Moisture Dynamics in Residential Construction

TREMCO Barrier Solutions

Moisture Dynamics
Learning Objectives

- The course objectives are to understand:
  - The dynamics of moisture movement and governing laws
  - The factors that govern the rate and direction vapor flow
  - The performance of frame walls and moisture control priorities
  - Improved construction methods for moisture control

Tremco Barrier Solutions
Speaker & Background

- Dr. Jim Wells PhD. - Technical Director, TBS
  - Graduated & Taught Engineering at Purdue
    Aeronautics, Astronautics & Engineering Sciences
  - Over 30 years R&D in Construction Products
    - Owens Corning: Insulation & Roofing Systems -15 years
    - Koch Materials: Highway Systems – 5 years
    - Residential Barrier Systems – 10+ years

Tremco Barrier Solutions

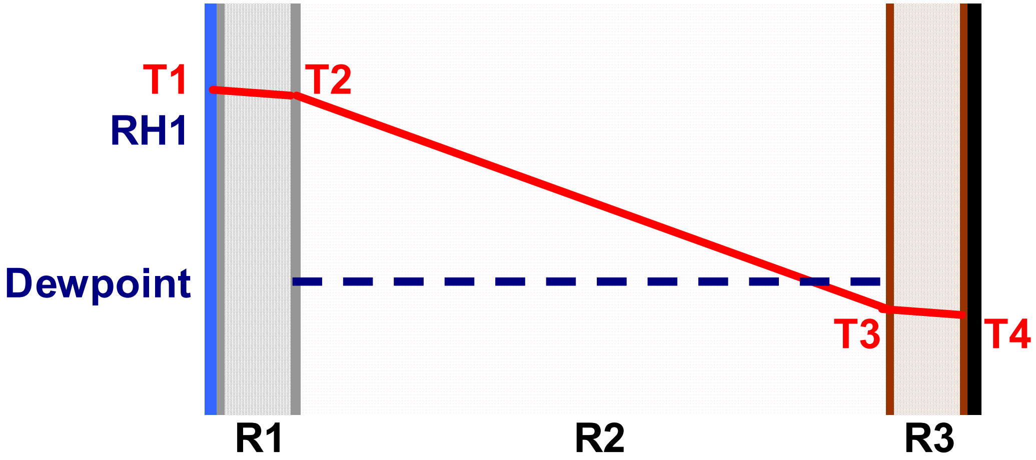
RPM Company Background

Moisture Dynamics Fundamentals

- **Consistent with the laws of nature**
  - Rocks roll downhill - well understood, law of gravity
  - Moisture and heat move predictably, by specific laws (more complicated and interactive)
- **Applied to the Home Envelope: Barrier Science**
  - Understanding how the laws of heat and moisture operate
  - Providing intelligent design for building envelope products and systems
- **Protecting Homes with Barrier Science^SM**
  - Stop what we want to stop: liquid water, moist air flow, condensation
  - Transmit what we want to transmit: water vapor (allowing incidental moisture to dry)

Moisture Dynamics Fundamentals

T3 = T4 + (T1-T4)*R3/(R1+R2+R3)



Dewpoint model: too simple to properly predict moisture issues

Moisture Dynamics Fundamentals

- **Moisture is dynamic**
  - Always moving (example: 2 water glasses)
  - Dynamic equilibrium appears as no moisture movement
- **Two primary modes of transport**
  - Liquid
    - Liquid flow through holes (leaks)
    - Capillary flow within/between solids
  - Vapor
    - Carried by bulk air flow
    - Diffusion through solids

Moisture Dynamics Fundamentals

- **Moisture issues are complex, since moisture moves in so many ways**
  - Mass flow, moist air movement (through openings)
  - Sorption and de-sorption, capillary action
  - Vaporization and condensation (liquid/vapor change)
  - **Diffusion (moisture moving through solid materials)**
- **Which way does it go? Should we stop it or help it?**
- **How tight is too tight? How do we know?**
- **To find answers we need to**
  - **Properly understand the questions**
  - **Understand the science behind the answers**

Moisture Dynamics Fundamentals

- **Air changes** and **permeability** are not the same.
  - Air (with water vapor) passes through holes - ACH
    - Moisture laden air can condense and add water to walls
    - You can't assume that the uncontrolled air will actually dry out an affected area (inconsistent)
    - **Uncontrolled air movement is a problem not a solution**
  - Water vapor passes through solids without holes - perms
    - Perms dry out all wall cavities at predictable rates
    - You can't increase perms by adding more material
      - Perms of OSB plus anything is less than OSB alone: 4-6 at high RH
    - **Only <u>extremes</u> of vapor diffusion could ever cause a problem**
      - **Normally it helps solve, <u>not cause</u>, problems**

Moisture Dynamics Fundamentals

- **Conditions for vapor diffusion**
  - Water vapor pressure difference
  - Vapor permeable transmission medium
    - Vapor can flow through permeable solid materials
      Wood, polymers, organic materials – **Yes**
      Glass, metal, non-porous inorganic materials – **No**
- **Factors that Determine Amount and Rate**
  - Size of the vapor pressure difference
    - determined by temperature and relative humidity
  - Permeance of the medium (perms)
  - **Net water vapor flow is always from high to low vapor pressure**

