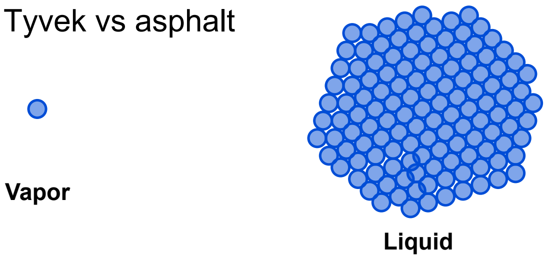
Heat Air and Moisture No.24/78

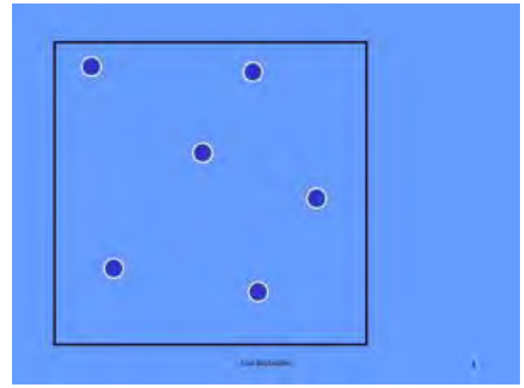
Water: Liquid vs Vapor

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

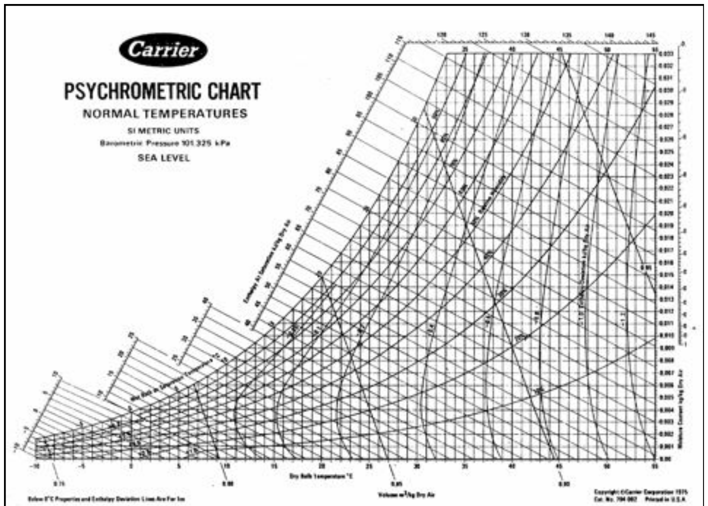


Building Science 2008 Heat Air and Moisture No.25/78

Vapor Pressure: water as a gas

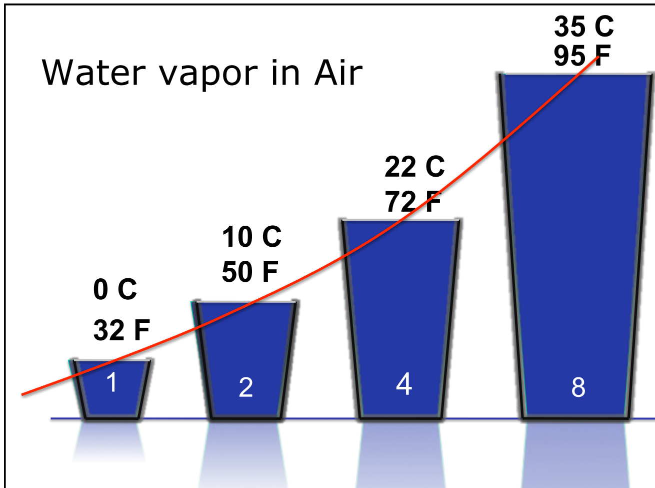


Building Science 2008 Heat Air and Moisture No.26/78

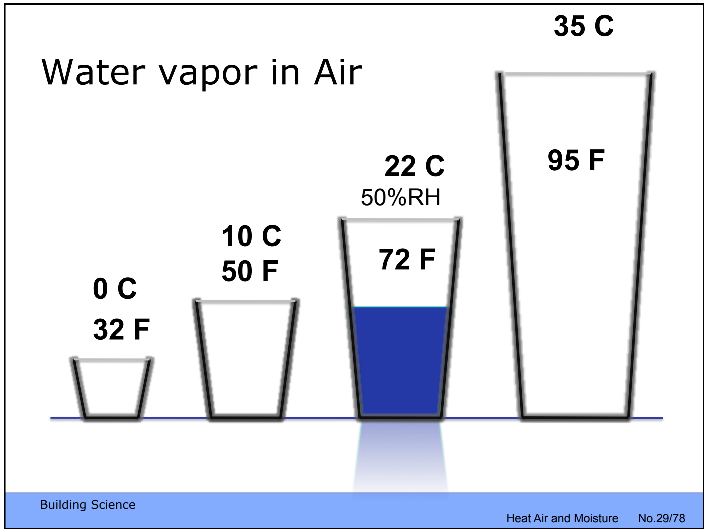


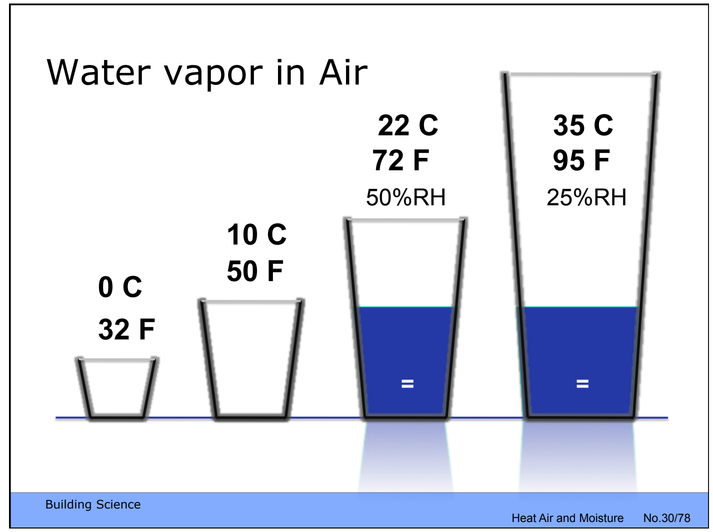
Heat Air and Moisture No.27/78

