Building a Better Wall
[Support from DOE Building America Program]

EEBA: High Performance Home Summit
October 10, 2017

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University of Minnesota & NorthernSTAR

Patricia K. Gunderson
Home Innovation Research Labs
Introductions

• Patricia K. Gunderson
  – Sustainability Research Engineer
  – P.E., LEED AP BD+C, CPHC
  – Home Innovation Research Labs

• Patrick H. Huelman
  – Cold Climate Housing Coordinator
  – NorthernSTAR Project Lead
  – University of Minnesota
Audience Poll

Raise your hand if you’re a...

▪ Builder
▪ Program manager
▪ Home rater/energy prof
▪ Manufacturer/supplier

IF you're builder, then are you building to...

▪ Energy Star
▪ Net-Zero ready
▪ LEED, NGBS, Passive House
Wall System: Desired Outcomes

- Easy to Build
- Cost Effective
- Energy Efficient
- Durable
- Comfortable
- Readily available
- Healthy
- Resilient
# The Modern Enclosure Conundrum

<table>
<thead>
<tr>
<th>Build it to avoid every kind of moisture.</th>
<th>But imperfections happen in design, execution, and operation!!!</th>
</tr>
</thead>
</table>

- It gets wet from outside in and inside out!
- Therefore, all moisture susceptible materials must be able to dry in the proper direction.
  - that can be outward in winter; inward in summer
  - except below grade, which can only dry inward.
The Modern Enclosure Conundrum

• Has the traditional 2x6 cavity wall hit the end of the road?
  – Too little thermal insulation
  – Too little drying potential
    • in cold and/or humid climates
  – Too risky / not robust
    • requires high-end execution
The Modern Enclosure Conundrum

- The Risks Go Way Up With ...
  - Poor exterior bulk water control
  - Cladding that is not drained & vented
    - especially for reservoir claddings
  - Significant air-conditioning use
    - increased and longer use
    - lower indoor temperature and RH
High-Performance Enclosures

• A New Approach for ...
  – Walls
  – Roof
  – Slab
  – Foundation

• Move the structure to the inside and move the control layers to the outside ...
  – It simply works and works everywhere!!!

[Diagram: A wall, roof, and slab diagram with arrows indicating the movement of layers]

The “Perfect Wall”*

* BSI-001: The Perfect Wall
Joseph Lstiburek
Building Science Corporation
Connections Are Critical, Too!

* BSI-001: The Perfect Wall
Joseph Lstiburek
Building Science Corporation
The 4 Control Layers

• Every enclosure element must have four control layers ...
  – Water control
  – Air control
  – Thermal control
  – Vapor control
The 4 Control Layers

• Take the time to examine your schematics ...

Apply the pen line test...
Water Control Layer(s)

• General Overview
  – The intent is to keep water from reaching any moisture susceptible layers.
    • Primary drivers are gravity, wind, capillarity.
    • You can (should) take steps to reduce the drivers.

• This is absolutely essential,
  – especially as we remove drying potential with increased insulation, reduced air flow, and multiple vapor retarders!
Water Control Layer(s)

• Theoretical Framework: 3 D’s
  – Deflect
  – Drain
  – Dry
Air Control Layer(s)

• General Overview
  – The intent is to keep air from moving across the building enclosure carrying heat and moisture to locations that can create problems.
    • Primary driver is air pressures.
    • You can (and must) manage the pressure differences.

• This is absolutely critical in modern construction.
Air Control Layer(s)

• Where does it belong?
  – Inside
  – Outside
  – In between
  – Both

• In the past, it was generally thought the air control layer should be on the inside for cold climates and outside for hot-humid climates.
Thermal Control Layer(s)

• Goal: slow the transmission of thermal energy
  – The drive is from warm to cold
  – Defined by indoor and outdoor conditions
  – Temperature difference (delta T) defines the potential

• This is the easy one – R-value!
  – How much?
  – Where?
  – What type?
  – Geometry governs – weighted area
Vapor Control Layer(s)

• Goal: control vapor diffusion through wall materials.
  – The drive is from moist to dry
  – Defined by indoor and outdoor conditions
  – Vapor pressure difference defines the potential

