Better Walls & Bigger Buildings

SCALING HIGH PERFORMANCE

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Colin Shane | M. Eng., P.Eng., P.E.
Principal, Senior Project Manager
Outline

→ Introductions
→ Bigger and higher performance
→ Building form
→ Insulation strategies
→ Air tightness
Who is RDH?
New Construction
Existing Buildings
Research, Energy & Communications
Energy Efficiency & Sustainability
Building Enclosure Control Functions

1 – Water is defined here as precipitation (rain, snow, hail, etc.) and ground water
2 – Vapor is separately defined here as the water vapor in air, as well as condensate moisture
Maslow’s (and Colin’s) Hierarchy of Needs
High-Performance Buildings

→ “… integrates and optimizes all major high-performance building attributes, including energy efficiency, durability, life cycle performance, and occupant productivity.”

Energy Policy Act of 2005
Sec. 914. Building Standards

→ Reducing operational energy WHILE increasing durability

“There is no more sustainable a building than a durable one.”
- Michael Aoki-Kramer
Challenges – Bigger Buildings

→ Tall Structures
  → More repetitive, more exposed, difficult access, need for more speed
  → Less focus on roof and more on walls for weather protection

→ Low to Mid-rise Structures
  → Easier access to walls from ground
  → Greater focus on roof for weather protection than walls
Challenges – Bigger Buildings

→ Increased height = increased rain deposition at upper floors and cumulative run-down at lower levels

→ Water shedding features become more critical – continuity, drip edges, flashings etc.

→ Increased exposure to moisture during construction (severity & length of time)

→ Need for more robust in-service water penetration control strategy – good practice: drained & ventilated rainscreen walls
Advantages – Bigger Buildings

- Six units of surface.
  One unit of floor.

- Two units of floor.
  Six units of surface.
Advantages – Bigger Buildings

Three units of floor.
Six units of surface.

Six units of floor.
Six units of surface.
Form factor: Simple shapes save money & energy

North Park Passive House: First multi-unit PH building in B.C.

Photo: Bernhardt Construction
Form factor: Simple shapes save money & energy

- 2/3 of labor costs
- 1/3 of labor costs
- 10 kWh / m²a

Graphic courtesy Mark Bernhardt
Form factor = 1:1
Form not an issue at 30 stories

Power Tower, Linz, Austria
RHW2 Tower, Vienna
Cornell Tech Residence, NYC
Why We are Insulating More

→ Increasing energy efficiency expectations are **changing** insulation requirements in codes
  
  → Passive House
  
  → Increasing code requirements in residential and commercial codes

→ **Better accounting for thermal bridging** means not overlooking bridging by details and interfaces
How to Insulate More

Stuff It?

Wrap It?
More than one way to get there…
Adding Insulation to Wood-Frame Walls

Baseline
2x6 w/ R-22
batts = ~R-16
effective

Exterior Insulation:
R-20 to R-40+ effective
• Constraints: cladding attachment, wall thickness
• Good durability

Deep or Double Stud:
R-20 to R-40+ effective
• Constraints
  wall thickness
• Fair durability, sensitive to air/vapour

Split Insulation:
R-20 to R-40+ effective
• Constraints: cladding attachment
• Good durability with proper design
Types of Insulation & Cladding Attachment

→ **Continuous Girts** – Rigid or Semi-rigid boards or spray-foam (i.e. almost anything works)

→ **Intermittent Clip & Rail Systems** – Semi-rigid boards or spray-foam (i.e. flexibility & ease of installation is key)

→ **Screws through Insulation** – rigid insulation boards (i.e. stiff enough to support compression load)
Cladding Attachments – A Race to the Top

→ Rock Bottom – a 60-80% loss in effective R-value
Cladding Attachments – A Race to the Top

→ Near Bottom – a 50-70% loss in effective R-value

*Horizontal Z-girts*
Cladding Attachments – A Race to the Top

→ Hardly Better – a 40-60% loss in effective R-value

Crossing Z-girts
Cladding Attachments – A Race to the Top

→ Getting A Bit Better – a 30-50% loss in effective R-value (spacing dependent)
Cladding Attachments – A Race to the Top

→ Better but Not Great – a 25-50% loss in effective R-value (spacing dependent)

Galvanized Steel Clip & Rail
Cladding Attachments – A Race to the Top

→ Improving Still – a 15-40% loss in effective R-value (spacing dependent & impacted negatively by partial continuous framing)

Galvanized Steel Clip & Rail w/ Thermal Break
Cladding Attachments – A Race to the Top

- High performance – a 10-40% loss in effective R-value (spacing dependent)
Optimizing Clip Spacing
Cladding Attachments – A Race to the Top

