Learning Objectives

At the end of this program, participants will be able to:

1. Understand the functions of materials used to achieve control of heat, air, and moisture in the building envelope.
2. Understand the mechanics of moisture movement in building assemblies.
3. Understand the properties of wood and wood products that relate to heat, air, and moisture transfer and the conditions that can lead to mold and decay.
4. Evaluate various building envelope designs for moisture performance strengths and potential risks.
Quest for the “perfect wall”

The Perfect Wall by J. Lstiburek
www.buildingscience.com

Cross-laminated timber (CLT)

Courtesy of Darryl Byle, www.crosslamsolutions.com
WoodWorks

Case Study

CLT Milestone in Montana

Cross Laminated Timber Makes its Mark with The Long Hall

It happened so quickly that most design and construction professionals probably missed it: but when the first commercial building project in the U.S. constructed with cross laminated timber (CLT) was completed in 2017, it opened the door for cross-laminated timber to enter the building industry.

The Long Hall in Helena, Montana exemplifies many of the benefits of CLT construction—speed of installation, environmental and aesthetic benefits of exposed wood structure, long spans, and a two-story structure took just five days to erect, and gave the owner a sustainable, energy-efficient building.

woodworks.org

A ‘Company of Discovery’ Discovers Wood

Promega Uses Innovative Mix of Cross-Laminated Timber and Glulam for New Facility

You can tell a lot about a company by the way they treat their clients and employees. You can also tell a lot by the way they build their buildings.

Promega, a leading biotech firm headquartered in Madison, Wisconsin, calls itself as a company of discovery. “That’s their business, biological discovery, and this philosophy of discovery crosses over into everything they do,” said Dave Russell, from Archway Consulting, design consultant for Promega. The example of the offices is to design their new client and staff space, called The Crossroads, through a process of discovery—and not decision. The wood was one of those discoveries. In the end, we used glulam beams and cross laminated timber (CLT) to make a statement that this is a special and unusual space.”

woodworks.org
Buildings that endure

Hōryū Gakumonji temple, Japan, 8th c.

Heddal stave church, Norway, early 13th c.
Perfect design?

- Perfect execution on the construction site?
- Perfect building operation and maintenance?
- How “robust” or “tolerant” is the design?
- Able to recover from unexpected conditions?

Robust design

1. Recognize hazards that cause moisture damage
2. Minimize risk of wetting → Design principles and control layers
3. Maximize drying potential

The Perfect Wall by J. Lstiburek
www.buildingscience.com

Courtesy of Steve Easley
Hazards

- Rain water intrusion
  - Risky roof design
  - Flashing errors (windows, doors, deck ledgers, roof-wall intersections)
- Reservoir claddings not adequately separated from structural sheathing
- Untreated wood below grade
- Ice dams
- Unusually high indoor humidity levels
- Damp foundations
- Construction moisture

Loads

Drivers

- Liquid water flow
  - Gravity
  - Capillary action
  - Momentum (wind-driven)
  - Air pressure
- Vapor transfer by air flow
  - Air pressure difference
- Vapor diffusion
  - Vapor pressure difference
ASHRAE/DOE/IECC climate zones

Moisture loads – precipitation
Typical annual values

Horizontal surface

Vertical surface

20 inches → 100 lb/ft²
40 inches → 200 lb/ft²
60 inches → 300 lb/ft²

50-100 lb/ft²

Depends on
• Climate
• Wall orientation
• Building geometry
• Exposure
Moisture loads – winter vapor flow

Playback seasonal values for cold climate

Vapor carried by air leakage

Outdoors - cold
Indoors + warm

1 lb/ft²

Depends on
• Indoor humidity levels
• Leakage paths
• Pressure difference

Vapor diffusion (assuming 1 perm vapor retarder)

Outdoors cold low V.P.
Indoors warm high V.P.