• Pay special attention in ...
  – Very cold climates
  – Hot humid climates
  – High humidity environments
    • Follow code requirements
Vapor Control Layer(s)

• This is more of a strategy than a specific layer.
  – Higher potential vapor drive requires more care
  – The prevalence of air-conditioning means sometimes you must manage vapor from humid outdoors.
  – There must always be a clear drying direction
    • If anything gets wet, the only possibility for drying is by vapor diffusion
Vapor Control Layer(s)

• Theoretical Framework
  – Class 1 = < 0.1 perm  “impermeable”
  – Class 2 = 0.1 to 1.0 perm  “semi-impermeable”
  – Class 3 = 1.0 to 10 perm  “semi-permeable”
  – Class 4 = > 10 perm  “permeable”

• Follow local code
• Consider a variable-perm material, like “smart” vapor retarders or kraft facing
It’s Not That Complicated
(Cladding/Drainage/4 in 1 Control Layer/Structure)

* BSI-001: The Perfect Wall
Joseph Lstiburek
Building Science Corporation
A Residential Variation

* BSI-001: The Perfect Wall
Joseph Lstiburek
Building Science Corporation
How Much Exterior Insulation?

Thermal resistance (and boundary temps) govern the temperature of the surfaces within the assembly layers.

\[ T_{\text{back of sheathing}} = T_{\text{interior}} - (T_{\text{interior}} - T_{\text{exterior}}) \times \left( \frac{R_{\text{batt}}}{R_{\text{total}}} \right) \]
Condensation Potential

- Typical 2x6 cavity insulated wall in Chicago, IL
Condensation Potential

- 2x4 cavity insulated wall w/ R-7.5 in Chicago, IL
Ratio of Exterior to Interior R-Value*  
(Heating season vapor drive and condensation potential)

<table>
<thead>
<tr>
<th>Indoor RH</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>50</th>
<th>60</th>
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<tbody>
<tr>
<td>Dew point °C</td>
<td>-3.0</td>
<td>0.0</td>
<td>2.5</td>
<td>4.7</td>
<td>6.6</td>
<td>9.9</td>
<td>12.7</td>
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<tr>
<td>°F</td>
<td>26.6</td>
<td>32.0</td>
<td>36.6</td>
<td>40.5</td>
<td>44.0</td>
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<td>0</td>
<td>32</td>
<td>0.00</td>
<td>0.00</td>
<td>0.12</td>
<td>0.23</td>
<td>0.32</td>
<td>0.47</td>
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<tr>
<td>-5</td>
<td>23</td>
<td>0.08</td>
<td>0.19</td>
<td>0.29</td>
<td>0.37</td>
<td>0.45</td>
<td>0.57</td>
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<tr>
<td>-10</td>
<td>14</td>
<td>0.23</td>
<td>0.32</td>
<td>0.40</td>
<td>0.48</td>
<td>0.54</td>
<td>0.64</td>
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<tr>
<td>-15</td>
<td>5</td>
<td>0.33</td>
<td>0.42</td>
<td>0.49</td>
<td>0.55</td>
<td>0.60</td>
<td>0.69</td>
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<td>-20</td>
<td>-4</td>
<td>0.41</td>
<td>0.49</td>
<td>0.55</td>
<td>0.60</td>
<td>0.65</td>
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<tr>
<td>-25</td>
<td>-13</td>
<td>0.48</td>
<td>0.54</td>
<td>0.60</td>
<td>0.65</td>
<td>0.69</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Note that higher interior relative humidity combined with lower outdoor temps (larger delta T) requires more exterior insulation.

