Field Evaluation of Thermal and Moisture Response of Highly Insulated Wood-frame Walls

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Session 9: Walls – Hygrothermal Performance & Durability,
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Overview

1. Overview
2. Project background & motivation
3. Project approach
4. Performance assessment
5. Defining performance attributes
6. Wall configurations
7. Test protocol & monitoring period
8. Results from field study
9. Summary
Project background

- **Background on and motivation for project**
- Homebuilders* have interest in providing homes that meet or exceed ENERGY STAR® requirements and are “durable”
  - ENERGY STAR® Program: Intended to promote & advances energy efficiency in Canada - supported by US Environmental Protection Agency
  - ENERGY STAR® qualified new home - 20% more energy efficient than home built to code (on average)
**Project background**

Key questions of interest to industry and industry stakeholders**
- Demonstrate compliance to NBC code (*NBC § 9.36 / Min. $R_{eff}$-value for walls)
- Do highly-insulated wall assemblies nominally perform ‘adequately’?
  - When compared to a NBC-compliant reference wall
  - Adequate performance as relates to thermal and hygrothermal performance when subjected to Canadian climate extremes

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>HDD</th>
<th>e.g. Location</th>
<th>$R_{eff}$</th>
<th>*NBC compliant Wall assembly 2 X 6-in. @ 16-in. o.c.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z4</td>
<td>&lt; 3000</td>
<td>Vancouver, Victoria</td>
<td>15.8</td>
<td>R19 (GF batt insulation)</td>
</tr>
<tr>
<td>Z5</td>
<td>3000-3999</td>
<td>Toronto</td>
<td>17.5</td>
<td>R22 (GF batt insulation)</td>
</tr>
<tr>
<td>Z6</td>
<td>4000-4999</td>
<td>Ottawa, St. John’s</td>
<td>17.5</td>
<td>R22 (GF batt insulation)</td>
</tr>
<tr>
<td>Z7A</td>
<td>5000-5999</td>
<td>Edmonton</td>
<td>17.5</td>
<td>R22 (GF batt insulation)</td>
</tr>
<tr>
<td>Z7B</td>
<td>6000-6999</td>
<td>Whitehorse</td>
<td>21.9</td>
<td>R22 (batt) + R5 (rigid)</td>
</tr>
<tr>
<td>Z8</td>
<td>&gt;8000</td>
<td>Yellowknife</td>
<td>21.9</td>
<td>R22 (batt) + R5 (rigid)</td>
</tr>
</tbody>
</table>

**Agencies / Associations supporting adoption of ENERGY STAR® homes: e.g. CMHC / NRCan / CHBA - Canadian Home builders association**
Project background

Key questions of interest to Industry

• Compliance with NBCC
  • i.e. equal or better “performance” for “moisture control” as compared to NBCC specified “Reference wall”

• Moisture control ⇒ control of effects of water entry and condensation

• Lack of moisture control ⇒ “Moisture control problems”?

  “Moisture control problems”?  
  • Risk to water uptake and subsequent formation of mold or rot by moisture sensitive components in wall assembly
  • “MEWS cladding study”*
**Project objective & approach**

- Investigate risk of condensation in wall assemblies having different levels of thermal resistance (R-value)
- Monitor thermal and hygrothermal response of a set of 3 wall assemblies to local climate conditions over ~ 9 month period
- Wall exposed to natural and local climate effects in NRC’s Field Exposure of Walls (Test) Facility (FEWF)
**Project objective & approach**

- Wall exposed to local climate effects
  - Each year monitor 3 wall assemblies over exposure period
  - Exposure period: January to September (cold, mild & warm months)

- Results from field study
  - Phase 1 / Yr 1 – 1st set 3 walls having exterior insulation \((R4 – R5)\)
  - Phase 2 / Yr 2 – 2nd set of 3 walls – various insulation types

**FEWF**
Field Exposure of Walls test Facility

Buildings XII (2013) – VIP insulation / retrofit
Performance assessment

Performance of wall assemblies based on performance attributes of selected areas of interest within wall

- Performance attributes considered: mold risk index*
- Selected areas: e.g., sheathing panel in contact with WRB membrane

Adequate performance for “alternative” code solution:

- Wall assemblies exhibit performance as good or better than Reference code-compliant wall assembly
- Should performance of wall assemblies be found inadequate in comparison to Reference wall – not a suitable solution
Performance attribute: mold index

- Indicator of risk to formation of mold or rot fungi
- Based on T, RH conditions and time
- **Does not predict likelihood of occurrence**
  - Would additionally depend on several other factors

- Mold fungi cause no damage to wood other than discoloration – but considered a precursor to decay
- Decay fungi actually weaken wood structure
- Decay only occurs above fiber saturation point (i.e. >27-30% moisture content of wood or >97% RH)
- Most wood-decay fungi exist at temperatures from 10 to 40 °C

