Durability and hygrothermal performance of building envelope

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Content of presentation

1. Large-scale envelope testing
2. Air movement, air leakage and surface coefficient
3. Wood modeling
4. Whole building performance assessment
1. Full scale testing

Simulated rain infiltration

Summer condensation
Stochastic determination of water leakage risks

Using

– leakage due to defects in rain penetration chamber
Patterns of redistribution of water depending on material surface properties
Large-scale test - Wetting method
Finding ratio of water leakage into windowsill defect
Using weather data to determine wind-driven rain
Set up of wall assemblies in the Chamber

Gypsum access panels for gravimetry
Wetting

Method of rainwater insertion
Experimental Results

The graph shows the moisture content over time for different locations on a wall. The x-axis represents time in days, ranging from 0 to 63, while the y-axis represents moisture content in percent. The graph is divided into three phases:

- **Wetting phase** - This phase shows an initial increase in moisture content, particularly noticeable in the wet areas where the moisture content spikes.
- **Drying phase 1** - During this phase, there is a noticeable decrease in moisture content, indicating the start of the drying process.
- **Drying phase 2** - This phase continues the drying process, with some areas showing a more gradual decrease in moisture content.

The different locations on the wall are labeled as follows:

- **Wall 16 row A Left 1**
- **Wall 16 row A Center**
- **Wall 16 row A Right 1**
- **Wall 16 row B Left 1**
- **Wall 16 row B Right 1**
- **Wall 16 row C Left 1**
- **Wall 16 row C Right 1**
- **Wall 16 row D Left 1**
- **Wall 16 row D Center**
- **Wall 16 row D Right 1**
- **Wall 16 row D Right 2**

Each location has a unique line color and marker style that helps in distinguishing the data for that particular location.
Experimental Results – Sheathing

OSB-sheathed walls
Plywood-sheathed walls
Fiberboard-sheathed walls

Test 1
Test 2
Parametric analyses – loading duration

Global M in the bottom plate

<table>
<thead>
<tr>
<th>Month</th>
<th>Interior $p_v$ [Pa]</th>
<th>Exterior $p_v$ [Pa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>995</td>
<td>539-604</td>
</tr>
<tr>
<td>May</td>
<td>1070</td>
<td>945-953</td>
</tr>
<tr>
<td>June</td>
<td>1461</td>
<td>1391-1463</td>
</tr>
<tr>
<td>July</td>
<td>1827</td>
<td>1600-1682</td>
</tr>
<tr>
<td>August</td>
<td>1827</td>
<td>1552-1680</td>
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<tr>
<td>September</td>
<td>1070</td>
<td>1142-1333</td>
</tr>
<tr>
<td>November</td>
<td>995</td>
<td>794-854</td>
</tr>
</tbody>
</table>
On-going test

Full height walls

Climate of
  august
  september
  october
  november

More control of water dripping pattern

Monitoring of moisture content gradient
OSB  fiber board
2. Role of air movement

Air movement

Surface coefficients

Material-air interaction
Testing of flat roofs insulated with cellulose fiber with different air leakage paths
Results

Exposure in hours for all cavities to moisture and temperature

Legend
- 0 hour
- 1 to 49 hours
- 50 to 99 hours
- 100 to 299 hours
- 300 and more

Zone of conditions leading to fungi growth
Moisture Performance of Leaky Exterior Walls with Added Insulation

Air leakage configurations

- **Long leakage path**
  - Indoor
  - 1/8" X 14" (2 mm X 360 mm)
  - Outdoor

- **Concentrated leakage path**
  - Indoor
  - 1 1/4" 30 mm Ø
  - Outdoor
  - 12" (300 mm)

- **Distributed leakage path**
  - Indoor
  - 42 holes, 3/16" (4 mm) Ø each
  - Outdoor
  - 12" (300 mm)

8'-0" high (2.4 m)
Results - isohygrons

Long path

Wetting

Day 0

Day 31

Day 45

Day 72

Day 73

Day 97

Day 119

Cold side

Warm side

Wetting

Drying

MC [%]

Day 0 Day 31 Day 45 Day 72 Day 73 Day 97 Day 119

MC (%)
Modeling and experimental work towards quantification of air leaks through the building envelope
Standards methods have been developed to find the precise locations of air leakage using infrared thermography.

marianne bérubé, 9/26/2006
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marianne bérubé, 9/26/2006
Stochastic determination of air leakage paths and related risks

Using
- Infrared thermography
- PIV
- CFD
Required for modeling, determination of surface coefficients for heat and mass transport
Determination of surface coefficients for heat and mass transport

Using
- laminar flow tunnel measurements
- microtome

Determination of convective transfer coefficients as a function of moisture content, surface roughness, air velocity
Determination of surface coefficients for heat and mass transport

Using
- CFD
Determination of Surface Coefficients with CFD

Chilton-Colburn Analogy: 

\[ h_m = \frac{h_c}{\rho c_p Le^{2/3}} \]
Velocity Boundary Layer Results

- Semi-Empirical Equation - Laminar Sublayer
- Semi-empirical Equation - Log-law
- Empirical Equation - Spalding (1961)
- k-e standard
- k-e RNG
- k-e realizable
- k-w standard
- k-w SST
- Spalart-Allmaras
- RSM
- WF - ke
- WF - kw
Temperature Boundary Layer Results