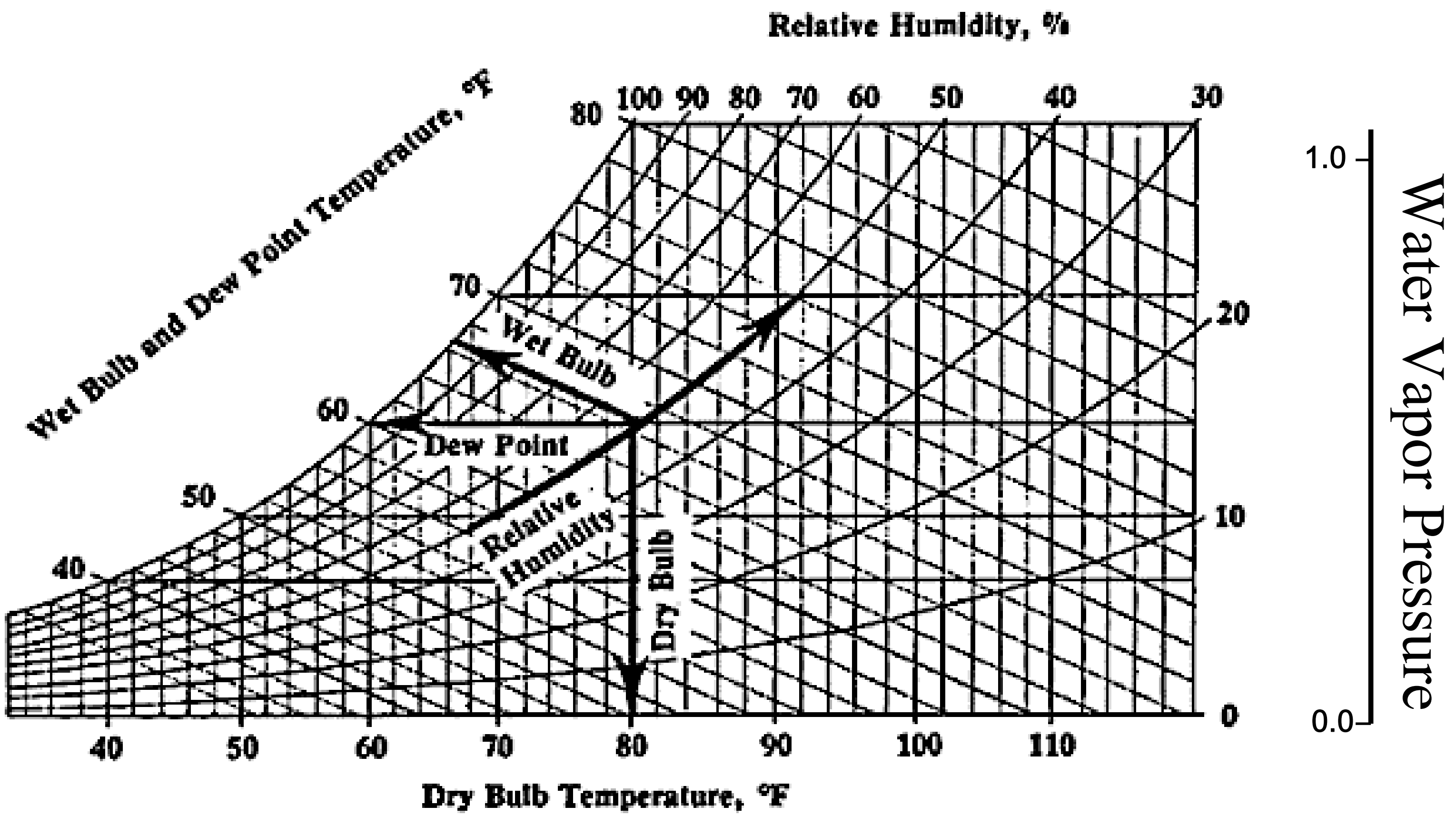
Moisture Dynamics Fundamentals

- **Perm:** a unit of ***permeance*** or ***water vapor transmission*** resulting from a partial pressure difference across a material.
- One US perm is ***1 grain*** of water vapor ***per hour***, ***per ft^2***, ***per inch of mercury pressure difference***.
  - 1.00 US Perms = 1.52 Metric Perms
- One metric perm (not SI) is ***1 gram*** of water vapor ***per day***, ***per m^2***, per mm of mercury.
  - 1.00 Metric Perms = 0.66 US Perms

Moisture Dynamics Fundamentals

- **Psychrometrics: the science of the heat and water vapor properties of air.**
- **Relates the important variables**
  - Temperatures (wet- and dry-bulb), total water content
  - Relative humidity, dew point, volumetric data
  - Vapor pressure
- **Psychrometric Chart**
  - Indispensible tool for moisture study
  - Used to determine vapor flow direction and 'driving force'

Moisture Dynamics Fundamentals



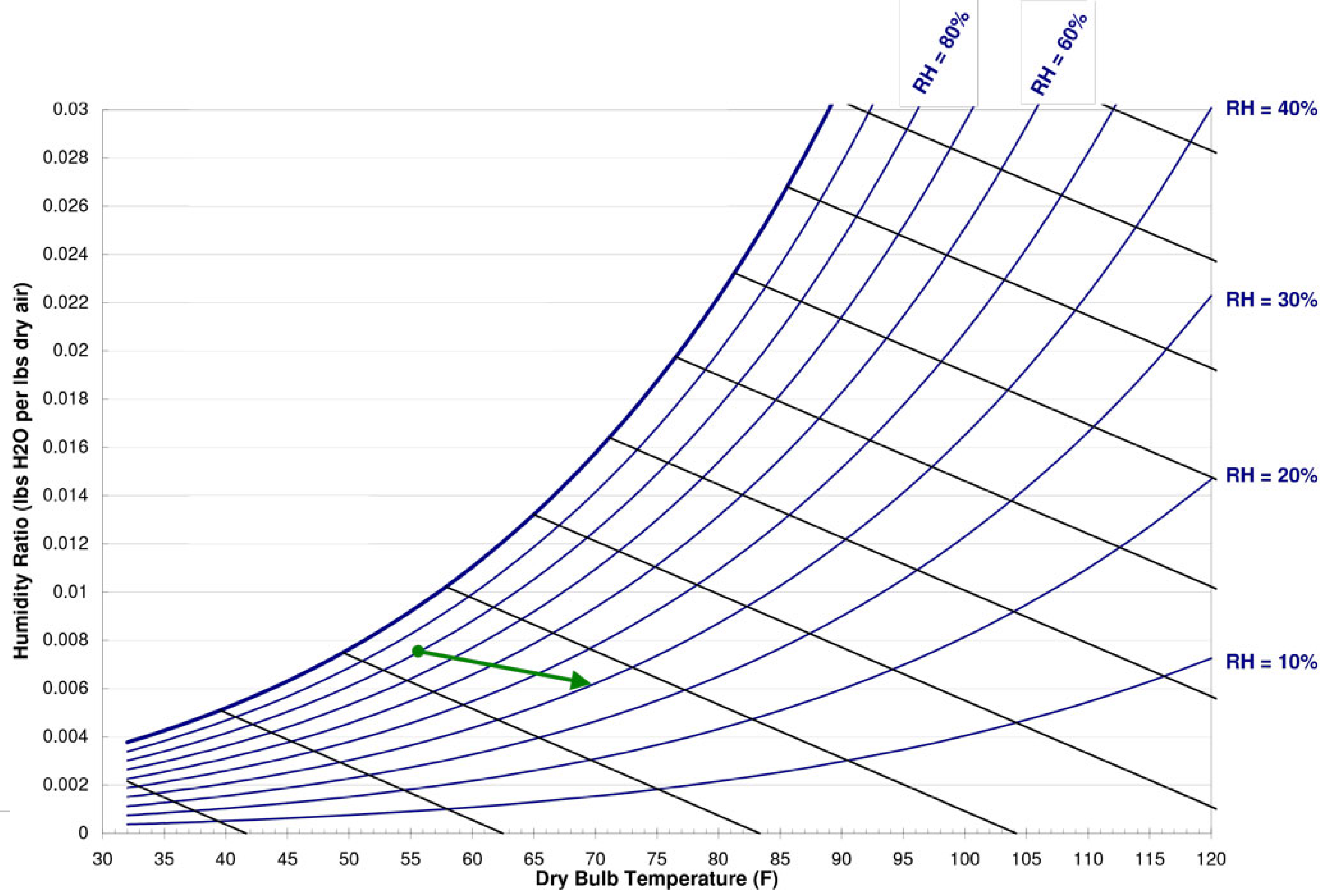
Moisture Dynamics Fundamentals

- **Exercise: Moisture flow direction, out or in?**
- Inside: 70º F, 40% RH Outside: 55º F, 80% RH
- **IN**
- Inside: 70º F, 40% RH Outside: 55º F, 50% RH
- **OUT**
- Inside: 70º F, 40% RH Outside: 90º F, 20% RH
- **NEITHER, NO NET FLOW**

Moisture Dynamics

Flow Direction: out or in?