* High Performance Enclosures: John Straube, 2012
EP&B: Overview of Presentation

- The Problem
  - Why are existing solutions not good enough?
- The Solution
  - How does it meet industry’s needs?
  - What are the advantages?
  - What performance targets must it meet?
- The Research
  - Constructability
  - Structural Lab Testing
  - Moisture Monitoring
  - Cost Comparison
- Summary
  - Recommendations and Design Guidance
The Problem

- Need for energy efficiency
  - Strict code requirements
  - Rising energy costs
- Lack of market penetration for High-R walls
  - Cost
  - Complexity
  - Training
  - Manufacturer resistance
  - Low market adoption for exterior c.i. (~11%, residential, all thicknesses) and SIPs (< 5%)
- Need a basic option that can perform and be flexible (field-framing and panelization)
A Solution: EP&B

High-R walls with rigid foam insulation interior to the wood structural sheathing
EP&B: Characteristics

1. The bottom plate is one dimension larger than the studs.

2. The top plates are one dimension larger than the studs.

3. There is a layer of rigid insulation in the two-inch space between the stud framing and OSB sheathing.

4. Double rim board (beam) functions as a header, and is inset to provide space for a continuous insulation thermal break.
EP&B: Control Layers

Water –

• WRB, shingle-applied, fastened to OSB sheathing

OR

• Treated OSB sheathing detailed properly (liquid-applied or taped seams)
EP&B: Control Layers

Air –

• Rigid foam and framing, sealed as described, performs as the air barrier in addition to the vapor barrier

OR

• WRB, taped to itself and to transition members
**EP&B: Control Layers**

**Thermal** – two layers of insulation

- Rigid foam (1) protects cavity fill (2)
- Extended plates constitute <5% thermal bridge
- Can perform as the air barrier in addition to the vapor barrier
EP&B: Control Layers

Vapor – Two lines of defense:

• Rigid foam, sealed with caulk or ccSPF, is a distinct, centrally-located vapor control plane with effective drying to the direction from which the source moisture originated – exterior to the exterior and interior to the interior.

• Variable or Class II interior vapor retarder recommended in cold climates and any building with high indoor humidity: Kraft or “smart” vapor retarders
  ■ avoid a dual vapor retarder condition: HI recommends against poly sheeting or a Class I vapor retarder
  ■ follow local code requirements
EP&B: **Advantages**

- Suitable for use in all climate zones
- Flexible configurations to achieve above-code thermal performance even in CZ 8
- 95% of the wall area is free of thermal bridging
- Estimated cost: comparable to exterior c.i., $/sf of wall; in some cases $0.50 to $1.00 less than a comparable code wall with exterior c.i.
- Can be panelized for packaged delivery to the site
EP&B: Advantages

- Standard framing and air sealing techniques
- Relies on extended bottom and double top plates for wood structural panel attachment
- Uses standard nails in a common fastening schedule (3-1/2-in @ 3/6)
- Exterior OSB allows conventional methods for
  - Drainage plane treatment
  - Window installation
  - Cladding attachment
**EP&B: Advantages**

Exterior OSB allows use of IRC Table R703.3.2

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>NUMBER AND TYPE OF FASTENER</th>
<th>SPACING OF FASTENERS&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior wall covering (weighing 3 psf or less) attachment to wood structural panel sheathing, either direct or over foam sheathing a maximum of 2 in. thick.&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Ring shank roofing nail (0.148&quot; min dia.)</td>
<td>12 in. o.c.</td>
</tr>
<tr>
<td></td>
<td>Ring shank nail (0.148&quot; min dia.)</td>
<td>15 in. o.c.</td>
</tr>
<tr>
<td></td>
<td>#6 screw (0.138&quot; min dia.)</td>
<td>12 in. o.c.</td>
</tr>
</tbody>
</table>

<sup>a</sup> Fastener length shall be sufficient to penetrate back side of the wood structural panel sheathing by at least 1/4 in. The wood structural panel sheathing shall be not less than 7/16 in. in thickness.

<sup>b</sup> Spacing of fasteners is per 12 in. of siding width. For other siding widths, multiply “Spacing of Fasteners” above by a factor of 12’s, where “s” is the siding width in inches. Faster spacing shall never be greater that the manufacturer’s minimum recommendations.