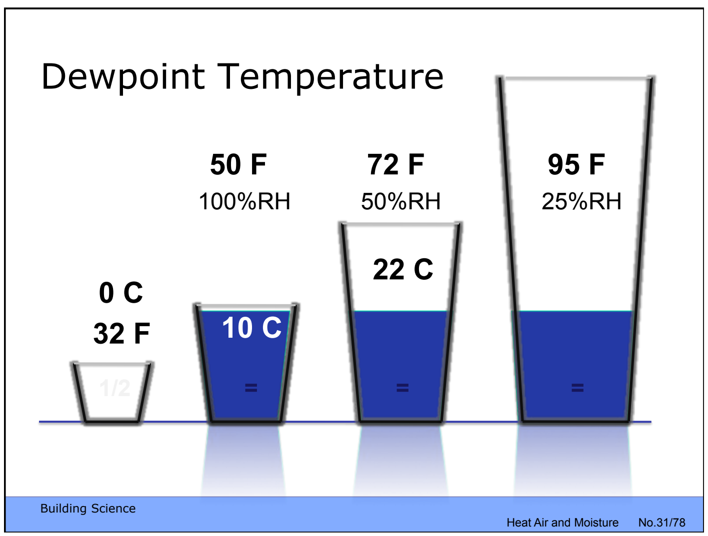
Water vapor in Air

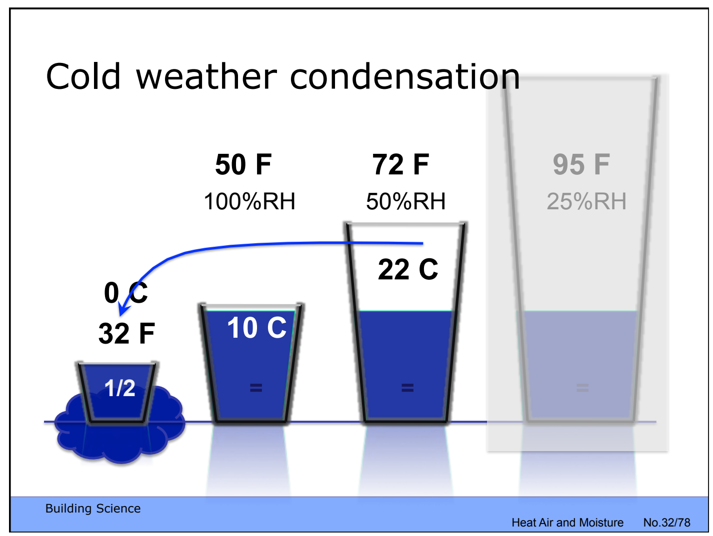


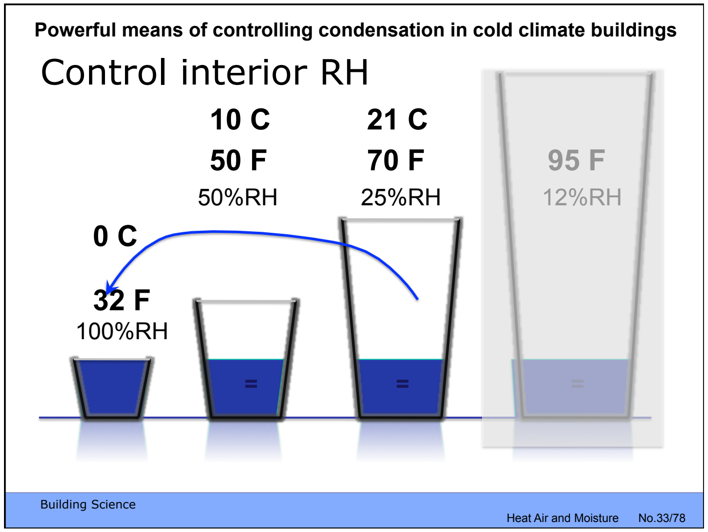
Building Science Heat Air and Moisture No.28/78

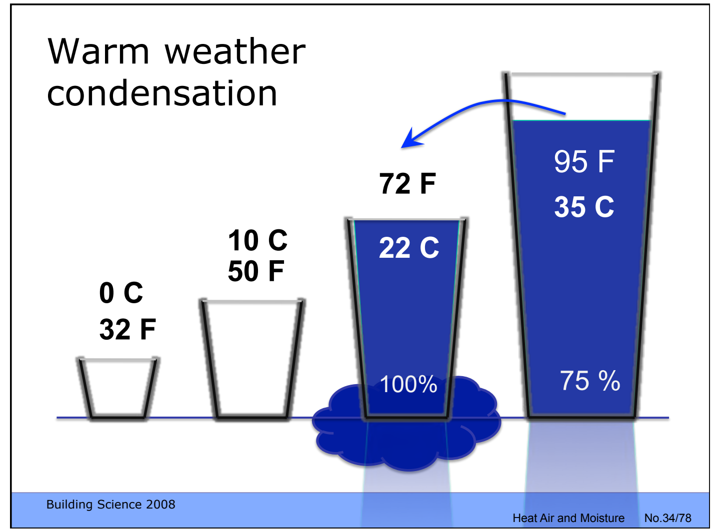

Water vapor in Air
35 C
95 F
22 C
50%RH
72 F
10 C
50 F
0 C
32 F
Building Science
Heat Air and Moisture No.29/78

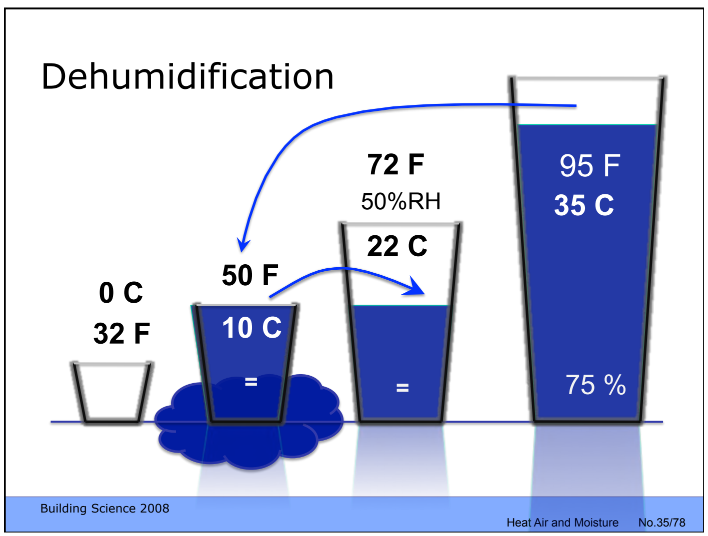

Water vapor in Air
22 C
72 F
50%RH
35 C
95 F
25%RH
10 C
50 F
0 C
32 F
=
=
Building Science
Heat Air and Moisture No.30/78