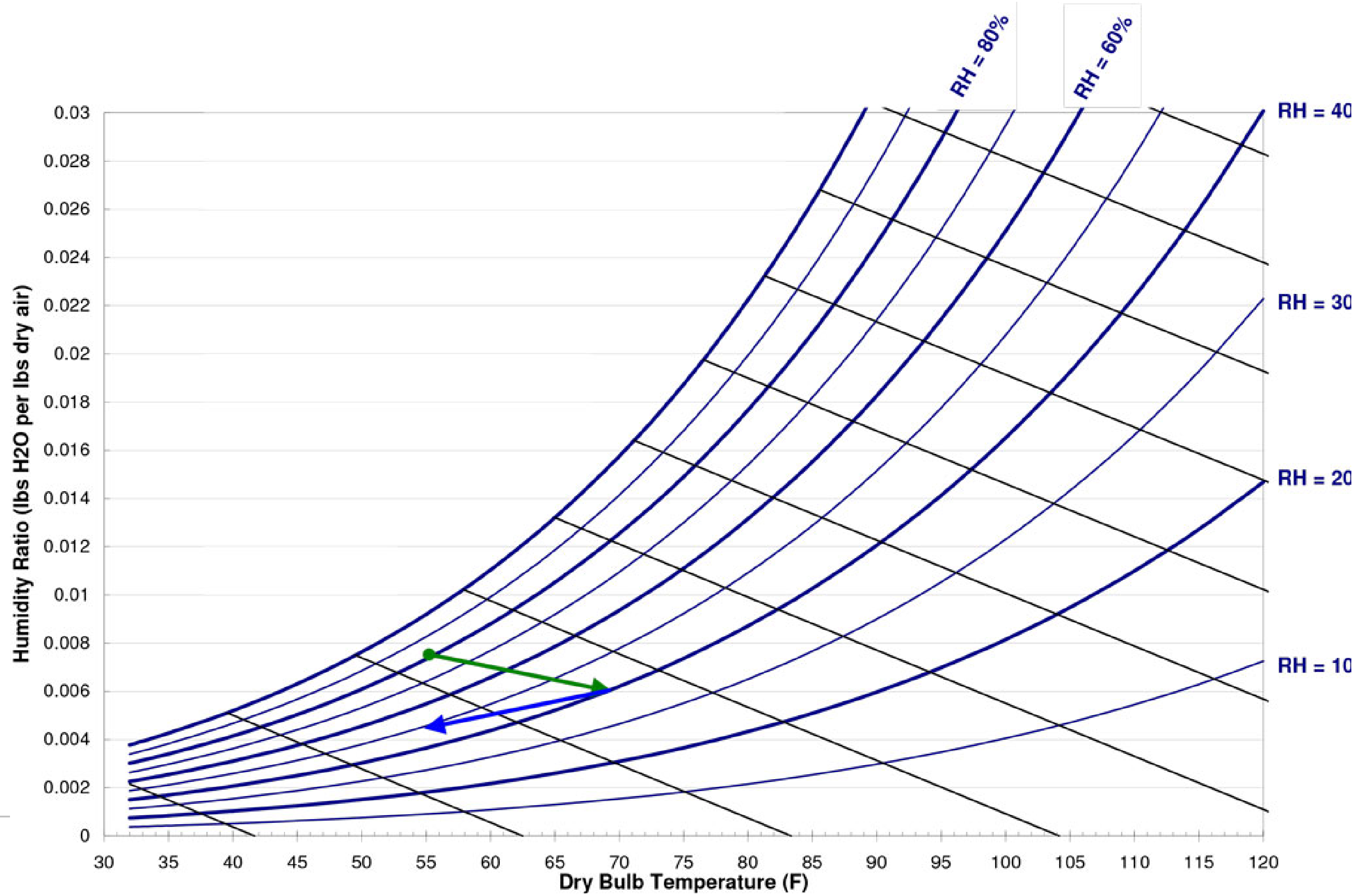
– **Inside:** 70º F, 40% RH **IN** **Outside:** 55º F, 80% RH



Moisture Dynamics

Flow Direction: out or in?

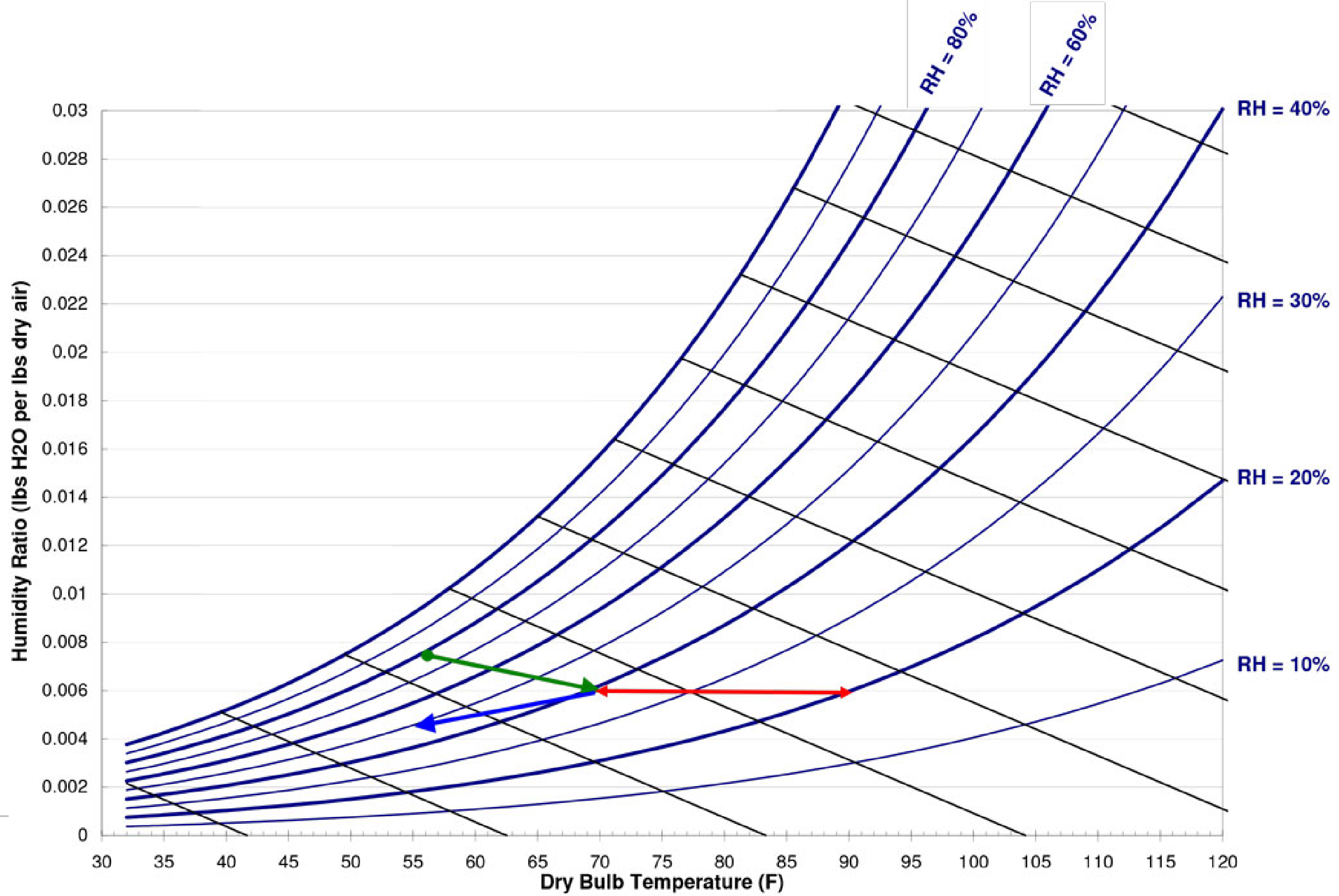
– **Inside:** 70º F, 40% RH **OUT** **Outside:** 55º F, 50% RH