*Instead of the complexity of Tables R703.15.1 and 703.15.2*
The Research: Test Homes:  Grand Rapids, MI

Finished houses appear conventional with clean sight lines.
Two EP&B Test Homes: Grand Rapids, MI

Once the EP&B walls are up, finish and detail just as you would a typical light-frame wall.
Two EP&B Test Homes: Building the Walls
Two EP&B Test Homes: Detailing
Observation: *tips and tricks*

- Caulk or spray foam all connections and transitions (or tape WRB as air barrier)
- Stagger sheathing joints and maintain thermal breaks at corners
- Control nailing angles at sheathing joints
- Pay attention to connections between factory-produced panels (not specific to EP&B!)
EP&B Construction Guide: Draft

Extended Plate and Beam Construction Guide DRAFT

Home Innovation Research Labs

May, 2017
Planning: Insulating Rigid Foam Layer

A table saw or circular saw is best for vertical cuts (rigid) in the rigid foam sheathing that provides the thermal break. Cross-cut the foam to fit between the plates using the table saw or, cut to match the full length of the studs. Consider the need and ensure that the rigid foam will be snug. 90 degree cuts avoid gapping. Lay the pre-cut rigid foam into place between the top and bottom plates, snap the studs. Don’t worry about a small bow in the rigid foam—the OSB will be stiff enough to overcome that, once it is nailed on.

Holland headers and cripples, take advantage of scrap foam pieces, and tack them into place with a few cap nails. All rigid foam joints should land on studs. In the EP&B configuration, the foam sheathing installed on the interior side of the OSB provides a distinct, centrally-located vapor control plane with effective drying to the direction where the source moisture comes from—in contrast to the exterior and interior to the interior. To secure this layer is uninterrupted, use manufacturer-approved tape (such as DOW Weathermate) to seal all seams between rigid foam panels and where they meet framing at the top and bottom plates. Check the spec. sheet to make sure the tape is approved for use on wood. A single line of 1/2-1/8-in. tape at the top of the wall can seal both the foam/plastic connection and the plastic/plastic connection. Tap the seams with a bead of pressure. where moisture vapor is high, such as in winter conditions in climate zones 6, 7, and 8. Fully detailed taping also allows the rigid foam layer to serve as the air barrier. Pre-cutting lengths of rigid foam is preferred, but if you do have to trim foam in place next to an extended plate, be sure to adjust the guide plate of the circular saw to ensure you do not cut into the lumber below.

ALTERNATE: If you do not have a table saw on site, you can cut a circular saw to cut the rigid foam sheathing in place stop the void. Lay the foam onto the wall, flipped to the bottom plate and overlapping the top plate. Use a few cap nails to hold the RPS in place, then snap a chalk line along the top edge coincident with the bottom of the first top plate. Use a circular saw to cut away the excess foam. Take care to cut the guide plate for 2-in. depth and cut the guide of the saw flat against the foam’s surface for a square cut to ensure a smooth line. The foam is then pressed into place between the plates and against the wall. Adjust the height of the circular saw to protect the framing.

Planning: Wood Structural Panel (WSP)

For required structural bonding to match the performance of the IRC prescriptive wall, the OSB must always be oriented vertically—no horizontal joints are allowed. All OSB and rigid foam joints must occur at studs, but not at the same stud—plan your sheet placement to avoid the occurrence of an OSB seam at the same stud where two sheets of rigid foam meet. That rigid foam joint tightly together, but provide the typical 1/4-in gap when installing OSB (a 1/8-in nail works great). When bulding a single long wall in two sections that will be attached once the walls are tipped up, plan for the overlap of the rigid foam and OSB, to maintain the staggered vertical joints (see photo, bottom left).

For the first two walls, generally the long walls on opposite sides of the building, you can composite all wall layers (including rigid foam and OSB) while the wall is laying flat on the floor deck. When building the perpendicular short walls, plan your outside corners to maintain the thermal break, which probably means leaving some gaps as both the rigid foam and the OSB, to be filled in after the wall is erected.

Plan your sheet: if the pre-cut studs are at 92-5/8-in., the new wall height will then 24 plates will be 97-3/4 in. A 48-ft sheet of plywood is 95-1/8 in. at 45-7/8 in., which makes it 1-5/8 in. short. You can apply that extra gap at the top and locate the first top plate (rather than the second top plate) for structural bonding, or you can split the difference by leaving a 5-1/4 gap at both top and bottom.

ALTERNATE: A third option for OSB placement vertically is to do what the Grand Rapids framing crew did. The first floor rose was 96 in. ungrounded breaker box from the outside plane to accommodate 2-in. of continuous insulation. To simplify air-sealing at the 3rd floor, our crew designed the walls so that the OSB would then be on the inside plate and extend down across the room, requiring some 9-ft OSB and some rare during setup.