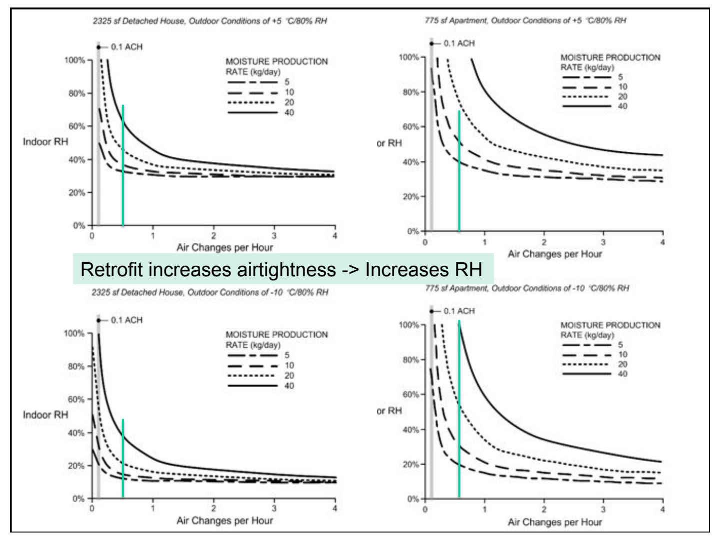

Dewpoint Temperature
50 F
100%RH
72 F
50%RH
95 F
25%RH
22 C
0 C
32 F
10 C
1/2
=
=
=
Building Science
Heat Air and Moisture No.31/78

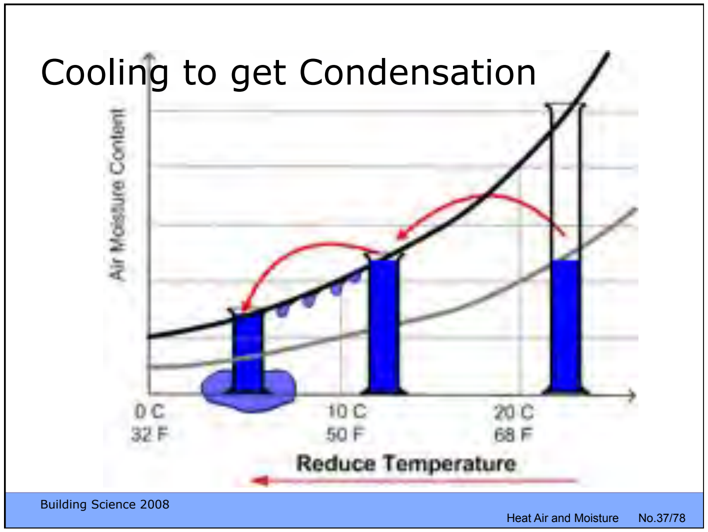

Cold weather condensation
50 F
100%RH
72 F
50%RH
95 F
25%RH
22 C
0 C
32 F
10 C
1/2
=
=
=
Building Science
Heat Air and Moisture No.32/78


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

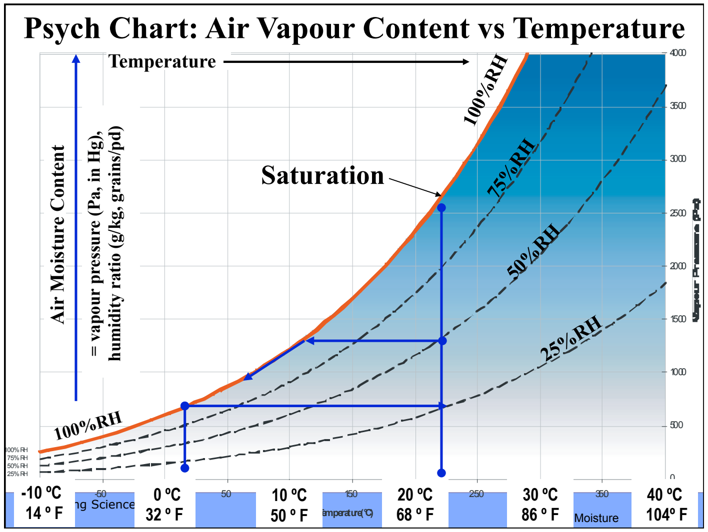

Warm weather condensation
0 C
32 F
10 C
50 F
72 F
22 C
100%
95 F
35 C
75 %
Building Science 2008
Heat Air and Moisture No.34/78


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

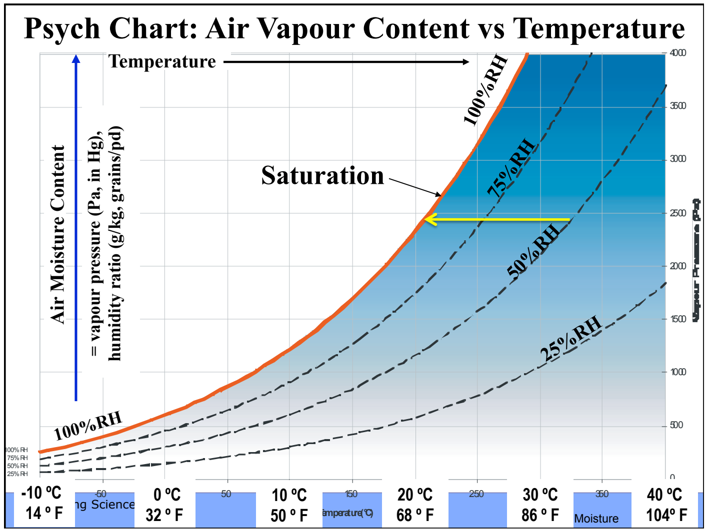

Retrofit increases airtightness -> Increases RH
Indoor RH
Air Changes per Hour
MOISTURE PRODUCTION RATE (kg/day)
0.1 ACH



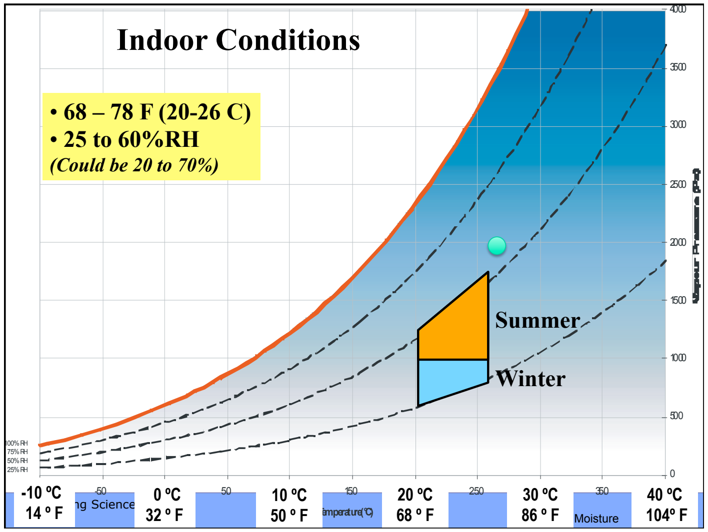
Cooling to get Condensation
Air Moisture Content
0 C
32 F
10 C
50 F
20 C
68 F
Reduce Temperature
Building Science 2008
Heat Air and Moisture No.37/78



