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
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℠**
  – 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

\[ T_3 = T_4 + (T_1 - T_4) \frac{R_3}{(R_1 + R_2 + R_3)} \]

*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 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 extremes of vapor diffusion could ever cause a problem
      - Normally it helps solve, *not cause*, problems
• **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 ft², 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 m², per mm of mercury*.
  - 1.00 Metric Perms = 0.66 US Perms
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
- Indispensable tool for moisture study
- Used to determine vapor flow direction and ‘driving force’
Moisture Dynamics Fundamentals

Water Vapor Pressure

Relative Humidity, %

Dry Bulb Temperature, °F

Wet Bulb and Dew Point Temperature, °F

Dew Point

Relative Humidity

Dry Bulb

Wet Bulb

0.0 1.0
Moisture Dynamics
Fundamentals

• **Exercise: Moisture flow direction, out or in?**

  • Inside: 70° F, 40% RH          Outside: 55° F, 80% RH  
  • **IN**
  • Inside: 70° F, 40% RH          Outside: 55° F, 50% RH  
  • **OUT**
  • Inside: 70° F, 40% RH          Outside: 90° F, 20% RH  
  • **NEITHER, NO NET FLOW**
Moisture Dynamics

Flow Direction: out or in?

- Inside: 70° F, 40% RH  IN  Outside: 55° F, 80% RH
Moisture Dynamics
Flow Direction: out or in?

- **Inside:** 70° F, 40% RH  **OUT**  **Outside:** 55° F, 50% RH
Moisture Dynamics

Flow Direction: out or in?

- **Inside:** 70° F, 40% RH  NEITHER  **Outside:** 90° F, 20% RH
Moisture Dynamics

Flow Direction: out or in?

- **Inside**: 70°F, 40% RH
- IN-large
- **Outside**: 90°F, 80% RH
### Water Vapor Pressure (.01 inch Hg)

<table>
<thead>
<tr>
<th>°F \ RH %</th>
<th>100</th>
<th>70</th>
<th>40</th>
<th>10</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<tr>
<td>0</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
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<td>20</td>
<td>10</td>
<td>7</td>
<td>4</td>
<td>1</td>
<td>0</td>
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<tr>
<td>40</td>
<td>25</td>
<td>17</td>
<td>10</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>60</td>
<td>52</td>
<td>37</td>
<td>21</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>80</td>
<td>103</td>
<td>72</td>
<td>41</td>
<td>10</td>
<td>2</td>
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<tr>
<td>100</td>
<td>194</td>
<td>135</td>
<td>77</td>
<td>19</td>
<td>4</td>
</tr>
<tr>
<td>120</td>
<td>345</td>
<td>242</td>
<td>138</td>
<td>34</td>
<td>7</td>
</tr>
<tr>
<td>140</td>
<td>589</td>
<td>412</td>
<td>236</td>
<td>59</td>
<td>12</td>
</tr>
</tbody>
</table>

\[
V_P (100 \, F, \, 2\% \, RH) = V_P (0 \, F, \, 100\% \, RH)
\]

\[
V_P (120 \, F, \, 100\% \, RH) = 50 \times V_P (20 \, F, \, 70\% \, RH)
\]
Moisture Dynamics Fundamentals

### Wall Permeance Humidity Dependence

<table>
<thead>
<tr>
<th>Material</th>
<th>RH %</th>
<th>25</th>
<th>35</th>
<th>45</th>
<th>55</th>
<th>65</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drywall &amp; Paint</td>
<td>25</td>
<td>4.0</td>
<td>5.7</td>
<td>7.4</td>
<td>9.0</td>
<td>10.7</td>
<td>12.4</td>
</tr>
<tr>
<td>OSB &amp; WRB</td>
<td>25</td>
<td>0.4</td>
<td>0.8</td>
<td>1.0</td>
<td>1.3</td>
<td>1.6</td>
<td>3.8</td>
</tr>
</tbody>
</table>

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?

Maximum Possible Wall Cavity Interior RH% January Weather - Full Moisture Equilibrium

[Graph showing relative humidity percentages for different wall cavity locations: Drywall surface, FG mid-cavity, OSB surface. The graph includes data for Minneapolis, Lexington, and Tampa.]
Moisture Dynamics Fundamentals

• What amount flows in what length of time?
• Equation for vapor transport
• \[ W = 0.000053 \times A \times P \times T \times \Delta VP \]

  \[ W = \text{weight of water (pounds)} \]
  \[ A = \text{transport area (ft}^2\text{)} \]
  \[ P = \text{permeability of transport medium (US perms)} \]
  \[ T = \text{time (hours)} \]
  \[ \Delta VP = \text{difference in vapor pressure of water vapor in inches of mercury} \]

• \( P \) and \( \Delta VP \) values change with Temp and RH
Moisture Dynamics
Fundamentals

- **System permeance of OSB Plus WRB**
  - $P_S = P_1 \times P_2 / (P_1 + P_2)$ 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
Muscle Dynamics
Fundamentals

Realistic Wall Cavity Interior RH%
3 Months (Dec - Feb) - Diffusion Limited

Relative Humidity %

Drywall surface  FG mid-cavity  OSB surface

Wall Cavity Location

Minneapolis  Lexington  Tampa

Moisture Dynamics
Fundamentals

Realistic Wall Cavity Interior RH%
3 Months (Dec - Feb) - Diffusion Limited

Relative Humidity %

Drywall surface  FG mid-cavity  OSB surface

Wall Cavity Location

Minneapolis  Lexington  Tampa
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

<table>
<thead>
<tr>
<th>Month</th>
<th>VPD</th>
<th>Flow</th>
<th>Liquid-applied (16)</th>
<th>House Wrap (58)</th>
</tr>
</thead>
<tbody>
<tr>
<td>July</td>
<td>0.22</td>
<td>in</td>
<td>0.29</td>
<td>0.33</td>
</tr>
<tr>
<td>October</td>
<td>0.03</td>
<td>out</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>January</td>
<td>0.17</td>
<td>out</td>
<td>0.22</td>
<td>0.25</td>
</tr>
<tr>
<td>April</td>
<td>0.05</td>
<td>out</td>
<td>0.06</td>
<td>0.07</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Month</th>
<th>VPD</th>
<th>Flow</th>
<th>Potential Moisture Vapor Movement via Air Leakage Through OSB+WRB (Cups water/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Liquid-applied (16)</td>
</tr>
<tr>
<td>July</td>
<td>0.22</td>
<td>in</td>
<td>1.6</td>
</tr>
<tr>
<td>October</td>
<td>0.03</td>
<td>out</td>
<td>0.2</td>
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<td>12.2</td>
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</tr>
<tr>
<td>9.0</td>
<td>3.6</td>
</tr>
</tbody>
</table>

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

Air leakage rate and differences are conservative
• 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
  – 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

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

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?
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