Anagnost*, S. E. (2011), Wood Decay, Fungi, Stain and Mold, New England Kiln Drying Association Meeting, Oneonta, NY; *Chair and Associate Professor, SUNY, Syracuse, New York
**Mould Index criterion**

Most recent model by *Viitanen et al*

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Table 1. Mold Index for Experiments and Modeling
(New Determinations for Index Levels 3 and 4 are Presented in Bold)

<table>
<thead>
<tr>
<th>Index</th>
<th>Description of Growth Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No growth</td>
</tr>
<tr>
<td>1</td>
<td>Small amounts of mold on surface (microscope), initial stages of local growth</td>
</tr>
<tr>
<td>2</td>
<td>Several local mold growth colonies on surface (microscope)</td>
</tr>
<tr>
<td>3</td>
<td>Visual findings of mold on surface, &lt; 10% coverage, or &lt; 50% coverage of mold (microscope)</td>
</tr>
<tr>
<td>4</td>
<td>Visual findings of mold on surface, 10%-50% coverage, or &gt; 50% coverage of mold (microscope)</td>
</tr>
<tr>
<td>5</td>
<td>Plenty of growth on surface, &gt; 50% coverage (visual)</td>
</tr>
<tr>
<td>6</td>
<td>Heavy and tight growth, coverage about 100%</td>
</tr>
</tbody>
</table>

Wall configurations with structural sheathing

1. Gypsum board
2. Vapour Barrier (WVP = 60 ng/(Pa.s.m^2))
3. Top plate
4. Bottom plate
5. Fiber insulation (R-24)
6. OSB
7. WRB (WVP = 1400 ng/(Pa.s.m^2))
8. Exterior Insulation:
   (a) EPS of 1 in thick (R4/in.)
   (b) XPS of 2 in thick (R5/in.)
   (c) MF of 3 in thick (R4/in.)
9. Air
10. Vinyl siding installed on 19 mm strapping (WVP = 40-70 perms, S.V. Glass, Building Science Corporation, 2010)
## Wall configurations – Nominal R-values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Wall 1</th>
<th>Wall 2</th>
<th>Wall 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x6 Wood-Framing Cavity Insulation</td>
<td>Batt Insulation of R-24</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Exterior Insulation Details</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Type</strong></td>
<td>EPS</td>
<td>XPS</td>
<td>Mineral Fibre</td>
</tr>
<tr>
<td>Thickness (in)</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Dry Density (kg/m³)</td>
<td>18</td>
<td>26</td>
<td>122</td>
</tr>
<tr>
<td>Dry Thermal Conductivity (W/(m•K))</td>
<td>0.0369</td>
<td>0.0290</td>
<td>0.0347</td>
</tr>
<tr>
<td>Total R-value (ft²•hr•°F/BTU)</td>
<td>3.91</td>
<td>9.95</td>
<td>12.47</td>
</tr>
<tr>
<td>R-value ((ft²•hr•°F/BTU)/in)</td>
<td>3.91</td>
<td>4.97</td>
<td>4.16</td>
</tr>
</tbody>
</table>

Approx. Nominal Total R-Value of Insulation

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>34</td>
<td>36</td>
<td></td>
</tr>
</tbody>
</table>
Phase 1 (WA set: 1, 2, 3)

Dimensions are in inch

**Total R-36:**
- R-12 MF (3-in.)
- R-24 GF (5.5-in.)

**Total R-34:**
- R-10 XPS (2-in.)
- R-24 GF (5.5-in.)

**Total R-28:**
- R-4 EPS (1-in.)
- R-24 GF (5.5-in.)
Phase 2 (WA set: 4, 5, 6)

Total R-40:
- R-39.5 Cellulose (11-in.)

Total R-45:
- R-16 SPF (2.4-in.)
- R-29 GF (6.6-in.)

Total R-34:
- R-10 XPS (2-in.)
- R-24 GF (5.5-in.)
## Test protocol over monitoring period

### Phase 1 (2013/14)

<table>
<thead>
<tr>
<th>Period</th>
<th>Interior conditions</th>
<th>Exterior conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperature (°C)</td>
<td>RH (%)</td>
</tr>
<tr>
<td>A (175 days)</td>
<td>21</td>
<td>35</td>
</tr>
<tr>
<td>B (20 days)</td>
<td>21</td>
<td>50</td>
</tr>
<tr>
<td>C (40 days)</td>
<td>21</td>
<td>Variable / natural</td>
</tr>
<tr>
<td>D (100 days)</td>
<td>21</td>
<td>Variable / natural</td>
</tr>
</tbody>
</table>