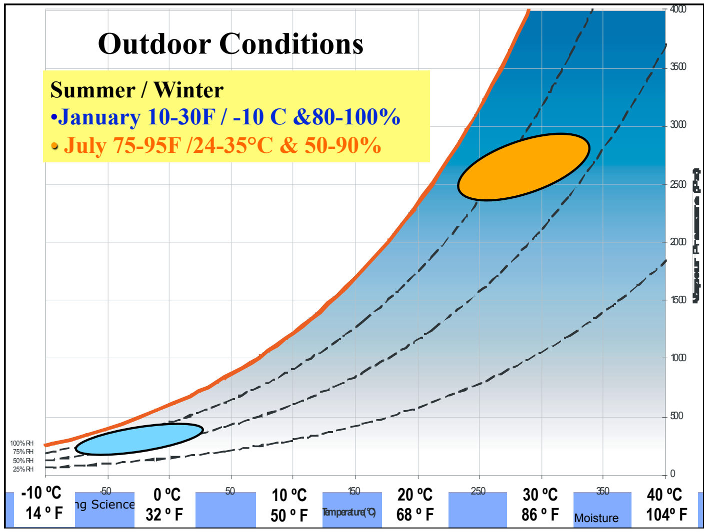
Psych Chart: Air Vapour Content vs Temperature
Temperature
Air Moisture Content
= vapour pressure (Pa, in Hg), humidity ratio (g/kg, grains/pd)
Saturation
100%RH
75%RH
50%RH
25%RH
100%RH
-10 °C 14 ° F
0 °C 32 ° F
10 °C 50 ° F
20 °C 68 ° F
30 °C 86 ° F
40 °C 104° F

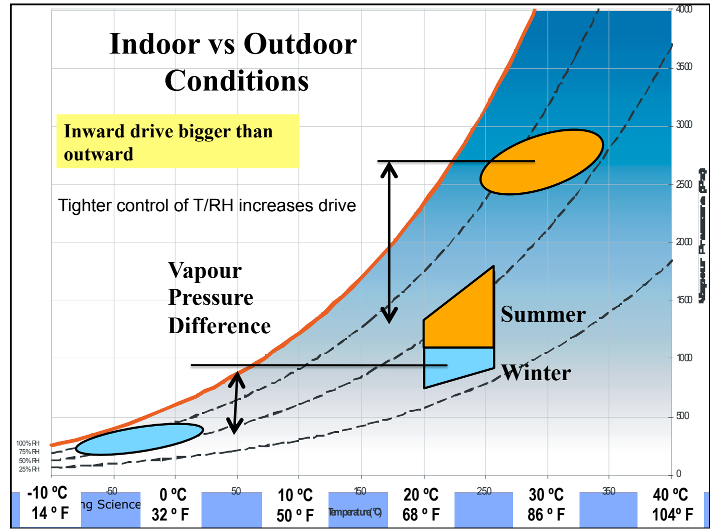


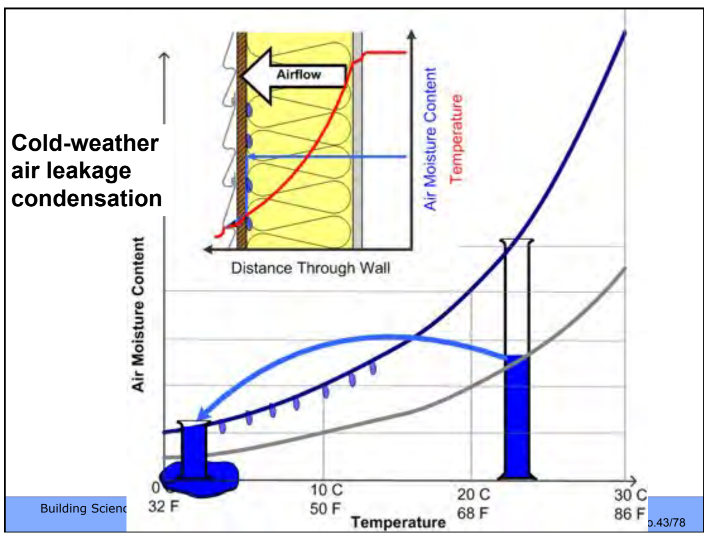
Psych Chart: Air Vapour Content vs Temperature
Temperature
Air Moisture Content
= vapour pressure (Pa, in Hg), humidity ratio (g/kg, grains/pd)
Saturation
100%RH
75%RH
50%RH
25%RH
100%RH
-10 °C 14 ° F
0 °C 32 ° F
10 °C 50 ° F
20 °C 68 ° F
30 °C 86 ° F
40 °C 104° F