0.1 lb/ft²

Depends on
• Indoor humidity levels
• Vapor permeance

Moisture storage capacity of wood

Amount of moisture in 1 ft³ at 50% RH:

Air............... 0.0006 lb
XPS............... 0.005 lb
Gypsum.......... 0.2 lb
Wood............. 2 lb

Depends on
• Indoor humidity levels
• Leakage paths
• Vapor permeance

Benefits of storage capacity

• Wood can store moisture when humidity rises and give it off when humidity drops
• Buffering reduces humidity peaks and troughs
• Analogous to thermal mass
• Lowers risk of moisture damage
• Wood-frame wall with plywood/OSB sheathing has much greater buffering capacity than steel-stud wall with gypsum sheathing

Solar-driven inward diffusion

• Reservoir cladding
  • Brick veneer
  • Stone veneer
  • Stucco
  • Cement board, etc.
• Wetted by rain
• Later warmed by solar radiation
• Strong drive for inward vapor diffusion
• Avoid impermeable interior layers
  • Polyethylene
  • Vinyl wall covering
**Thresholds for damage**

- Corrosion of embedded fasteners
- Mold growth

**Mold growth**

- Nutrient source
- Oxygen
- Suitable temperature
- Available moisture
  - Surface RH above 80% near room temperature
  - (higher surface RH necessary at lower temp)
- Time for initiation of growth depends on moisture and temperature conditions

**Bulk Water Management**

**Design principles**

- Deflection
- Drainage
  - Water shedding surface
  - Water-resistive barrier
- Drying
- Durable materials

*Rain Control in Buildings* by J. Straube  
www.buildingscience.com  
Image courtesy of APA:  
www.apawood.org
Roof overhangs

Reduce wind-driven rain load on walls

Data source: Survey of building envelope failures in the coastal climate of British Columbia, Morrison Hershfield, 1996

Drained/ventilated claddings

• Improved water management:
  – Drainage
  – Capillary break
  – Pressure moderation
• Improved drying of cladding and sheathing
• Reduced inward vapor drive from reservoir claddings

Further info: All About Rainscreens by M. Holladay
www.greenbuildingadvisor.com

Water-resistive barriers

• Function: drain liquid water that passes the cladding
• Many options:
  – Asphalt-impregnated building paper
  – Plastic building wraps
  – Fully-adhered membranes
  – Liquid-applied membranes
  – OSB with integral WRB, taped
  – Rigid foam, taped

Further info: All About Water-Resistive Barriers by M. Holladay
www.greenbuildingadvisor.com

Courtesy of APA, www.apawood.org
Air Leakage

Problems with uncontrolled air leakage

- High energy cost
- Comfort issues
- Noise issues
- Air quality issues
- Moisture problems

Further info: Air Flow Control in Buildings by J. Straube
www.buildingscience.com
Ventilation fans, air distribution, duct leakage

Air barrier systems

- Must be continuous, durable, rigid or supported, able to withstand pressure in both directions
- Approaches
  - Airtight drywall approach
  - Sealed interior membranes
  - Spray polyurethane foam
  - Taped rigid sheathing
  - Sealed exterior membranes

Further info: Air Barrier Association of America
www.airbarrier.org

Vapor Diffusion

- High concentration → low concentration
- High temperature → low temperature

Basic design principles

- Assess winter and summer vapor drives
- Select assembly that is
  1. not vulnerable to moisture accumulation
  2. as vapor-open as possible to maximize drying potential
Vapor permeance categories

<table>
<thead>
<tr>
<th>Vapor impermeable</th>
<th>Vapor semi-impermeable</th>
<th>Vapor semi-permeable</th>
<th>Vapor permeable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I VR</td>
<td>Class II VR</td>
<td>Class III VR</td>
<td>(not considered a VR)</td>
</tr>
<tr>
<td>0.1 perm</td>
<td>1 perm</td>
<td>10 perms</td>
<td></td>
</tr>
</tbody>
</table>

polyethylene foil, Kraft-faced batt, vapor retardant paint, latex paint, gypsum board, fibrous insulation

2012 IBC and IRC wall requirements

- Class I or II vapor retarders shall be provided on the interior side of frame walls in Zones 5, 6, 7, 8 and Marine 4.
  - Exceptions:
    1. Basement walls.
    2. Below-grade portion of any wall.
    3. Construction where moisture or its freezing will not damage the materials.