The bottom edge of the OSB can be nailed to the sill plate, completing the framing connection. Additional nails at the sole plate can be much less frequent. This technique can be used even if the panel of OSB does not extend all the way down to the sill plate for connection. The structural connection will then be made at the sole plate, at center, and the top near the edge is non-committal, but useful for air-sealing. Occasional nails through the sill, so the load band keeps the connection tight, and a taper can be added at the bottom to support the siding.
Window and Door Openings

Removing both the rigid foam and the OSB in a single operation is the preferred method, saving time and effort. Double check that your penciled notes, the window and door openings will still be visible on the top face of the second top plate once the OSB is placed and nailed. Lay the OSB over the rigid foam and attach with 5-1/2-in. nails. Economize by using foam scraps at headers and cripple locations. Snap chalk lines at all vertical and horizontal opening edges.

CIRCULAR SAW: The cleaned cuts with the least debris will be made with a circular saw. A 7-1/4-in. blade is recommended to cut the full depth of the 3-in. rigid foam and the 1/4-in. OSB. Drill all four corners and snap chalk lines. Start the saw a few inches from the drilled corner and sink the blade into the OSB. Follow the chalk line on all four sides. Cut the OSB all the way to the drilled corner, but do not overcut – the short sections of rigid foam in each corner can be removed later with the 5-in. blade or a reciprocating saw. Follow similar steps of using a track saw.

ROUTER: Use a 4-in. (or longer) pilot panel bit with a self-driving tip and a cutting depth (flute) of at least 3-1/4-in. Push through each opening near a corner and use the 2x framing below the rigid foam as a guide. A long bit with a solid guide head is necessary to reach the full depth and seat against the 2x so the pass will be true. A router creates more debris than a circular saw.

ALTERNATE: Two Separate Cuts. Cut the rigid foam first with a reciprocating saw, then make a second pass with the circular saw to cut the OSB. This is more time-consuming, but has the advantage of providing some limited views of the framing, and is thus more forgiving. With practice, this can be done with very little time taken for measurements.

Once you have the framing in place, start by eating in the OSB, cut the openings out of the foam with the reciprocating saw. Use the 2x framing to guide the saw’s path – this should be both by eye and by feel. Although the cut is not clean, it’s strong enough to provide a good connection to the wood framing, if you keep the blade perpendicular and don’t remove too much material. Initially, you’ll guide the saw along the 2x by feel. Once the frame is cut out, a reciprocating saw can be used to remove the rigid foam from the opening. If you want to cut additional insulation (6.7) to the rim, now is the time. The Grand Rapids demonstration crew used a 1-in. rigid foam and made sure the thermal break was continuous at corners.

Water-Resistant Barrier (WRB)

Attach and detail the water-resistance barriers (WRB) when all openings have been cut, both top plates are nailed on and the OSB is attached per the EP&B’s Formwork Schedule. Fold back the WRB from wall edges and track it temporarily.

Rim Band

Lab tests confirm good structural performance with a single or double rim located at the exterior plane, but inserting the rim by 1 in. also meets IRC performance targets in lab tests, and improves thermal performance by making room for a continuous insulation layer of exterior rigid foam. A final option allows a 2-in. inset of the WRB prior the entire wall to assembly, and the sandwich formers connect to the sill plate. Illustrations at the bottom of this page.

If you intend to add continuous insulation (RI) to the rim, now is the time. The Grand Rapids demonstration crew used 1-in. rigid foam and made sure the thermal break was continuous at corners.
EP&B: Status

- Shear wall testing results:
  - Calculated Allowable Design Racking Shear Load Value is 256 lbs/ft. (plf)
  - AC269.1 2013: demonstrated IRC braced-wall equivalent
  - Meets baseline performance for both intermittent and continuous braced wall performance
  - Code language will be proposed to the IRC to include EP&B as a prescriptive braced wall
• Avg maximum unit shear load: **857 lbs/ft**; exceeds the **560 lbs/ft** target by **53%**
• Engineered Design: Allowable Racking Shear Load Value: **256 lbs/ft**
Intermittent Braced Walls: \textit{AC269.1 / ASTM E72}