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

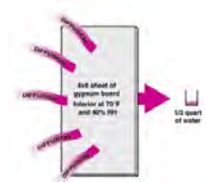


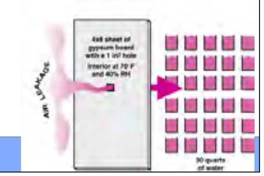




Air leakage

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





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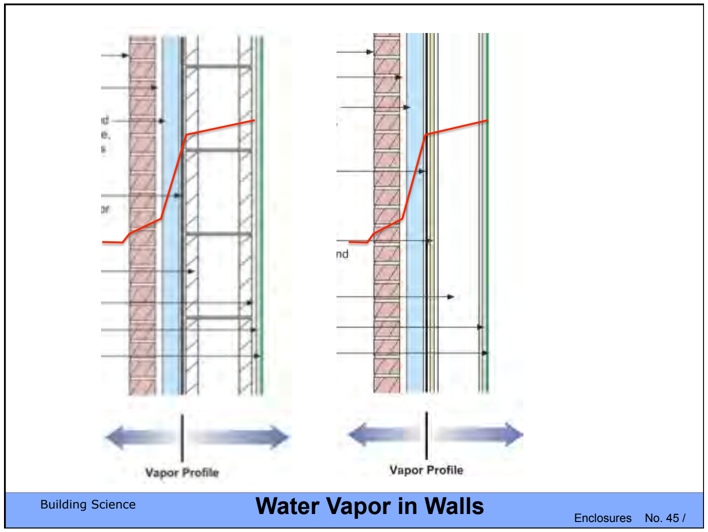
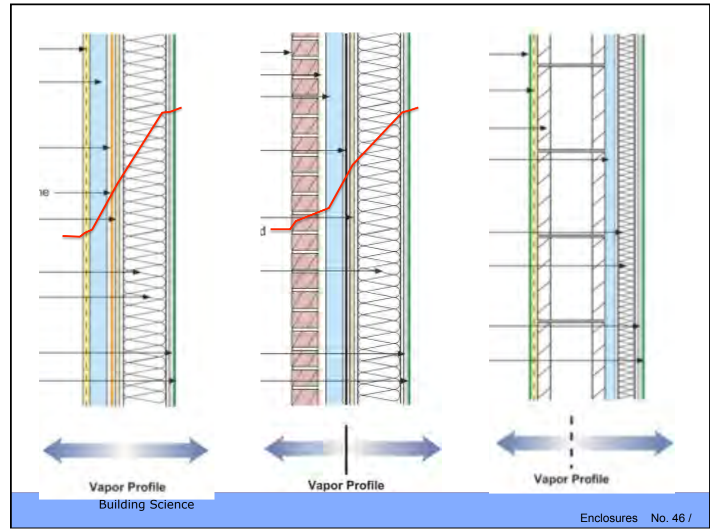
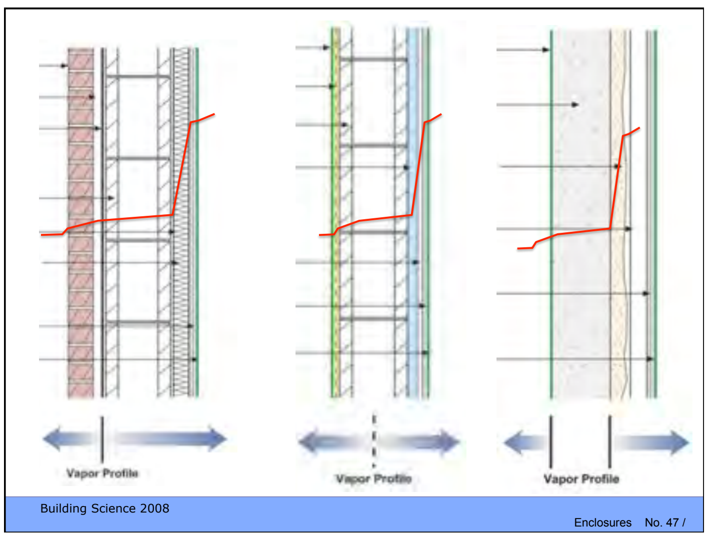
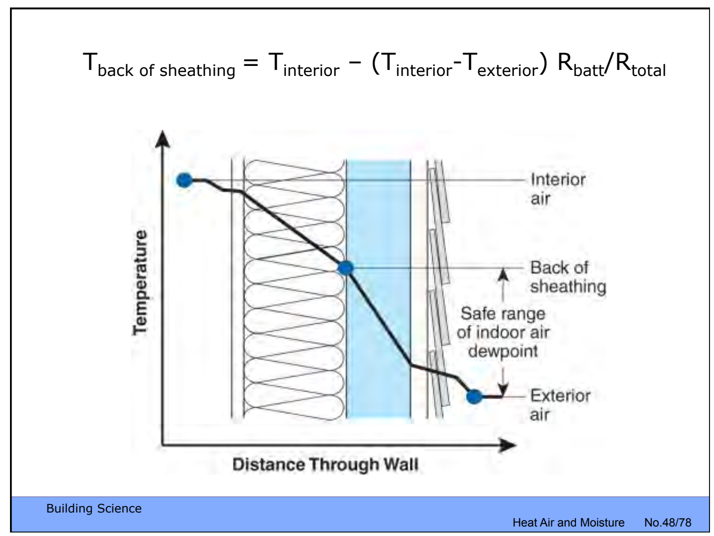
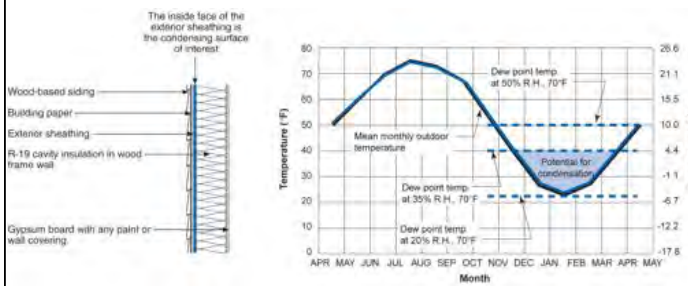

Vapor Profile
Vapor Profile
Building Science
Water Vapor in Walls
Enclosures No. 45 /


Vapor Profile
Vapor Profile
Vapor Profile
Building Science
Enclosures No. 46 /


Vapor Profile
Vapor Profile
Vapor Profile
Building Science 2008
Enclosures No. 47 /


$T_{back\ of\ sheathing} = T_{interior} - (T_{interior} - T_{exterior})\ R_{batt}/R_{total}$
Temperature
Interior air
Back of sheathing
Safe range of indoor air dewpoint
Exterior air
Distance Through Wall
Building Science
Heat Air and Moisture No.48/78

No exterior sheathing



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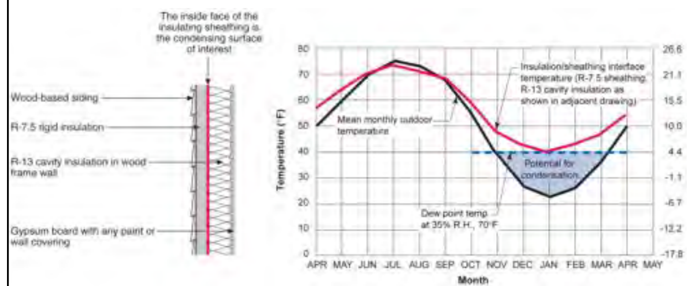
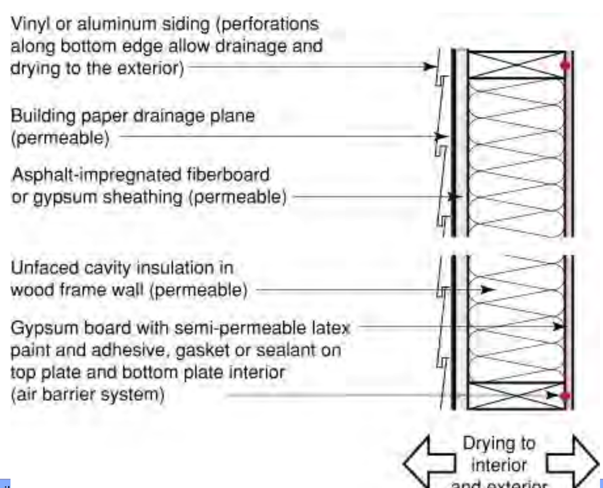
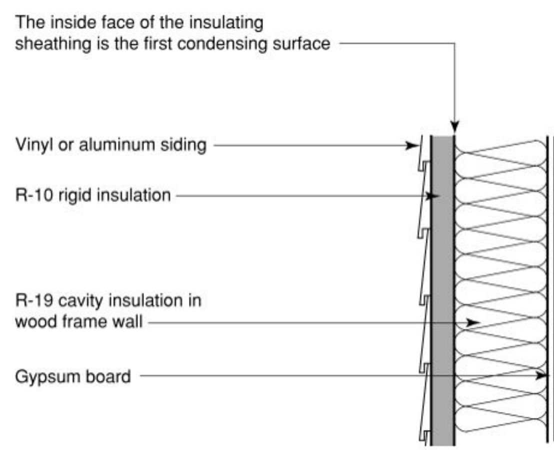
With exterior insulation