- High performance – a 10-35% loss in effective R-value (spacing dependent)

Stainless Steel Clip & Rail
Cladding Attachments – A Race to the Top

→ Higher Performance - Improved Stainless Steel <10% to 20% loss in effective R-value (system and spacing dependent)
Cladding Attachments – A Race to the Top

→ High performance – a 5-20% loss in effective R-value (spacing & screw type dependent)
Case Study: Bullitt Center – Split Insulated Non-Combustible Wall Assembly

→ Metal panel cladding
→ 1” horizontal metal hat tracks
→ 3 ½” semi-rigid mineral fiber (R-14.7) between 3 ½” fiberglass clips (16” x 48” spacing)
→ Fluid applied vapor permeable WRB/air barrier on gypsum sheathing
→ 6” mineral fiber batts (R-19) between 6” steel studs (outboard of slab edge)
→ Gypsum drywall

→ Effective R-value R-26.6
Bullitt Center – Exterior Wall Construction
Screws Through Insulation Highly Effective

Percent Effectiveness of Exterior Insulation (Typical Range)

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Galvanized Steel Screws

Stainless Steel Screws
Screws through Insulation – Chi-Values

<table>
<thead>
<tr>
<th>R_{si}-Value Ext. Insulation (m^2K/W)</th>
<th>Nominal R_{si}-Value Wall (m^2K/W)</th>
<th>Chi (W/K)</th>
<th>Chi/Area (W/m^2K)</th>
<th>Effectiveness of Exterior Insulation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12''x16''</td>
</tr>
<tr>
<td><strong>a) 2x6 Exterior Insulated Wood Framed Wall with R_{si} 3.87 Cavity Fill, #10 screws</strong></td>
<td></td>
<td></td>
<td></td>
<td>12''x16''</td>
</tr>
<tr>
<td>4''</td>
<td>2.82</td>
<td>6.71</td>
<td>0.0010</td>
<td>0.0082</td>
</tr>
<tr>
<td>8''</td>
<td>5.64</td>
<td>9.51</td>
<td>0.0012</td>
<td>0.0098</td>
</tr>
<tr>
<td>12''</td>
<td>8.45</td>
<td>12.33</td>
<td>0.0013</td>
<td>0.0103</td>
</tr>
<tr>
<td><strong>b) 7'' Cross Laminated Timber (CLT) Exterior Insulated, #12 screws</strong></td>
<td></td>
<td></td>
<td></td>
<td>12''x16''</td>
</tr>
<tr>
<td>10''</td>
<td>7.04</td>
<td>8.84</td>
<td>0.0018</td>
<td>0.0145</td>
</tr>
<tr>
<td><strong>c) 3 5/8'' Steel Stud Wall no Cavity Fill, #10 screws</strong></td>
<td></td>
<td></td>
<td></td>
<td>12''x16''</td>
</tr>
<tr>
<td>4''</td>
<td>2.82</td>
<td>3.44</td>
<td>0.0076</td>
<td>0.0613</td>
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</tbody>
</table>
Screws Through Insulation

→ Gaining popularity to meet increasing R-value requirements

→ Uncertainty about:
  → How to do it
  → Allowable loads
  → Fastener types
  → Fastener spacing
  → Angle of installation
  → Deflection
Design and Forces

Service Load State
(Section View)
Early Testing – ca. 2010
Early Testing
Early Testing

Figure 9: Short term deflection testing results (4" thick insulation)
Expanded Testing & Research
Expanded Testing & Research

→ 3”, 6”, 9” and 12” thicknesses of insulation

→ Different insulation types (mineral wool and XPS) and different compressive strengths

→ Different screw head types (pan and countersunk)
Testing – Insulation Type

Load Displacement for Different Insulation Types (6” Thick)
Cladding Weights

→ Most claddings are “light weight” with only a few select products being heavier
Testing – Insulation Type

Load Displacement for Different Insulation Types (6” Thick)

- Stucco
- Vinyl, Metal, Wood Siding
- Stone Veneer
- Stucco
- 1/64”

RDH BUILDING SCIENCE
Testing – Insulation Thickness

Load Displacement for Different Mineral Wool Thicknesses

Displacement (mm)

Load (lb)

Load (kg)

Displacement (1/1000")

Vinyl, Metal, Wood Siding

Stone Veneer

Stucco

Thick Stone Veneer, Very Heavy Cladding

Thin Stone Veneer

RDH

3 inch 6 inch 9 inch 12 inch
Testing – Insulation Thickness

→ For the record, this is what 12” of insulation looks like…
Testing – Different Fastener Arrangements

Horizontal
(90°)