Moisture Dynamics

Flow Direction: out or in?

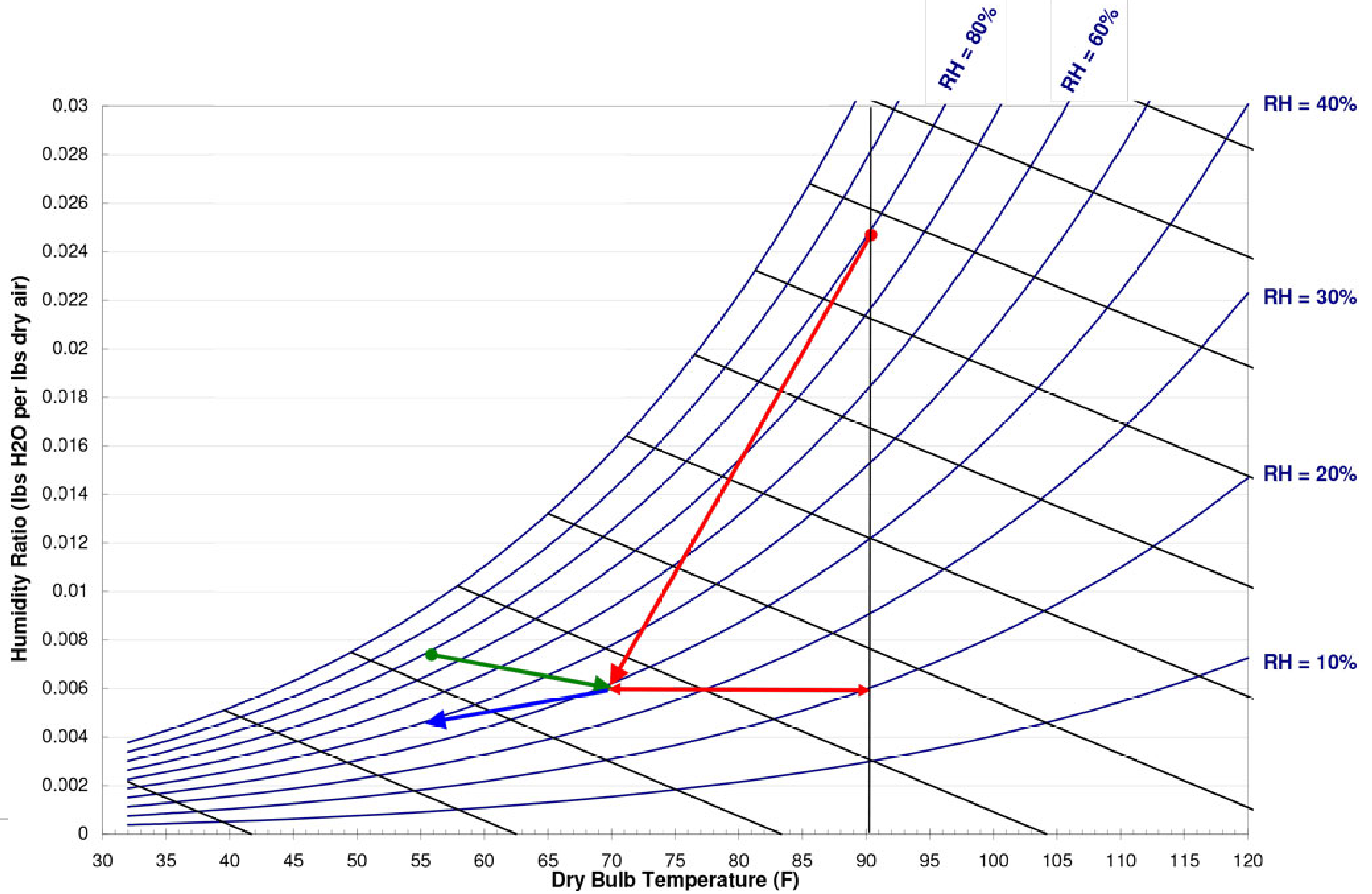
- **Inside:** 70º F, 40% RH **NEITHER** **Outside:** 90º F, 20% RH



Moisture Dynamics

Flow Direction: out or in?

– **Inside:** 70º F, 40% RH **IN-large** **Outside:** 90º F, 80% RH



Moisture Dynamics Fundamentals

Water Vapor Pressure (.01 inch Hg)					
°F \ RH %	100	70	40	10	2
-20	1	1	1	0	0
0	4	3	2	0	0
20	10	7	4	1	0
40	25	17	10	2	0
60	52	37	21	5	1
80	103	72	41	10	2
100	194	135	77	19	4
120	345	242	138	34	7
140	589	412	236	59	12

VP (100 F, 2% RH) = VP (0 F, 100% RH)

VP (120 F, 100% RH) = 50 * VP (20 F, 70% RH)