Building Science 2008 Heat Air and Moisture No.50/78



Buil Heat Air and Moisture No.51/78

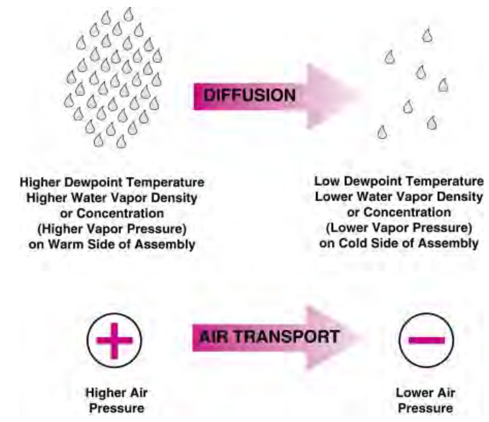


Building Science Heat Air and Moisture No.52/78

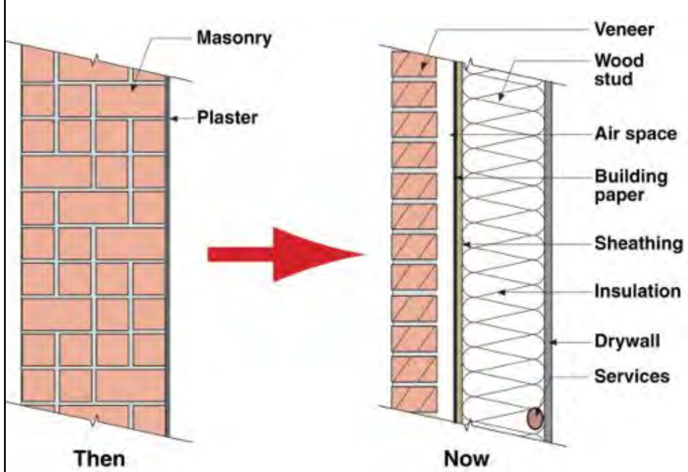
Water Vapour Transport

- 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

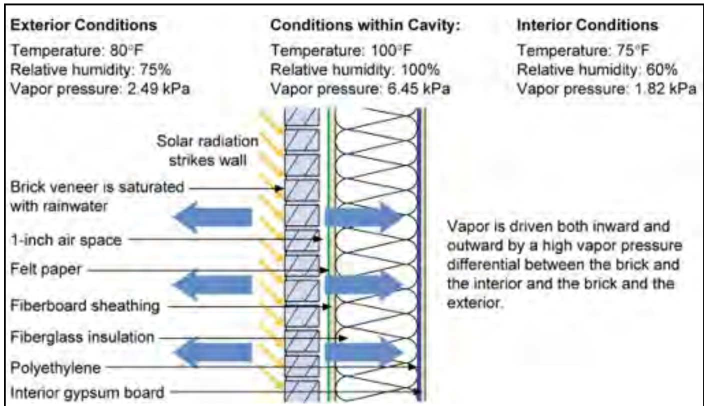
Building Science 2008 Heat Air and Moisture No.53/78



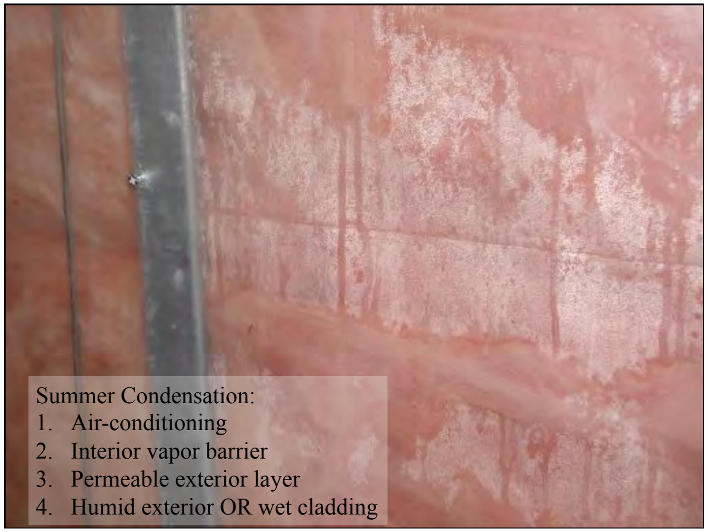
Building Science Heat Air and Moisture No.54/78

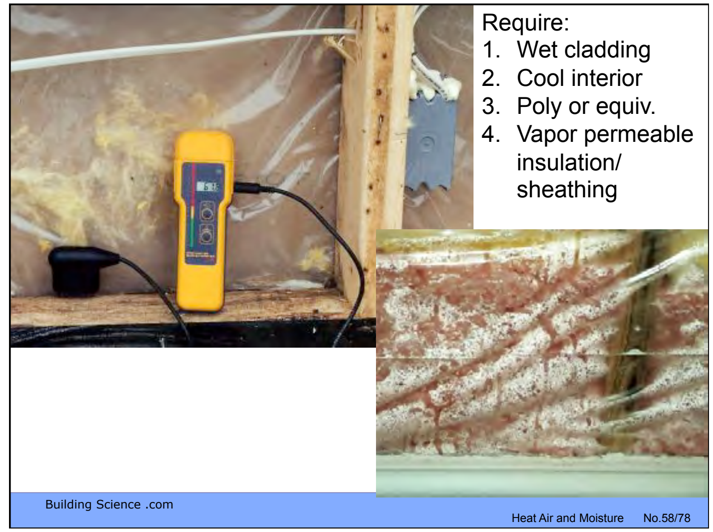


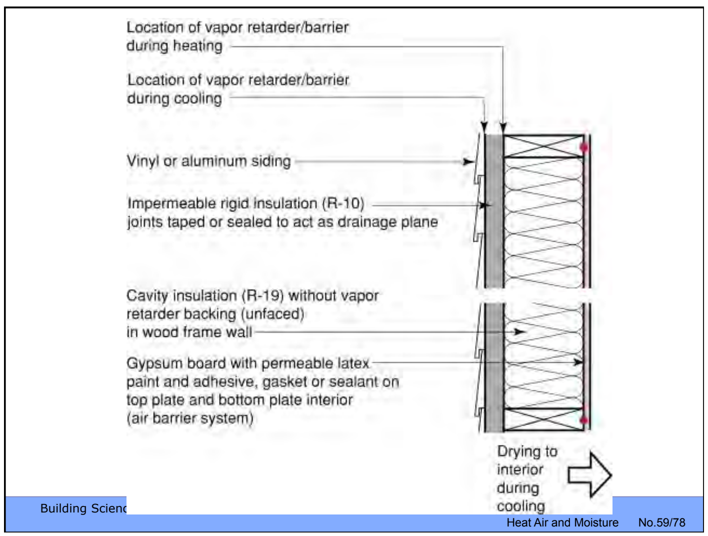
Building Science 2008 Heat Air and Moisture No.55/78