<table>
<thead>
<tr>
<th>Wall Type</th>
<th>Max Shear Load (lb) (Peak)</th>
<th>Net Defl at Peak Load (in.)</th>
<th>Unit Shear, lbs/ft (plf)</th>
<th>Deflection at 23% load</th>
<th>Deflection at 46% load</th>
<th>Deflection at 200 plf</th>
<th>Deflection at 400 plf</th>
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</thead>
<tbody>
<tr>
<td>AC269.1 Criteria:</td>
<td>&gt;4,480</td>
<td>&gt;0.75</td>
<td>&gt;560</td>
<td>&lt;0.2</td>
<td>&lt;0.6</td>
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<tr>
<td>EPB 3/6-1</td>
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<td>3.35</td>
<td>882</td>
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<td>EPB 3/6-2</td>
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<td>EPB 3/6-3</td>
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<tr>
<td>EPB 3/6-Average</td>
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<td>3.62</td>
<td>858</td>
<td>0.134</td>
<td>0.359</td>
<td>0.127</td>
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</table>
Continuous Braced Walls: AC269.1 / ASTM E564
EP&B Moisture Data: Two Test Houses

Generally – accepted threshold indicating potential for moisture risk is 20% MC.

- 60+ sensors monitor moisture content and temperature in Studs, Plates and OSB
- RH and Dewpoint of various locations within the wall are tracked
- Average peak OSB moisture content less than 15%, well below accepted levels of risk
EP&B Moisture Data: Two Test Houses
August 2016 to August 2017: Framing ≤ 16% MC

Good moisture performance for framing with both ccSPF flash and blown fiberglass AND R-15 Kraft-faced fiberglass batts
EP&B Moisture Data: Two Test Houses
August 2016 to August 2017: OSB ≤ 17% MC

Good moisture performance for framing with both ccSPF flash and blown fiberglass AND R-15 Kraft-faced fiberglass batts
**EP&B Moisture Data: OSB Outlier**

August 2016 to August 2017

**Outlier:** rises above 25% OSB MC, dries to 11%, nearby stud performing well, 3 out of 4 OSB sensors in same bay show good performance.

**Presumption:** a construction imperfection (or damage to sensor)

**Conclusion:** Even with local intrusion of moisture, EP&B walls can still dry out adequately
EP&B: Summary

- Highly Constructable
- Good structural performance
- Good thermal performance
- Good moisture performance
- Cost effective
- Simplicity with low risk
- Can be factory-panelized
**EP&B Summary:**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>EP&amp;B 2x4/2x6</th>
<th>EP&amp;B 2x6/2x7.5*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid Insulation Choice</td>
<td>EPS</td>
<td>XPS</td>
</tr>
<tr>
<td>EP&amp;B Nominal Insulation</td>
<td>13+8</td>
<td>13+10</td>
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<table>
<thead>
<tr>
<th>Climate Zone</th>
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<tr>
<td>CZ 1, 2</td>
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<td></td>
<td>Exceeds</td>
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</tbody>
</table>

* Denotes actual dimension of 7.5-in (ripped from a 2x10)

# For compound requirements (“+”) the first value is cavity insulation, the second is continuous insulation or insulated siding

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An EP&B wall can provide above-code performance in every US climate zone.
EP&B: Making the Case

- Who should consider EP&B?
  - Builders looking to incorporate rigid foam for the first time
  - Builders who already use exterior c.i. but would like a more conventional approach that can reduce cost, complexity and risk
  - Builders who would like to deliver rigid foam insulation through factory panelization, with associated time savings and quality control

- How to find design guidance?
  - DOE Building America website
  - Home Innovation website
Building a Better Wall
[Support from DOE Building America Program]

Patrick H. Huelman
University of Minnesota &
NorthernSTAR
Affordable, Solid Panel “Perfect Wall” System

Research Project Update – Quarter 4

- Developed two complete MonoPath house designs (bid sets)
- Completed modeling for ZERH, energy, and moisture performance
- Began construction of Twin Cities - Habitat for Humanity home
  - new enclosure contractor/builder was trained with this house
  - panel erection observed by other partners and potential builders
  - structure completed in 2 days; dried-in and secure in 8 days
- Partners onboard to build eight more houses by winter
  - bringing on a new community/building partner