1:6
(80.5°)

45°

Truss
(90° + 45°)
Testing – Fastener Arrangements

Load Displacement for Different Fastener Arrangements

Displacement (mm)

Load (lb)

Load (kg)

Displacement (1/1000")

- Red: Countersunk @90°
- Green: Pan Head @90°
- Blue: Countersunk @1 in 6
- Yellow: Countersunk @45°
- Purple: Truss System (per truss)
Testing – Fastener Arrangements

Load Displacement for Different Fastener Arrangements

Displacement (mm)

Load (lb)

Displacement (1/1000")

- Countersunk @90°
- Pan Head @90°
- Countersunk @45°
- Countersunk @1 in 6
- Truss System (per truss)

Vinyl, Metal, Wood Siding
Thick Stone Veneer, Very Heavy Cladding
Thin Stone Veneer
Stucco
Testing – Is this just the fastener?

- Countersunk @90°
- Countersunk @45°
- No Insulation @90°
- Countersunk @1 in 6

Load (lb) vs. Displacement (1/1000")
Testing – What if we miss the stud?

Load Displacement for Screw Penetration into Framing vs. Non-Framing (9" Insulation) and 8D Nail Rainscreen (No Insulation)

Displacement (mm)

Load (lb)

Displacement (1/1000")

Rainscreen 8D Nail – 2x6 SPF Framing – 3/4" Plywood - Test #2

5/8" Plywood – 1/2" Plywood - Test #1

Vinyl, Metal, Wood Siding

Stucco

Thin Stone Veneer

Thick Stone Veneer, Very Heavy Cladding

Rainscreen 8D Nail (First Loading)

2x6 SPF Framing

3/4" Plywood – Test #2

5/8" Plywood

1/2" Plywood - Test #1

What if we miss the stud?
Deflection - How much is too much?

→ Difficult to define precise deflection limit but many claddings can easily accommodate 1/8” (125 mil, 3mm) deflection

→ Staged loading of the support system helps to “pre-deflect” the strapping prior to cladding completion

→ Can see it is different than strapping direct to sheathing, but not much
Deflection - How much is too much?

→ Comparison: Wood Shrinkage
  → One wood-frame storey: Double top plate, single bottom plate, 8’ ceilings, rim joist
  → Assume 19% initial MC and 10% final MC at equilibrium with interior
  → Wood shrinkage due to drying
    › 0.25%/MC across grain
    › 0.0053%/MC with grain

→ Approximately 3/8” (375mil, 10mm) shrinkage in one storey height
  › Roughly 10x more than measured deflection in test for any arrangement
Testing – Ultimate Failure Modes

- Withdrawal
- Tensile Failure
- Pull-Through
Testing – Ultimate Failure Mode

4 ½” (115 mm)  
807 lbs

5 1/8” (131 mm)  
719 lbs

5 ¼” (133 mm)  
0 lbs (failure)
Testing – Ultimate Failure Mode

½” Plywood: Fastener Pulled Out of Sheathing
(> 250 lbs per fastener)
Case Study – Bella Bella Passive House
Air Leakage – Wasted Energy
Air Penetration Control – Why?

→ Code requirement
  → IECC C402.5

→ Moisture
  → Air holds moisture that can be transported and deposited within assemblies.

→ Energy
  → Unintentional airflow through the building enclosure can account for as much as 50% of the space heat loss/gain in buildings.
Air, Vapor, or Water Barrier?

→ Air is made up of oxygen, nitrogen, and water vapor (water vapor is the smallest molecule)
Air Leakage vs. Vapor Diffusion
Types of Air Barrier Systems

- **Loose Sheet Applied Membrane** – Taped Joints & Strapping
- **Sealed Gypsum Sheathing** – Sealant Filler at Joints
- **Liquid Applied** – Silicone sealants and silicone membrane at Joints
- **Sealed Plywood Sheathing** – Sealant & Membrane at Joints
- **Sealed Sheathing** – Membrane at Joints
- **Self-Adhered vapor permeable membrane**
- **Plywood sheathing with taped joints (good tape)**
Definitely Not An Air Barrier… But What Is?
Air Leakage - What are the results?

→ Previously very limited published data regarding in situ air leakage test results

→ General interest in results

→ ASHRAE Annual Conference

→ CEC and IECC include requirement for 0.4 cfm/sf
How Well Is the Industry Doing – WA State

Airtightness [L/(s·m²)] @ 75 Pa

- Leakiest tested
- Median & 1st/3rd quartile range
- Tightest tested
- Passive House Range equivalent ~ 0.6 ACH₅₀


54 Buildings, Oct 2015 RDH SEA Data
The Ramona – Building Enclosure Efficiency

2014 ASHRAE TECHNOLOGY AWARD CASE STUDIES

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Because the Ramona Apartments can't rely on tenant behavior for saving energy, the designers created an exceptionally airtight and thermally efficient building envelope. This included laying out the building in a U shape and choosing the right combination of windows and walls.