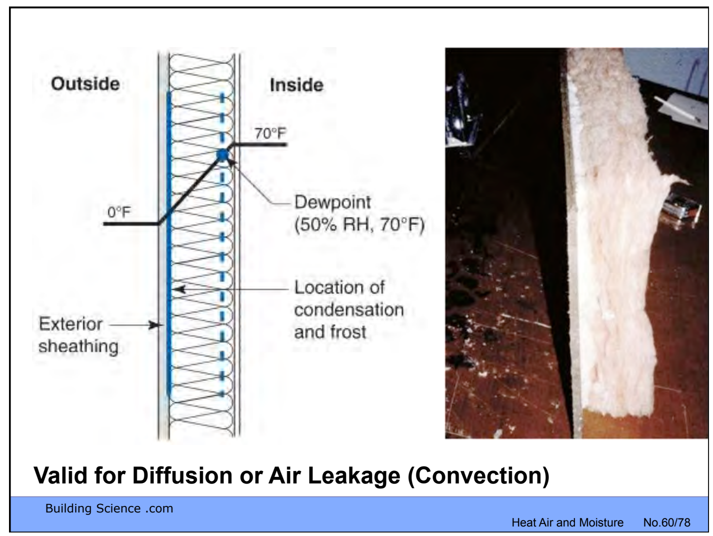


Building Science .com Heat Air and Moisture No.56/78


Summer Condensation:
1. Air-conditioning
2. Interior vapor barrier
3. Permeable exterior layer
4. Humid exterior OR wet cladding


Require:
1. Wet cladding
2. Cool interior
3. Poly or equiv.
4. Vapor permeable insulation/ sheathing
Building Science .com
Heat Air and Moisture No.58/78


Location of vapor retarder/barrier during heating
Location of vapor retarder/barrier during cooling
Vinyl or aluminum siding
Impermeable rigid insulation (R-10) joints taped or sealed to act as drainage plane
Cavity insulation (R-19) without vapor retarder backing (unfaced) in wood frame wall
Gypsum board with permeable latex paint and adhesive, gasket or sealant on top plate and bottom plate interior (air barrier system)
Drying to interior during cooling
Building Scienc
Heat Air and Moisture No.59/78


Outside
Inside
70°F
0°F
Dewpoint (50% RH, 70°F)
Location of condensation and frost
Exterior sheathing
Valid for Diffusion or Air Leakage (Convection)
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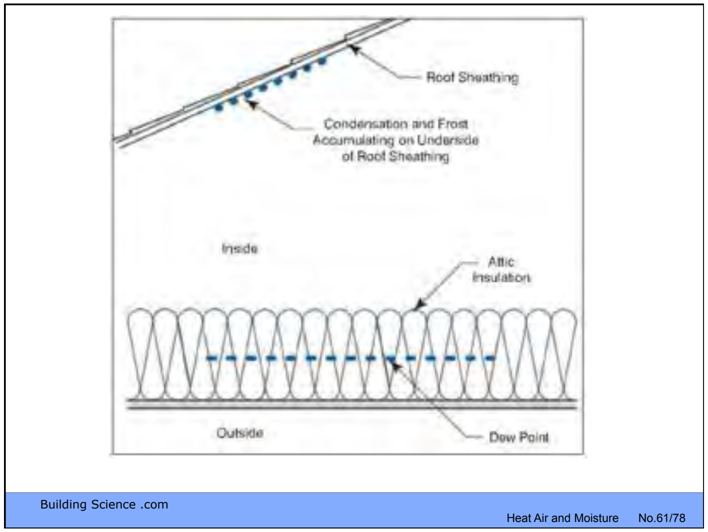
Heat Air and Moisture No.60/78


Roof Sheathing
Condensation and Frost Accumulating on Underside of Roof Sheathing
Inside
Attic Insulation
Outside
Dew Point
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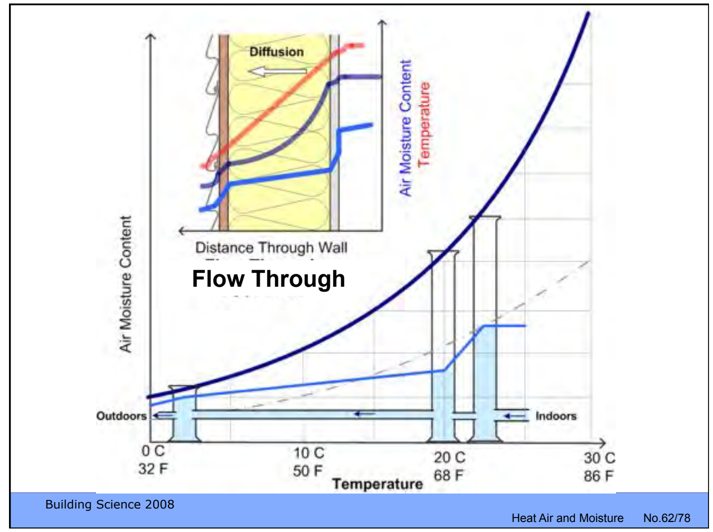
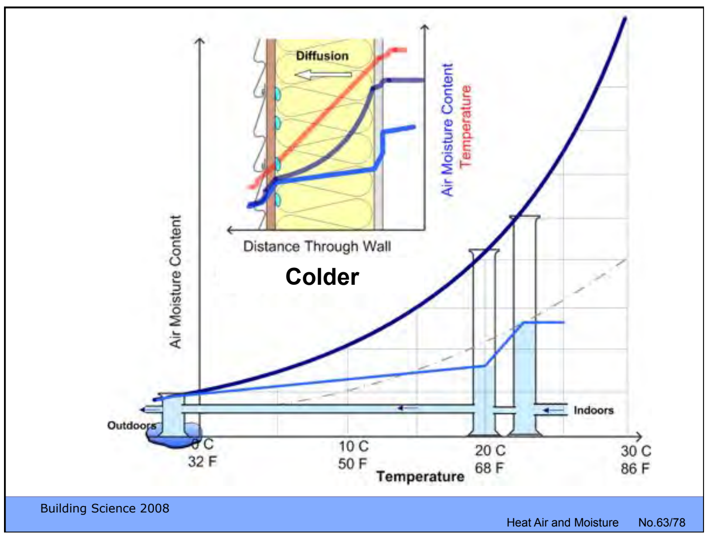
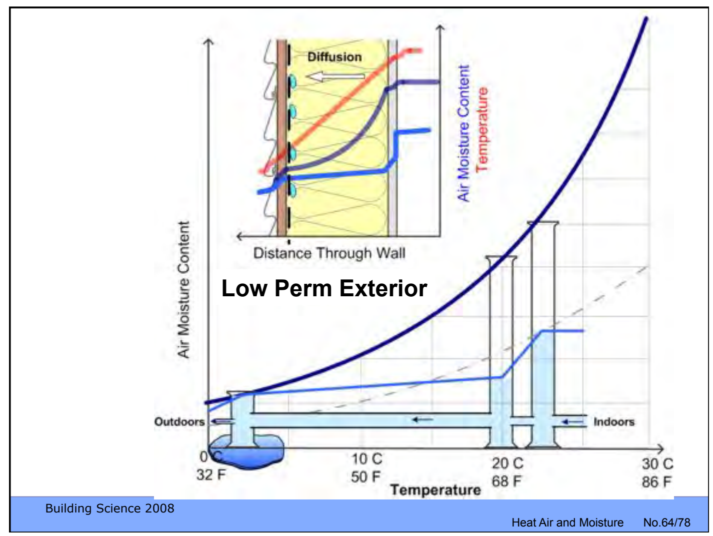
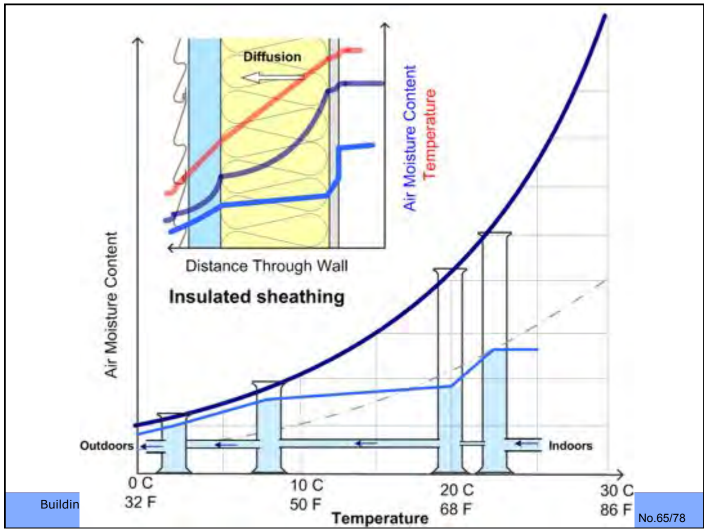
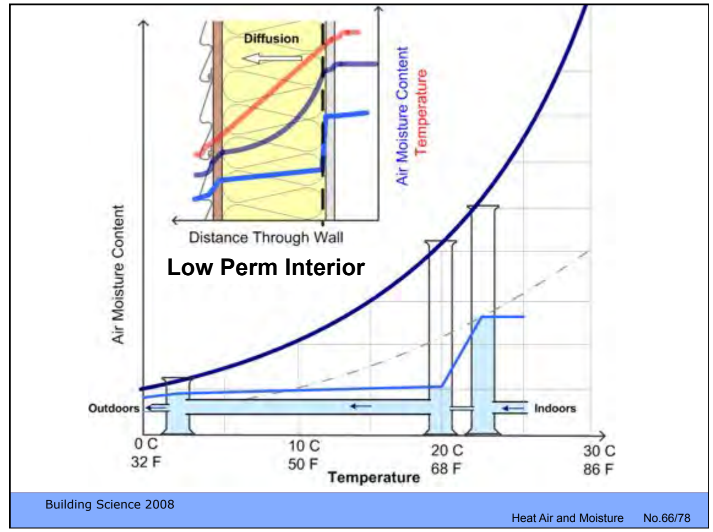
Heat Air and Moisture No.61/78

