Advanced Envelope Research for Factory-Built Housing

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Building America: Introduction
December 14, 2011

Mike Gestwick
Michael.Gestwick@nrel.gov
Introduction to Building America

• Reduce energy use in new and existing residential buildings
• Promote building science and systems engineering / integration approach
• “Do no harm”: Ensure safety, health and durability are maintained or improved
• Accelerate adoption of high performance technologies

www.buildingamerica.gov
Emanuel Levy is the President of The Levy Partnership, a multi-disciplinary consulting firm serving the housing industry. The Levy Partnership is the team lead for ARIES Collaborative, and is nationally known for their work in the housing arena, particularly in the area of industrialized, factory built modular and manufactured housing. Mr. Levy is also the Executive Director of the Systems Building Research Alliance, the non-profit research arm of the factory built housing industry. For nearly three decades, Mr. Levy has specialized in coordinating the work of multi-disciplinary teams, mainly focused on solving residential energy challenges. He is involved broadly in housing issues, having chaired ASHRAE committees, advised state, federal and international organizations on energy and green policy and technology, and has served as a member of the National Institute of Building Sciences Consultative Council.

Dr. Michael A. Mullens, PE is a leading authority in prefabricated homebuilding. He served as a faculty member in the Department of Industrial Engineering and Management Systems at the University of Central Florida, where he founded and led the UCF Housing Constructability Lab. He currently serves the industry as an engineering consultant, specializing in factory design and lean production.
Residential Energy Efficiency Technical Webinar
December 14, 2011 3:00 pm EST

Advanced Envelope Research for Factory Built Housing
ARIES Collaborative

• **Research-oriented:** ARIES focuses on reducing energy use in new and existing residential buildings by developing and delivering innovative energy efficiency strategies.

• **Innovation through collaboration:** ARIES is 50 members strong and growing. The team includes: home builders (factory and site), developers and owners, product suppliers, researchers, non-profit housing organizations...
Research Objective

Energy solutions for factory builders

• Provide factory homebuilders with high performance, cost effective alternative envelope designs that are part of a comprehensive solution for reaching net zero energy use

• Create product designs and fabrication methods that minimize total cost while maximizing product performance
Impetus

Regulatory pull, market push

• EISA (2007) requires that DOE develop new, far more stringent energy standards for manufactured homes. Thermal requirements for manufactured homes were last updated in 1994

• The factory building industry generally has few proven and cost-effective technologies for accomplishing such a major shift in envelope efficiency
Research Partners
Research Process

Phase 1  **Identification of Options**: identifying, vetting and selecting alternative, high-performance envelope technologies

Phase 2  **Preliminary Design/Development**: detailed design development, characterization and manufacturing process assessment of technologies. Paring of options

Phase 3  **Implementation and Testing**: prototyping, evaluation and testing of selected technologies
Phase 1: Identification of Options

Seven technologies
Identified by major insulation producers; and, vetted, debated and short-listed by leading factory home builders

1. Structural insulated panels for roof construction
2. Structural insulated panels for wall construction
3. Stud wall with structural insulative sheathing
4. Un-vented attic with insulating sheathing board
5. Flash and batt wall construction
6. Walls built of poured closed cell foam
7. Innovative new floor
Vetting the Options

Selection criteria

- System design
- Manufacturability
- Energy performance
- Code compliance
- Structural properties
- Cost (development, start up, recurring and maintenance)
# Qualitative Assessment Heat Map

<table>
<thead>
<tr>
<th>Option</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>Man.</th>
<th>Code</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Structural insulated panels or SIPs for ceilings</td>
<td>33 (7)</td>
<td>26 (3)</td>
<td>31 (5)</td>
<td>24 (4)</td>
<td>(6)</td>
<td>23 (5)</td>
<td>(4)</td>
<td>32 (6)</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2. Structural insulated panels or SIPs for walls</td>
<td>23 (2)</td>
<td>25 (2)</td>
<td>34 (6)</td>
<td>20 (1)</td>
<td>(5)</td>
<td>23 (5)</td>
<td>(3)</td>
<td>23 (4)</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>3. Stud wall with insulating sheathing board</td>
<td>23 (2)</td>
<td>24 (1)</td>
<td>20 (1)</td>
<td>20 (1)</td>
<td>(2)</td>
<td>10 (1)</td>
<td>(2)</td>
<td>17 (1)</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>4. Un-vented attic with insulating sheathing board</td>
<td>24 (4)</td>
<td>31 (7)</td>
<td>26 (4)</td>
<td>25 (5)</td>
<td>(3)</td>
<td>11 (2)</td>
<td>27 (5)</td>
<td>2</td>
<td>6</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>5. Flash and batt wall construction</td>
<td>11 (1)</td>
<td>29 (5)</td>
<td>25 (3)</td>
<td>23 (3)</td>
<td>(1)</td>
<td>20 (4)</td>
<td>(1)</td>
<td>20 (3)</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>6. Poured closed cell foam</td>
<td>25 (5)</td>
<td>29 (5)</td>
<td>22 (2)</td>
<td>27 (6)</td>
<td>(4)</td>
<td>19 (3)</td>
<td>19 (2)</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>7. Innovative new floor</td>
<td>28 (6)</td>
<td>28 (4)</td>
<td>31 (5)</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

Scores indicate the simple sum of the qualitative ratings. Figure in parenthesis is the rank for that rater. Key: red box = top pick; yellow box = second pick; green box = third pick.
Phase 2: Preliminary Design/Development

Options moving to Phase 2

1. Structural insulated panels for walls (SIPs)
2. Stud walls with insulative sheathing
3. Flash and batt wall construction

Plus a base case (baseline for measuring impact of the options)
Evaluation Parameters