Project Partners:
- MonoPath
- Twin Cities Habitat for Humanity
- Urban Homewoks
- Thrive Builders (Denver, CO)
- City of Minneapolis
- Building Knowledge, Inc
- Huber Engineered Woods & Unico

<table>
<thead>
<tr>
<th>Team and Partners</th>
<th>Topic Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>NorthernSTAR</td>
<td>Topic 1: Moisture Risk Management and High-Performance Envelope Systems</td>
</tr>
<tr>
<td>University of Minnesota</td>
<td></td>
</tr>
</tbody>
</table>
MonoPath (SEP-ETMMS)

• The primary objective is to validate:
  – a new enclosure technology
  – an innovative single enclosure contractor delivery

• The project will measure and compare:
  – performance (energy, moisture, air)
  – constructability and quality control
  – Costs (materials, labor, etc.)

• Demonstrate market acceptance
  – focus on affordable housing
Wall Comparisons

• MonoPath (SEP-ETMMS) will be compared to:
  – Base Code
  – DOE Zero Energy Ready Home
  – Hybrid Wall (Opti-MN)
Hybrid Wall
Review of Opti-MN Control Layers

• Water Control
  – Drainage behind cladding
  – “Peel & stick” membrane on sheathing

• Air Control
  – “Peel & stick” membrane on sheathing

• Vapor Control
  – “Peel & stick” membrane on sheathing

• Thermal Control
  – R-15 fiberglass in cavity
  – R-15 extruded polystyrene on exterior
University of Minnesota’s Team Opti-MN WINS TOP AWARD in DOE’s “Race to Zero” Student Design Competition
INTRODUCING | The Impact Home
OPTI-MN HYBRID WALL | Robust & Easy to Construct

Approachable and Appropriate Construction Materials and Methods

- Simplified design and shape
- Based on traditional construction materials and techniques
- Simplified ducting and hot water systems
OPTI-MN HYBRID WALL  |  Robust & Easy to Construct

- The air, water, and vapor control layer is over a traditional wood-frame wall
- Then rigid insulation, vented rainscreen, and siding is added to the exterior
- This approach limits moisture movement, yet facilitates bi-directional drying
Opti-MN (Hybrid) Summary

• Pros
  – Simple and familiar framing
  – No interior air sealing required; can glue drywall
  – High R-value; superior airtightness
  – Very robust; good drying potential both inside & out

• Cons
  – Cost of exterior control layers
  – Must hit the framing with exterior furring strips
MonoPath (SEP-ETMMS)

• Our working motto is simple:
  – Better Design, Better Systems, and Better Delivery
  – Provide Better Performance
  – At Lower Cost!

• Research hypotheses are straightforward:
  – This innovative building enclosure system outperforms conventional wood-frame construction at lower cost.
  – This innovative building delivery system ensures better QA/QC.
  – This optimized whole building system can deliver cost-effective Zero Energy Ready Homes for affordable housing.
Benefits of “Perfect Wall”

- Structure is kept warm/dry
- Control layers are simplified
- Continuous exterior insulation
- Critical control layers and materials are protected
- Back-ventilated cladding
- Sensitive materials can dry
- Can be used in any climate
Benefits of “Solid Panel”

- Reduces costs of the “Perfect Wall”
- Simplifies application of exterior insulation
- Requires less labor and less skill
- Speeds enclosure time (esp. dry-in)
- Stronger with enhanced protection (resilient)
Benefits of Single Enclosure Contractor

• Building process developed by MonoPath
  – reduces installation errors
  – speeds overall construction time
  – reduces overall construction cost

• More consistent performance outcomes
  – reliable insulation quality and performance
  – improved moisture management
  – remarkable and repeatable airtightness
Review of MonoPath Control Layers

• Water Control
  – Drainage behind cladding
  – “Peel & stick” membrane on wall panel