Vapor permeance can depend on RH

- Wood, wood-based materials, “smart vapor retarders” become more permeable as RH increases
- This allows assemblies to dry more rapidly
Vapor diffusion in wood

Wood based panels

Perm rating at 1/2 inch thickness

Types of rigid insulation

<table>
<thead>
<tr>
<th>Type</th>
<th>R-value/inch</th>
<th>Vapor permeance at 1”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foam plastics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expanded polystyrene</td>
<td>3.7 – 4.3</td>
<td>2 – 4</td>
</tr>
<tr>
<td>Extruded polystyrene</td>
<td>5.0 – 5.6</td>
<td>0.7 – 1.4</td>
</tr>
<tr>
<td>Polyisocyanurate</td>
<td>5.0 – 6.0</td>
<td>&lt; 0.1 (foil-faced)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 – 4 (glass-fiber-faced)</td>
</tr>
<tr>
<td>Glass fiber, semi-rigid board</td>
<td>3.5 – 4.2</td>
<td>&gt; 10</td>
</tr>
<tr>
<td>Mineral fiber, rigid board</td>
<td>3.5 – 4.3</td>
<td>&gt; 10</td>
</tr>
<tr>
<td>Wood fiber insulation board</td>
<td>2.7 – 4.0</td>
<td>&gt; 10</td>
</tr>
</tbody>
</table>
Temperature effect – ci

- Exterior ci reduces risk of cold weather moisture accumulation by warming interior materials such as wood structural sheathing.

Dew point calculations – caveats

- Only steady-state vapor diffusion
- Do NOT include:
  - Wind-driven rain
  - Liquid water movement
  - Air movement
  - Effects of sun and night sky radiation
  - Moisture storage
  - RH-dependent vapor permeance
  - More than one dimension

Vapor permeance effects – ci

- Vapor-tight exterior ci
  - Impedes outward drying
  - Reduces inward vapor drive from reservoir claddings
- Vapor-open exterior ci
  - Does not impede outward drying
  - May be vulnerable to inward vapor drive from reservoir cladding; select WRB with appropriate vapor resistance

Drying in both directions

- Ventilated cladding
- Gypsum board/latex paint
- Plywood/OSB
- Vapor-open ci
- Vapor-open WRB

Joni Mitchell, Water and Walls by J. Lstiburek
www.buildingscience.com
Drying outward

Ventilated cladding
Vapor-open ci
Vapor-open WRB

Gypsum board
Vapor retarder
Plywood/OSB

Drying inward

Reservoir cladding
Vapor-tight ci

Gypsum board/latex paint
Plywood/OSB

Avoid double vapor retarders

Cladding
Vapor-tight ci

Gypsum board/latex paint
Vapor retarder
Plywood/OSB

Cladding attachment with ci

• Furring strips/long screws
• Low thermal conductivity spacers
• Thermally isolated metal brackets

Macbeth Does Vapor Barriers by J. Lstiburek
www.buildingscience.com
Summary: key points for moisture design

• Minimize rain penetration
  – Roof overhangs, rainscreen cladding where needed
  – Proper detailing of WRB, flashing at interfaces
• Minimize air leakage moisture accumulation
  – Continuous air barrier system
  – Exterior cladding reduces risk
• Minimize solar-driven inward moisture from reservoir claddings
  – Ventilate the cladding
  – Design assemblies to dry inward
• Manage wintertime vapor diffusion in cold climates
  – Interior vapor retarder if necessary (smart vapor retarder preferable)
  – Sufficient thickness of exterior cladding
• Maximize drying potential
  – Design assemblies to dry in at least one direction appropriate to climate
  – The most robust designs can dry in both directions

Further information

• Water Management Guide, Joseph Lstiburek
• High Performance Enclosures, John Straube
• Building Science for Building Enclosures, John Straube and Eric Burnett
• Designing the Exterior Wall, Linda Brock
• ASTM Manual, Moisture Control in Buildings: The Key Factor in Mold Prevention
• The JLC Guide to Moisture Control


epa.gov/iaq
Questions?

This concludes The American Institute of Architects Continuing Education Systems Course

Sam Glass
USDA Forest Products Lab
svglass@fs.fed.us