### Phase 2 (2014/15)

<table>
<thead>
<tr>
<th>Period</th>
<th>Interior conditions</th>
<th>Exterior conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperature (°C)</td>
<td>RH (%)</td>
</tr>
<tr>
<td>A (40 days)</td>
<td>21</td>
<td>35</td>
</tr>
<tr>
<td>B (9 days)</td>
<td>21</td>
<td>Variable / natural</td>
</tr>
<tr>
<td>C (47 days)</td>
<td>21</td>
<td>Variable / natural</td>
</tr>
<tr>
<td>D (167 days)</td>
<td>21</td>
<td>Variable / natural</td>
</tr>
</tbody>
</table>
Air leakage measurements / 0.1 L/s–m² @ 75 Pa

<table>
<thead>
<tr>
<th>Project Phase</th>
<th>Wall</th>
<th>( \xi ) (L/min) = a ( \Delta P^n )</th>
</tr>
</thead>
</table>
|               |      | \begin{tabular}{l|l|l|}
|               | a    | n  |
| Phase 1       |      |    |
| W1            | 73.5 | 0.320 |
| W2            | 75.9 | 0.316 |
| W3            | 53.4 | 0.300 |
| Phase 2       |      |    |
| W4            | 0.685 | 0.989 |
| W5            | 0.654 | 0.766 |
| W6            | 0.593 | 0.953 |

*\(\Delta P\) in Pa

\[
\xi = a \left( \Delta P_{tot} \right)^n
\]

\(n\) (avg) = 0.69 \approx 0.7
Overview

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- Summary
Response of wall assembly W1 (EPS)

Monitoring period 2013/14

Temperature [T⁺]; Relative humidity [RH⁺] @ interior OSB surface; Dew point [T⁺]

Hygrothermal
Results – Phase 1

Phase 1: No condensation evident for any walls; Mold index < 1.1

- **Total R-28:**
  - R-4 EPS (1-in.)
  - R-24 GF (5.5-in.)

- **Total R-34:**
  - R-10 XPS (2-in.)
  - R-24 GF (5.5-in.)

- **Total R-36:**
  - R-12 MF (3-in.)
  - R-24 GF (5.5-in.)
Response of moisture detection strip to presence of moisture in wall
H – Response of W5

Total R-34:
- R-10 XPS (2-in.)
- R-24 GF (5.5-in.)

W5: Mold index < 1.8
Results – Phase 2

Phase 2: Mold index for all walls < 1.8

**Total R-40:**
R-39.5 Cellulose (11-in.)

**Total R-34:**
R-10 XPS (2-in.)
R-24 GF (5.5-in.)

**Total R-45:**
R-16 SPF (2.4-in.)
R-29 GF (6.6-in.)
Phase 1: No condensation evident for any walls; Mold index < 1.1

All walls meet or exceed code (NBC §9.36) requirements irrespective of C-Zone

Phase 2: Mold index < 1.8

W4 / W6: Zero Ready
## Proposed Walls for Phase III (FY 2015/2016)

<table>
<thead>
<tr>
<th>2015-2016 walls</th>
<th>Wall-2015-1</th>
<th>Wall 2015-2</th>
<th>Wall 2015-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>R24 + R5 1 inch XPS</td>
<td>Wall components</td>
<td>Wall components</td>
<td>Wall 2015-3 OSB as vapour barrier</td>
</tr>
<tr>
<td></td>
<td>• Vinyl siding</td>
<td>• Vinyl siding</td>
<td>• Replace poly vapour barrier with interior OSB taped for one of the walls to demonstrate the effectiveness of a smart vapour barrier.</td>
</tr>
<tr>
<td></td>
<td>• 1.5 in wide x 7/16&quot; thick furring strip installed vertically</td>
<td>• 1.5 in wide x 7/16&quot; thick furring strip installed vertically</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 1 inch XPS rigid foam insulation (exterior insulation)</td>
<td>• Wood-based diffusion board</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Sheathing membrane</td>
<td>• 2 x 10 studs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 11 mm OSB wood-sheathing</td>
<td>• Wood fibre insulation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 2x6 nominal stud cavity with R24 glass fiber insulation batts</td>
<td>• 11 mm OSB wood-sheathing (interior air and vapour barrier)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 6 mil poly air/vapour barrier</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• ½ inch painted drywall</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Notes:</td>
<td>XPS a low permeance product compared to (&gt;60ng) EPS</td>
<td>Service wall interior</td>
<td>Wall-2015-1 with poly vapour barrier replaced with OSB plywood. BC solution - wood sheathing from between studs and XPS to interior; cost the same.</td>
</tr>
<tr>
<td></td>
<td>Does not meet inboard-outboard ratio; change requirement in NBC (§ 9.27) &amp; see what happens</td>
<td>• 2x4 studs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• mineral wool or wood fibre insulation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• gypsum board</td>
<td></td>
</tr>
</tbody>
</table>
Thank you!

Acknowledgements —

CMHC – Canada Mortgage and Housing Corporation
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Hamed Saber
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