• Air Control
  – “Peel & stick” membrane on wall panel

• Vapor Control
  – “Peel & stick” membrane on wall panel

• Thermal Control
  – R-20 extruded polystyrene on exterior
Four homes built between 2001-2004; three in St. Paul and one in Minneapolis
Seven MonoPath homes built in St. Paul in 2014.
MonoPath Video

https://www.youtube.com/watch?v=lKpTf9u71dc
MonoPath Video Recap

• Foundation = typical with best practices
• Floor deck = mostly typical
• Enclosure (walls & roof) = 1 to 2 days w/ crane
  – Dried-in & Secure = 3 to 5 days
    • walls = primer, membrane windows, & insulation
    • roof = papered & shingled
• Interior framing & finishing = mostly typical
  – knock-down finish for exterior walls
  – electrical integrated in the baseboard and trim
MonoPath Summary

• Pros
  – Quick erection to dried-in & secured
  – Can use lower-skilled labor
  – Extremely robust
  – Significant strength advantages, but still testing?

• Cons
  – Certain design limitations until system is validated
  – Current upfront engineering costs
## Wall Comparison – Energy

<table>
<thead>
<tr>
<th>Plan = Cedar 2.0</th>
<th>HERS</th>
<th>Total Energy</th>
<th>Heating &amp; Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Energy (MMBtu)</td>
<td>Costs ($)</td>
</tr>
<tr>
<td>2015 MN Energy Code</td>
<td>70</td>
<td>135.6</td>
<td>$2140</td>
</tr>
<tr>
<td>Energy Star v3 (minimum)</td>
<td>60</td>
<td>114.0</td>
<td>$1935</td>
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<tr>
<td>DOE ZERH (minimum)</td>
<td>49</td>
<td>92.8</td>
<td>$1689</td>
</tr>
<tr>
<td>MonoPath (for TC-HfH)</td>
<td>44</td>
<td>81.5</td>
<td>$1536</td>
</tr>
<tr>
<td>Opti-MN (for TC-HfH)</td>
<td>43</td>
<td>79.3</td>
<td>$1521</td>
</tr>
</tbody>
</table>
Wall Comparison – Energy

![Energy Consumption Chart]

- **Energy Consumption (MMBtu/yr)**
- **Cedar 2.0 MN Energy Code**
- **Cedar 2.0 Energy Star v3**
- **Cedar 2.0 DOE ZERH**
- **Cedar 2.0 SEP-ETTMS Habitat**
- **Cedar 2.0 Opti-MN Habitat**
Wall Comparison – Energy

![Energy Costs ($/yr)](chart)

- **Cedar 2.0 MN Energy Code**
- **Cedar 2.0 Energy Star v3**
- **Cedar 2.0 DOE ZERH**
- **Cedar 2.0 SEP-ETTMS Habitat**
- **Cedar 2.0 Opti-MN Habitat**

- **heating**
- **cooling**
- **DHW**
- **lights+app**
- **service fee**

**U.S. Department of Energy**

**Energy Efficiency & Renewable Energy**

**Building America**

**U.S. Department of Energy**

**NorthernSTAR**

**University of Minnesota**

**Driven to Discover**
Wall Comparison – Condensation Analysis

Energy Star v3
Wall Comparison – Condensation Analysis
Opti-MN (hybrid)
Wall Comparison – Condensation Analysis
MonoPath
Wall Comparison – WUFI

Energy Star   Opti-MN (hybrid)   MonoPath
Wall Comparison – Costs

• Work in progress...
  – The Opti-MN costs more than the code minimum and base Energy Star.
  – The MonoPath cost less than the Opti-MN
    • Primarily due to framing material and labor savings.
  – We believe MonoPath will approach the same cost as the Energy Star, with a couple of caveats...
    • There is an upfront engineering cost premium.
    • There is a learning curve to capture labor savings.
    • Its superior airtightness demands a MUA system.
World-Class Research...

Building America Solution Center
BASC.energy.gov

...At Your Fingertips
Building a Better Wall
[with support from DOE Building America Program]

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MonoPath
http://www.mono-path.com/

Opti-MN
https://tinyurl.com/y9ssow8e

EP&B
https://tinyurl.com/y7xaf6pg
New Construction Guide to be published soon! Find it at the websites:
DOE Building America
Home Innovation Research Labs