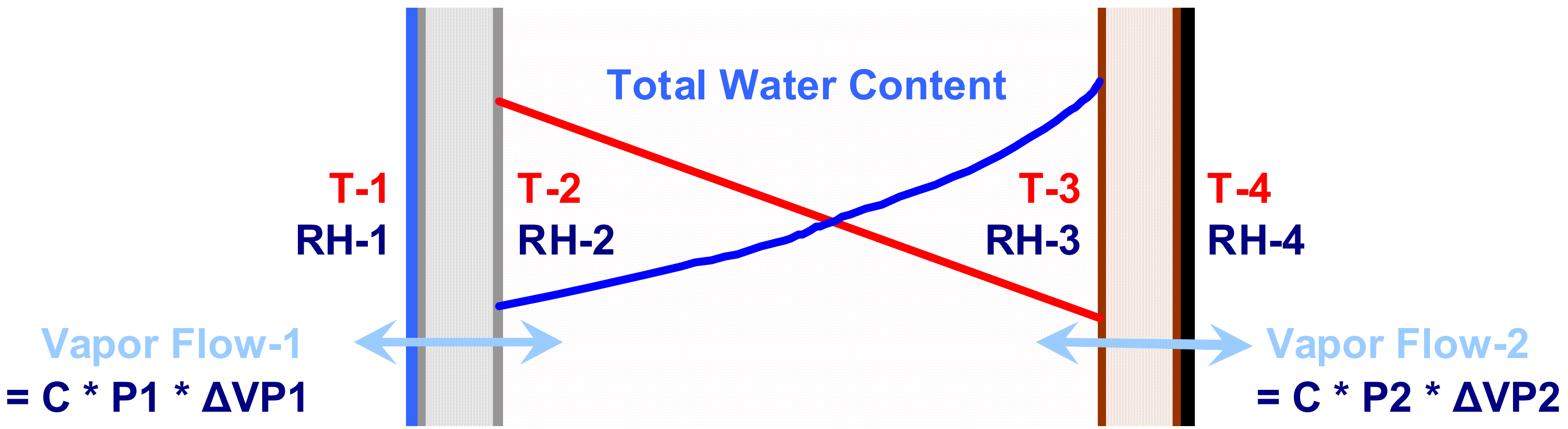
Moisture Dynamics Fundamentals

Wall Permeance Humidity Dependence						
RH %	25	35	45	55	65	75
Drywall & Paint	4.0	5.7	7.4	9.0	10.7	12.4
OSB & WRB	0.4	0.8	1.0	1.3	1.6	3.8

Permeance of common building materials depend on RH

Moisture Dynamics Fundamentals

Frame Wall Section with Liquid-applied WRB

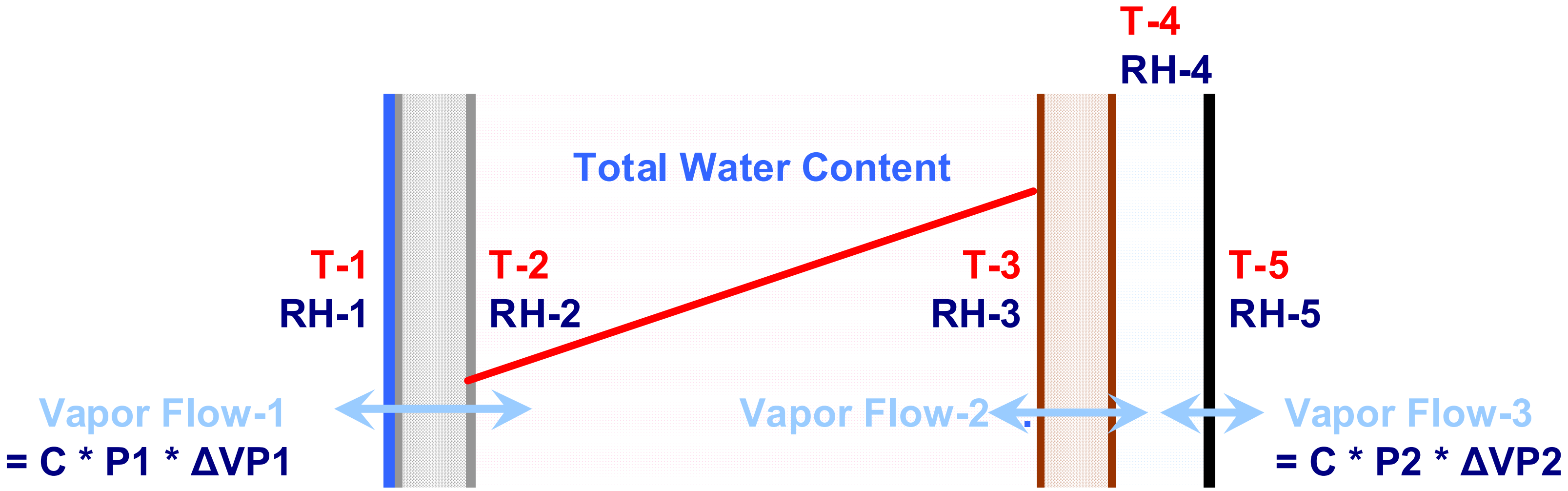


Winter Condition Illustrated

Moisture equilibrium is determined by the surface conditions (P and ΔVP) & moisture absorption within the cavity

Moisture Dynamics Fundamentals

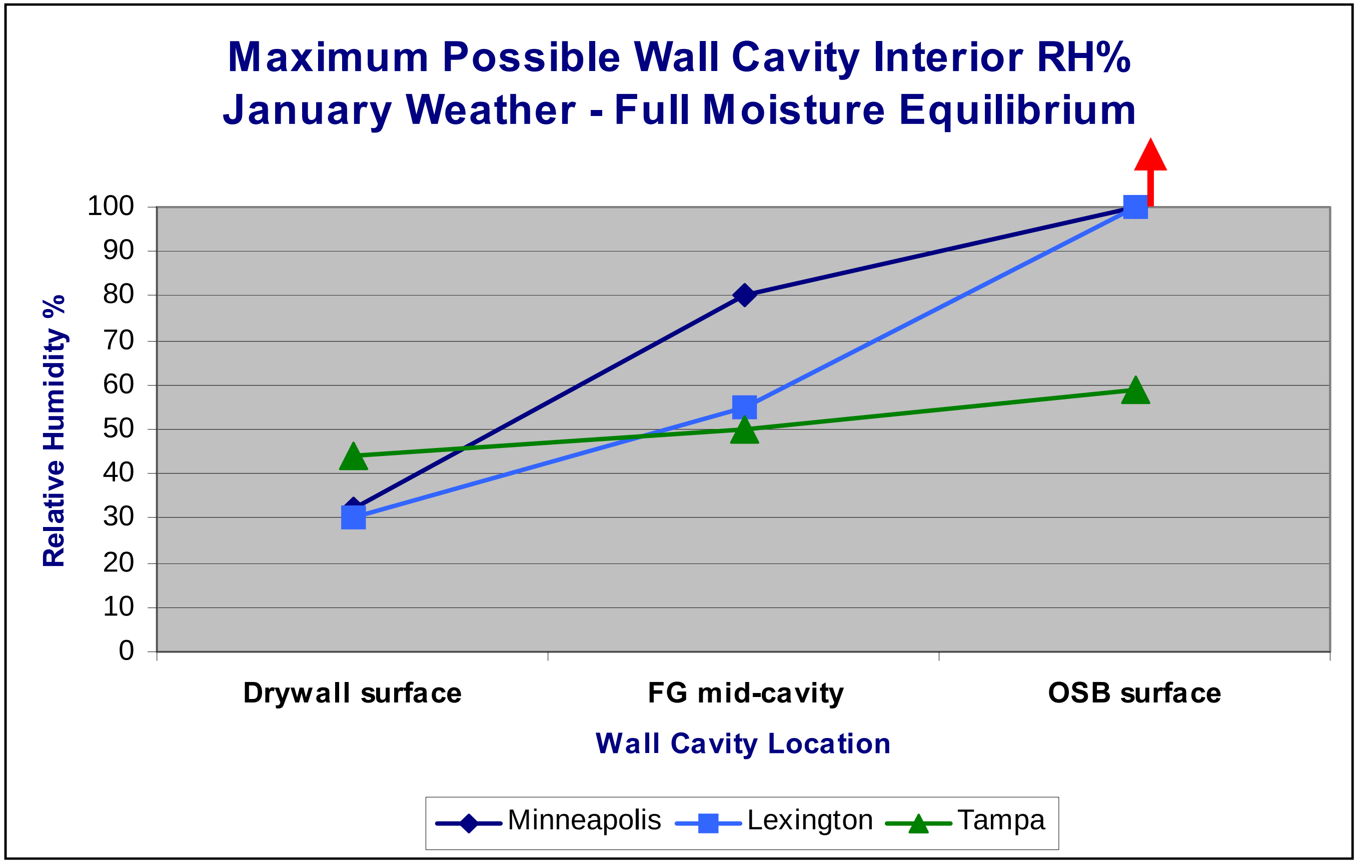
Frame Wall Section with Sheet-applied WRB