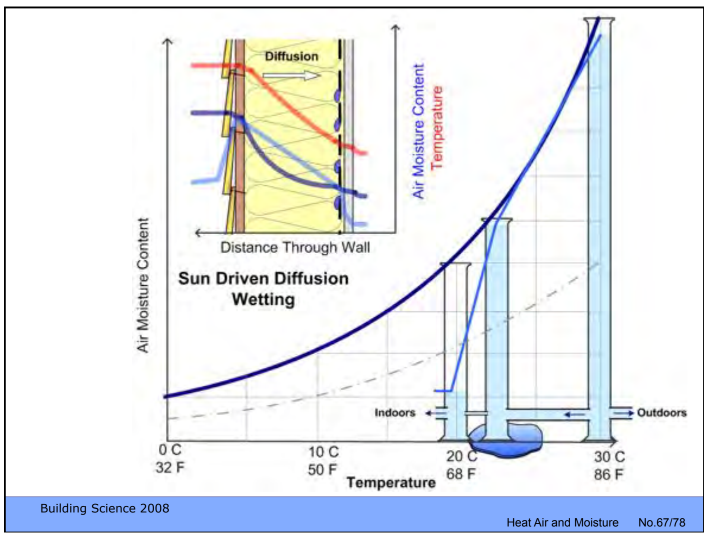

Diffusion
Air Moisture Content
Temperature
Distance Through Wall
Flow Through
Air Moisture Content
Outdoors
Indoors
0 C 32 F
10 C 50 F
20 C 68 F
30 C 86 F
Temperature
Building Science 2008
Heat Air and Moisture No.62/78


Diffusion
Air Moisture Content
Temperature
Distance Through Wall
Colder
Air Moisture Content
Outdoors
Indoors
32 F
10 C 50 F
20 C 68 F
30 C 86 F
Temperature
Building Science 2008
Heat Air and Moisture No.63/78


Diffusion
Air Moisture Content
Temperature
Distance Through Wall
Low Perm Exterior
Air Moisture Content
Outdoors
Indoors
32 F
10 C 50 F
20 C 68 F
30 C 86 F
Temperature
Building Science 2008
Heat Air and Moisture No.64/78







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

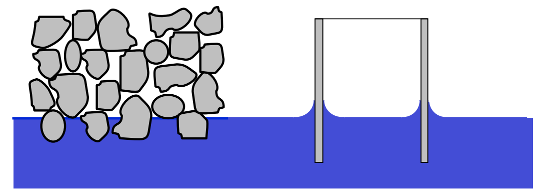
Building Science Heat Air and Moisture No.68/78

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

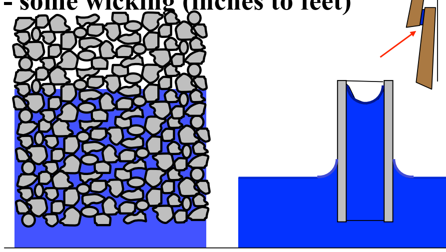
Capillary Flow

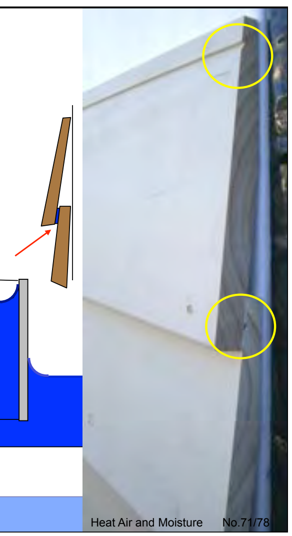
- Solution: use gaps
- Large pores - no suction (no “wicking”)
- Eg. : Crushed stone, air gaps
- Gravity flow allows drainage



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)