HONORABLE MENTION
RESIDENTIAL NEW
Affordable
And Efficient

BY ANDREW PAPE-SALMON, P.ENG., MEMBER ASHRAE; ED NISHIMURA, ARIEL LEVY, P.E., ASSOCIATE MEMBER ASHRAE
The Ramona Apartments

→ Architecture 2030 Challenge for reducing energy use.

→ In 2012 the building consumed 62% less energy than the average for residential buildings in the western region.
Getting to Lower Energy

LOAD REDUCTION

1. Building form
2. Enclosure
3. MEP
4. Renewables

Meeting loads as efficiently as possible
The Ramona – Massing & Layout for Energy

<table>
<thead>
<tr>
<th>Option</th>
<th>Shape</th>
<th>GSF/Ft²</th>
<th>Total Bldg. SF</th>
<th>FAR (40,000 SF site)</th>
<th>Hall SF/Ft²</th>
<th>Efficiency</th>
<th>Envelope Area</th>
<th>Fl. Area/Skin Ratio</th>
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<tbody>
<tr>
<td>1</td>
<td>O</td>
<td>29,500</td>
<td>177,000</td>
<td>4.43</td>
<td>2,600</td>
<td>91.2%</td>
<td>13,160</td>
<td>2.24</td>
</tr>
<tr>
<td>2</td>
<td>C</td>
<td>31,000</td>
<td>186,000</td>
<td>4.65</td>
<td>1,950</td>
<td>93.7%</td>
<td>11,860</td>
<td>2.61</td>
</tr>
<tr>
<td>3</td>
<td>U</td>
<td>30,750</td>
<td>184,500</td>
<td>4.61</td>
<td>2,020</td>
<td>93.4%</td>
<td>11,800</td>
<td>2.61</td>
</tr>
<tr>
<td>4</td>
<td>Double Bar</td>
<td>27,750</td>
<td>166,500</td>
<td>4.16</td>
<td>1,440</td>
<td>94.8%</td>
<td>12,800</td>
<td>2.17</td>
</tr>
<tr>
<td>5</td>
<td>H</td>
<td>31,500</td>
<td>189,000</td>
<td>4.73</td>
<td>2,050</td>
<td>93.5%</td>
<td>11,900</td>
<td>2.65</td>
</tr>
<tr>
<td>6</td>
<td>Crab</td>
<td>27,800</td>
<td>166,800</td>
<td>4.17</td>
<td>1,950</td>
<td>93.0%</td>
<td>12,900</td>
<td>2.16</td>
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<tr>
<td>7</td>
<td>Double E</td>
<td>29,150</td>
<td>174,900</td>
<td>4.37</td>
<td>1,470</td>
<td>95.0%</td>
<td>13,500</td>
<td>2.16</td>
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<tr>
<td>8</td>
<td>L + Point</td>
<td>29,500</td>
<td>177,000</td>
<td>4.43</td>
<td>1,540</td>
<td>94.8%</td>
<td>12,300</td>
<td>2.40</td>
</tr>
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</table>
Enclosure

- Wood framing (not “advanced”)
- R23 blown fiberglass
- Air barrier (Tyvek)
- High performance casement windows (U-0.26)
- Rainscreen cladding (brick veneer, fiber cement)
- Green roof with R30 polyiso
HVAC

- Electrical resistance in apartments
- Electric air to air heat pumps for common area heating and cooling, and for ventilation air
- Continuous balanced ventilation with heat recovery
  - Centralized system (two zones)
  - Fresh air directly ducted to each apartment
MEP

• High efficiency fluorescent lighting with controls
• High efficiency gas boilers for domestic hot water
  • Centralized system
  • Insulation at hot water distribution pipes
• Low-flow plumbing fixtures
• Water submeters at apartments
The Ramona – Air Barrier Construction
The Ramona – Air Leakage Testing
The Ramona - Results

Results

→ System (whole building)
  air tightness: 0.22 cfm/sf @ 1.57 psf

→ EUI = 22.9 (predicted)
→ EUI = 19.7 (actual)
→ EUI = 18.8 (actual, excluding commercial)
→ 2030 Challenge 2010 benchmark = 23
Discussion + Questions

FOR FURTHER INFORMATION PLEASE VISIT

→ www.rdh.com
→ www.buildingsciencelabs.com

→ Colin Shane - cshane@rdh.com