Summer Condition Illustrated

A sheet-applied WRB creates an additional vapor space that has significant impact on condensation/wetting of sheathing

Moisture Dynamics Fundamentals



When OSB surface reaches 100% RH plus; is it an issue?

Moisture Dynamics Fundamentals

- **What amount flows in what length of time?**
- **Equation for vapor transport**
- **$W = 0.000053 * A * P * T * \Delta VP$**

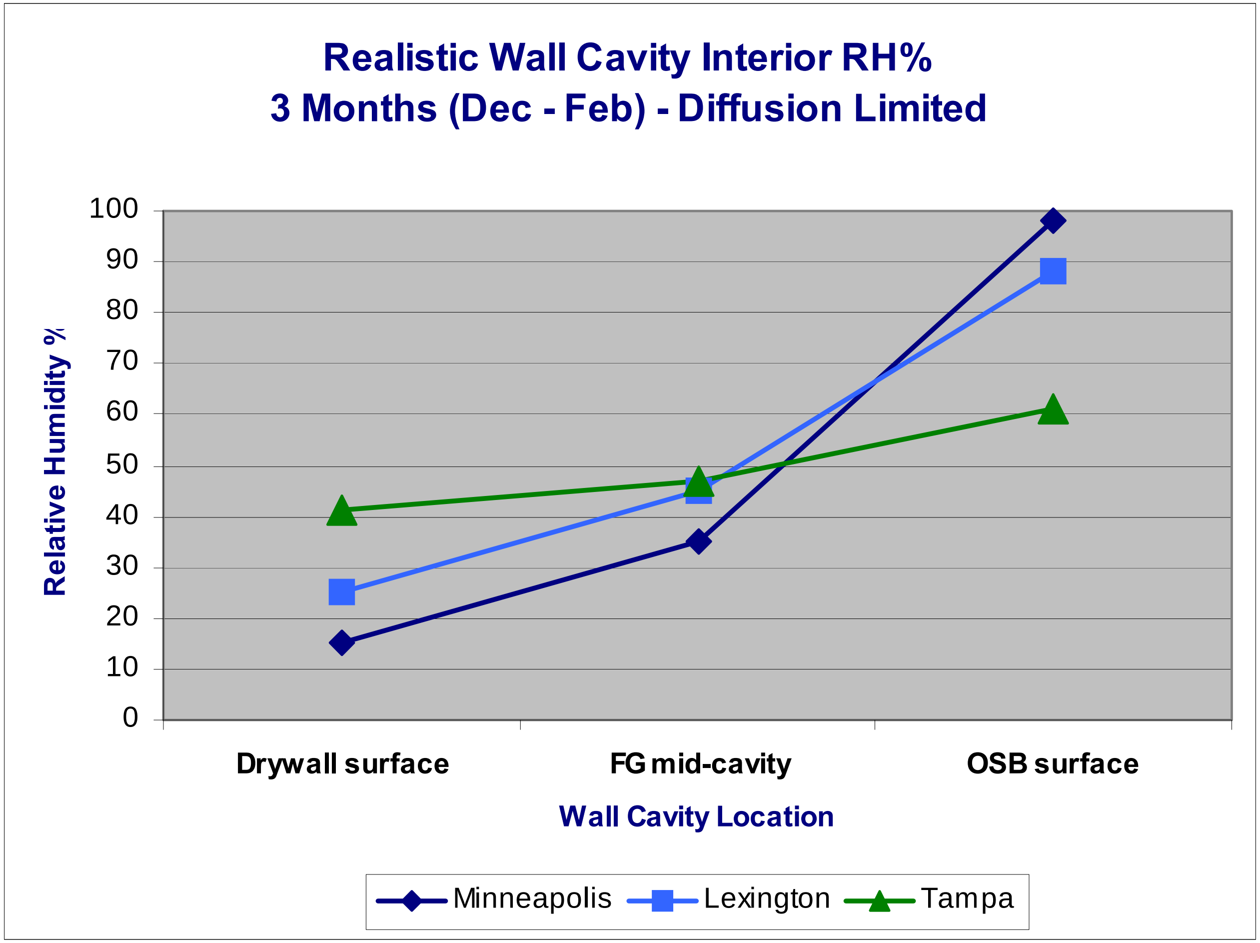
W = weight of water (pounds)
A = transport area (ft^2)
P = permeability of transport medium (US perms)
T = time (hours)
ΔVP = difference in vapor pressure of water vapor in inches of mercury

- **P and ΔVP values change with Temp and RH**

Moisture Dynamics Fundamentals

- **System permeance of OSB Plus WRB**
  - $P_S = P_1 * P_2 / (P_1 + P_2)$ system perms (2 components)
  - In humid environment, OSB alone = 4-6 perms,
  - OSB plus anything is lower perm than OSB alone
    - Using OSB perms = 4.0
    - OSB plus Tyvek(58) is ~ 3.7 perms, plus low-perm wrap(6) is ~ 2.4 perms
    - OSB plus Enviro-Dri (16) is ~ 3.2 perms
    - Difference is small and of little consequence
    - Amount of vapor transmitted (1/4 to 1/2 cup/mo during heating season) is far less than the framing absorbs (5 – 6 cups per 2x4 wall cavity)
  - Permeability is ***not*** the issue
  - Uncontrolled air flow is the issue