- Semi-empirical Equation - Laminar Sublayer
- Semi-empirical Equation - Log-law
- $k-e$ standard
- $k-e$ RNG
- $k-e$ realizable
- $k-w$ standard
- $k-w$ SST
- Spalart-Allmaras
- RSM
- WF - $k-e$
- WF - $k-w$

Graph showing the relationship between $T^+$ and $y^+$ for different turbulence models.
Convective Heat Transfer Coefficient Results

\[ St_x = \frac{C_{fx}/2}{1 + 12.8(\Pr^{0.68} - 1)\sqrt{C_{fx}/2}} \]

\[ Nu_x = 0.032 \Re^{0.8} \Pr^{0.43} \]
Combined heat and vapour transfer

1) Air flow
2) Convective heat transfer
3) Convective vapour transfer
4) Radiation
5) Thermal Diffusion
6) Vapour Diffusion
Modeling Exercise

Outlet

Adiabatic and impermeable wall

Air flow

Inlet

20.5 mm

y

37.5 mm

498 mm

Gypsum

Adiabatic and impermeable wall

x

Locations of RH and Temperature to be presented in spreadsheet
Modeling Exercise

\[ U(y) = \frac{3}{2} U_{av} [1 - 4(y/b)^2] \text{ m/s} \]

\[ U_{av} = 0.82 \text{ m/s} \]

Note: Not to scale
Modeling Exercise

\[ U(y) = \frac{3}{2} U_{av} \left[ 1 - 4 \left( \frac{y}{b} \right)^2 \right] \text{ m/s} \]

\[ U_{av} = 0.82 \text{ m/s} \]

Smallest Cell Heights:

- 30 elements: \( dy = 0.0001556 \text{ m} \)
- 44 elements: \( dy = 0.0003145 \text{ m} \)

Note: Not to scale
Modeling Exercise – RH Results
3. Wood modeling

Moisture movement in wood

Multi-scale approach
Required for modeling, orthotropic numerical model of the material wood

Currently modeled as homogeneous isotropic material
Water distribution

Microscopic view of wet wood
Orthotropic numerical model of the material wood

Using
- scanning electronic microscopy
- light microscopy
- mercury porosimetry
- helium pictometer
- pressure plates
- permeance tests
- sorption curves
Orthotropic numerical model of the material wood

Using
- Micro-focus X-ray
X-ray measurements of free water uptake in spruce

TANGENTIAL

RADIAL

LONGITUDINAL

5 min  14 min  30 min  47 min  60 min
Orthotropic numerical model of the material wood

Using multi-scale approach

Macroscale

Mesoscale

Cellular scale
MODELLING ON THE CELLULAR SCALE

lumen

wall

axisymmetric problem

pit
flow in lumen/pit solved by front-tracking method

Quasi static pressure equation
\[ \nabla \left( K \left( \nabla P_l + \rho_l g \cos \phi \right) \right) - S = 0 \]

Darcian flux equation
\[ u = \frac{\partial z}{\partial t} = -\frac{K}{\rho_l} \left( \nabla P_l + \rho_l g \cos \phi \right) \]

\[ p_c = \frac{4\sigma \cos \theta}{b} \]
SUBCELLULAR SCALE

Figure 19: Fluorescent tori in water-sprinkled spruce (above) and tori in fresh spruce (below). Scale bar is 10 μm.
Fig. 3.12. Center Surface view of the radial wall of a coniferous tracheid, showing a bordered pit. Left The same pit in section, arrows indicating the path of water from one tracheid into the next. Right Section showing the valve-like action of the torus. T torus; M pit membrane; B pit border. (Bailey 1913)
Fig. 1.11. Bordered pit of eastern hemlock (*Tsuga canadensis*), solvent-dried from green condition. The pit membrane consists of the net-like margo and the central torus. (Transmission electron micrograph courtesy W.A. Côté)
MODELLING ON THE SUB-CELLULAR SCALE

CFD modelling of flow

\[ Q = \xi \Delta P \]
MODELLING ON THE SUB-CELLULAR SCALE

Contours of velocity magnitude in a pit centerplane (half of pit cross-section)
MODELLING ON THE MESOSCALE
measurements modeling of one ring
Orthotropic numerical model of the material wood

multi-scale modeling

Macroscale orthotropic homogenized

Mesoscale continuum model

Cellular scale mixed model

Micro scale CFD
Conclusion

a global picture of our research program
Climatic loadings

Modeling of hygrothermal performance

Durability

exterior

interior
Stochastic
determination of water
leakage risks

Modeling of
hygrothermal performance

Durability

probability of
climatic conditions

probability of
defects
Modeling of hygrothermal performance

Durability

Stochastic determination of air leakage risks

probability of climatic conditions

probability of defects

Modeling of hygrothermal performance
Climatic loadings

Modeling of hygrothermal performance

Durability