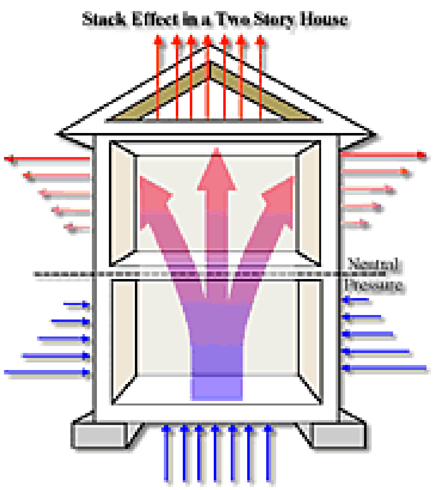
Moisture Dynamics Fundamentals



Moisture Dynamics
Air Infiltration & Moisture

Conditions for air infiltration

- Pressure difference (high to low)
- Holes, gaps, and cracks allowing air flow



Driving forces

- Temperature difference (stack effect)
- Wind
- Mechanical systems imbalance

ACH50 (test result) and ACHn (reality)

- ACHn (per day) is approx 1.3 times ACH50 (per hour)
- ACH50 (1 – 7) is approximately ACHn=(3 – 9) (0-18+)

Moisture Dynamics

Air Infiltration & Moisture

- **Columbus OH monthly average conditions – CZ5**

8' Stud Cavity 16" OC OSB sheathing			Potential Moisture Vapor Movement via Diffusion Through OSB+WRB (Cups water/month)	
Month	VPD	Flow	Liquid-applied (16)	House Wrap (58)
July	0.22	in	0.29	0.33
October	0.03	out	0.03	0.04
Januarty	0.17	out	0.22	0.25
April	0.05	out	0.06	0.07

Note: One wall cavity can absorb 5-6 cups of water at < 80% RH

Moisture Dynamics

Air Infiltration & Moisture

- **Data from Wall Section Leakage rates converted to monthly values, using Columbus average RH levels**

8' Stud Cavity 16" OC OSB sheathing			Potential Moisture Vapor Movement via Air Leakage Through OSB+WRB (Cups water/month)	
Month	VPD	Flow	Liquid-applied (16)	House Wrap (58)
July	0.22	in	1.6	12.2
October	0.03	out	0.2	1.7
Januarty	0.17	out	1.2	9.0
April	0.05	out	0.5	3.6

Note: One wall cavity can absorb 5-6 cups of water at < 80% RH

Air leakage rate and differences are conservative

Moisture Dynamics

Air Infiltration & Moisture

- ***Uncontrolled air movement can introduce over 100 times the moisture into walls than by diffusion!***
- **Moisture Control Priorities**
  - Stop liquid water leaks
  - Stop uncontrolled air movement
  - Maintain permeability for drying
  - Use wood frame construction –(*hygric buffering*)
- **Is it Too tight? In what sense?**
  - Uncontrolled air movement: the goal is zero
  - Vapor diffusion: prudent for more fail safe walls

Moisture Dynamics
Air Infiltration & Moisture

- **How did we get here, focused on vapor & barriers?**
  - In 1940's, US light frame homes began to be insulated
  - This led to increased peeling paint on the siding
  - Simple profile model ***assumed*** that vapor diffusion was the main issue
  - Ignored air flow and moisture absorption of materials
  - Today our tools (computers etc) and understanding are far better
- **Excellent resource for the science and history**
  - William B. Rose, Water in Buildings, John Wiley, esp. Ch 3
  - Research Architect, Building Research Council, University of Illinois

Moisture Dynamics

Air Infiltration & Moisture

- **History**
  - Focusing on diffusion as the major wetting factor was a mistake
  - Homes were not built tighter in 70's; they added more insulation
  - The same issues were seen in the 40's when insulation first added
  - Drying potential was decreased by the added insulation
  - The solution is to reduce wetting potential
  - Uncontrolled air flow through walls is a problem not a solution
    - Seat belts are a good analogy
- **Wall Performance**
  - Wetting potential: 1-water leaks, 2-moisture laden air, 3- diffusion
  - Drying potential: Tight WRB to block 1 & 2; permeable is more robust
- **Has this been verified in the "real" world?**

Moisture Dynamics

Air Infiltration & Moisture

- **The science is the same regardless of climate**
  - Some climates are more severe
  - Canada had many building failures in early 1980's
- **Canada successfully faced and solved these issues**
  - Needed to stop bulk water leaks and uncontrolled air movement
  - Canadian code has required water- / air-barriers since 1990
  - Moving to US, Massachusetts since 2001 commercially
  - **"Built it right, ventilate right" was the solution**
  - Over 20 years of history as verification
- **Liquid-applied WRBs provide the same fully-adhered air- and water-barrier methodology**

Moisture Dynamics
Air Infiltration & Moisture

- **Nationally Recognized Building Science Consultants**
  - **Joe Lstiburek, President Building Science Corporation**
    with extensive building science credentials and practical experience
    "The solution to moisture issues in walls is to decrease wetting potential, not trying to increase drying potential" "Build it tight and ventilate right."
  - **Steve Easley, Principle S.C. Easley & Associates**
    with extensive building science credentials and practical experience
    "my field experience has taught me that leaky building shells cause problems and increase chances for mold growth." "Build tight, ventilate right"

Moisture Dynamics

Moisture Control Priorities

- **To build it right; walls need three barriers**
  - **Stop liquid water leaks - WRB**
    - Exterior cladding doesn’t stop water
    - The water-resistive barrier must stops leaks
  - **Stop moist air movement through wall cavities - AB**
    - The air barrier stops air movement, and possibly water vapor
    - A liquid-applied WRB is the water-barrier and the air-barrier
  - **Stop heat loss with uncompromised insulation**
    - No gaps, air flow, or wet insulation material
- **Maintain Good Drying Potential – interior & exterior perms**

- tight, permeable construction is the answer

Moisture Dynamics
Water-Resistive Barriers

- **Exterior claddings (wood, brick, masonry, vinyl, etc.) don't stop water**
- **2006 & later (IBC, IRC) Require a "water-resistive barrier"**
  - **R703.1 General. …** "The exterior wall envelope shall be designed and constructed in a manner that prevents the accumulation of water within the wall assembly by providing a **water-resistant barrier** behind the exterior veneer…."
  - **R703.2 Water-resistive barrier.** "One layer of No. 15 asphalt felt, free from holes and breaks, complying with ASTM D 226 for Type 1 felt or other approved water-resistive barrier shall be applied over studs or sheathing of all exterior walls."
  - **2003 required only under brick, stucco, and stone; after 2006 required for all**
- **Only #15 asphalt felt is "hard-wired" into the code as WRB**
- **All others fit into the "other approved materials"**
  - **Liquid-applied WRB code standing is the same as wrap or other WRBs**
  - **Each category has its own set of testing requirements. Some are stringent; some are not.**
  - **Examples: sheet- and liquid-applied WRB**

Water-Resistive Barriers Alternatives

- **Several different types**
  - Exterior foam and tape
  - Factory applied sheathing surface and tape
  - Sheet-applied exterior barrier
  - Liquid-applied exterior barrier
- **Moisture performance and practical issues**
- **Most focus on sheet- and liquid-applied WRB**

Water-Resistive Barriers

Exterior Foam and Tape

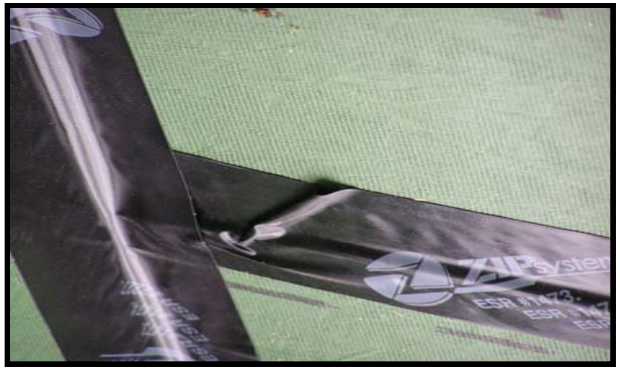
- Foam sheathing w/taped seams WRB and AB
  Lacks permeability– less than 1 perm.

Water-Resistive Barriers

Factory-applied Surface and Tape

- Pre-treated panels w/taped seams WRB and AB

  Performance of quality install like liquid-applied WRB



Drawbacks for surface damage, one side only, and tape issues

Water-Resistive Barriers

Sheet- and Liquid-applied WRB

- Sheet-applied WRB and AB (housewrap)
- Liquid-applied WRB and AB

Sheet- and Liquid-applied WRB Code Requirements

Liquid-applied (AC212)	House Wraps (AC38)
7 performance criteria	Only 4 performance criteria
Tests WRB materials & substrate together	Tests only sheets (no substrates)
Tests joint performance too	No tests for seam or tape integrity
Tests large-scale wall sections	Only small-scale, material-only tests
Specific, required, test methods	Multiple options (including very simple)
Difficult criteria to pass	Simple criteria to pass
Testing aimed at real performance issues	No tear, fastener leakage, seam testing
Tough testing that means something	Minimum requirements of little value
	Reynolds freezer wrap will pass AC38

Sheet-applied WRB
Performance and Issues

- **Common issues**
  - Water can flow between system and sheathing & then into wall
  - Hundreds / thousands of nails penetrate system
  - Significant water and air leakage

Sheet-applied WRB
Performance and Issues

Sheet-applied protection under normal/severe conditions

Sheet-applied WRB
Performance and Issues

- **Pennsylvania (PA) State Study Motivation**
  - There was/is little technical information as to the merits of using housewraps
  - The objective was to investigate the in-service performance of housewraps.
- **PA house wrap use survey detail**
  - 93 percent did not tape or otherwise seal joint locations
  - 73 percent did not tape or render the window/housewrap joint air or water tight
  - 70 percent used staples; many installations using staples had tears or holes
- **Conclusions**
  - Few installers seem to follow manufacturer’s installation instructions
  - Using staples can lead to tearing and stretching of the housewrap
  - Each of the proprietary housewraps has very different in-place performance
- **Common problems, but fixable with diligence**

Sheet-applied WRB Performance and Issues

- **Even without installation issues, felt and wraps leak**
- **Surfactants make wraps leak, that don't leak pure water**
  - Lowers the surface tension of water, flows through smaller spaces; an example is clean water vs. soapy water on car wax
  - Many sources: soluble resins from cedar, siding, paints, **stucco & mortar additives**, and power-washing
- **All wraps leaked through the sheet w/ "real-world" wetting**
  - **Wraps tested with 3.5" water solution for 2 hours (70 mph wind)**
  - Some wraps lost 10%, some 80% in 15 minutes, some 100% in 2 hrs (0 mph wind)
  - 15-pound felt lost 30%
  - Liquid-applied WRBs must pass 22" water column for 5 hours (NO Leaks)
- **Wraps also have water-condensing issue**
  - Hot sun drives water vapor through high-perm wrap,
  - Vapor trapped between wrap and lower perm sheathing condenses
  - Condensed water wets the sheathing but can't exit through wrap

- **http://bct.nrc.umass.edu/index.php/publications/by-title/housewraps-felt-paper-and-weather-penetration-barriers**

Liquid-applied WRB
Performance and Issues

Liquid-applied protection under normal/severe conditions

- Won't blow off, less leaks, call backs & cycle time during construction
- Dark color highlights any thin application areas
- Storm protection throughout life of home

Liquid-applied WRB
Performance and Issues

- Liquid-applied - moisture and air control (DuPont) the next generation in wall moisture and air control

Liquid-applied WRB
Performance and Issues

- Liquid-applied - moisture and air control (Sto)

Liquid-applied WRB
Performance and Issues

- Liquid-applied - moisture and air control (TBS)

- liquid-applied, next generation air/water barriers

Liquid-applied WRB Performance and Issues

- **Keeps external water out of the wall assembly**
  - 15-lb felt and wraps leak water under pressure, even low pressure
  - Liquid-applied WRB must withstand equivalent 5-hour, 200 mph wind, with no leaks
- **Controls/stops air flow through wall cavities**
  - Air leakage carries water vapor into wall cavities; from outside or inside
  - Under adverse conditions the water vapor can condense
  - Sheet-applied WRB effectiveness is often marginal
  - Liquid-applied WRB forms a seamless, fully and permanently attached barrier
- **Allows incidental water vapor to escape (permeable)**
  - Liquid-applied WRB have sufficient perms to allow water vapor transmission
  - When combined with OSB, Enviro-Dri vapor transmission is similar to wraps+OSB
  - High perm sheet-applied can have vapor trapping/wetting summer issue
  - Liquid-applied WRB neither absorb nor trap water
- **Liquid-applied performance is superior to house wraps**

Moisture Dynamics in Residential Construction

- ***Questions and Comments ?***

End of AIA Course Content

Moisture Dynamics
in Residential Construction

Enviro-Dri
Weather-Resistant Barrier Systems

- Extends protection from sill to roof line, fully adhered and permanently attached
- Code-approved water-resistive barrier
- Single system provides moisture and air control
- Superior alternative to wraps and taped systems
- Provides the enhanced performance needed for today’s energy and moisture control
- Forms a robust wall system with wood frame walls

Booth #908

Moisture Dynamics in Residential Construction

Orlando, FL Feb 28, 2013

TREMCO Barrier Solutions