Concurrent engineering
✓ Component design, material selection and assembly
✓ Thermal performance and moisture analysis
✓ Code compliance and structural performance
✓ Manufacturing process design and analysis
✓ Cost assessment
Identifying the Base case

Study assumptions

- Manufacturing plant: Clayton Homes, Bean Station, TN
- Climate: IECC map, zones 5 and 6
- Plant capacity: 1,000 homes (2,000 floors)
- Representative home features (e.g., 56’ x 28’ two-section home, 8’ ceiling height, 11% window area, etc.)
Base case - Design

Plan view

Wall framing:
2 x 6 Studs @ 16”/24” oc

Exterior siding

Exterior sheathing: 7/16” OSB or equal

Cavity Insulation type:
5-1/2” R-21 High density fiberglass batts

Interior finish:
1/2” Gypsum board or equal
Base case - Typical floor plan
Base case - Elevations

- **Front Elevation**
- **Left Side Elevation**
- **Rear Elevation**
- **Right Side Elevation**
1 - Structural Insulated Panels (SIPs) for Walls

- A sandwich panel comprised of expanded polystyrene insulation core between sheathing layers. The insulation core is glued to the sheathing creating a composite panel of high strength and rigidity.

- Panel composition:
  - **Core insulation:** Expanded polystyrene (EPS) blocks 5½” thick
  - **Sheathing:** 7/16” oriented strand board (24’ x 8’) on both sides
  - **Panel framing:** Surface spline with 1x or 2x top and bottom plates
  - **Interior finish:** Gypsum board or equal
SIPs - Strengths and Weaknesses

• **Strengths**
  - High structural strength with minimal thermal bridging
  - Speed and ease of construction
  - Fewer parts and joints reduce opportunity for errors in wall assembly

• **Weaknesses**
  - The very tight construction tolerance of SIP panels must be reflected in fabrication of interfacing components to prevent rework and delay
  - Panels are heavier than the other alternatives
  - Customized SIPs must be consistently produced to specification to minimize flow disruptions, which otherwise can slow home production
  - Relatively high cost
2 - Stud walls with Structural Insulative Sheathing

This wall design combines wood stud construction with a nearly continuous semi-structural foam board to achieve superior thermal performance and strength.
Insulative Sheathing - Strengths and Weaknesses

• **Strengths**
  - Combines some of the structural advantages of SIPS with improved thermal performance at a lower cost per R-value
  - Relatively little thermal bridging when compared with frame construction
  - Reduces lumber use resulting in lighter wall construction

• **Weaknesses**
  - Material cost of “structural” insulative sheathing can be higher
  - Potential for moisture condensation needs further investigation
3 - Flash and Batt wall construction

Hybrid of two insulation materials

- Relatively high R-value spray foam filling part of the wall cavity, with
- Standard fiberglass batt insulation
Flash and Batt - Strengths and Weaknesses

• **Strengths**
  - Achieves higher overall wall U-value than standard frame construction
  - Sealing the joints between framing and sheathing reduces air leakage
  - Production impact is relatively modest
  - Maximizes the benefits of expensive spray foam insulation while minimizing total cost by combining with less expensive batts

• **Weaknesses**
  - SPF requires special handling during spray process necessitating the use of protective gear and a 10' buffer to other workers
  - Relatively higher cost per R-value
  - Equipment maintenance adds to overall costs
# Proprietary Insulation Materials

<table>
<thead>
<tr>
<th>Property</th>
<th>BASF</th>
<th>AFM Corporation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Property</strong></td>
<td><strong>Styropor</strong></td>
<td><strong>Neopor</strong></td>
</tr>
<tr>
<td><strong>Description</strong></td>
<td>Modified expandable polystyrene</td>
<td>Polystyrene granules with a blowing agent for expansion. Raw material that is converted to closed cell rigid foam core for SIPs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Molded, closed cell expanded polystyrene rigid board foam plastic</td>
</tr>
<tr>
<td><strong>Application type</strong></td>
<td>General insulation, below grade use, fabrication, flotation, block molding applications, and general packaging</td>
<td>EIFS, interior system, ICF, SIPs, cavity wall and curtain wall systems</td>
</tr>
<tr>
<td><strong>R-value/inch</strong></td>
<td>3.6</td>
<td>4.5 - 4.6</td>
</tr>
<tr>
<td><strong>Standard thick. (in)</strong></td>
<td>Any</td>
<td>Any</td>
</tr>
<tr>
<td><strong>Available sizes</strong></td>
<td>Bead size: 0.35 mm - 1.7 mm</td>
<td>Any</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Density (lbs/cu. Ft.)</strong></td>
<td>0.9 – 4.0</td>
<td>1.15 – 1.8</td>
</tr>
<tr>
<td><strong>Weight (lbs/sq. ft.)</strong></td>
<td>Varies</td>
<td>Varies</td>
</tr>
</tbody>
</table>
Thermal Performance
Thermal Performance Standards

IECC 2009 requirements, Climate zones 5 and 6

- **R-20** or **R-13+5**
  (Wall insulation R-value),

  *or*

- **0.057** (Wall U-value)

Thermal Zone Maps: IECC (2009) and HUD MHCSS (1994)
Thermal Impact of Research

Whole house performance

<table>
<thead>
<tr>
<th>Research options</th>
<th>$U_{wall}$-value</th>
<th>$\Delta U_o$-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIPs</td>
<td>0.043</td>
<td>- 0.003</td>
</tr>
<tr>
<td>Stud walls with structural insulative sheathing</td>
<td>0.043</td>
<td>- 0.003</td>
</tr>
<tr>
<td>Flash and batt wall construction</td>
<td>0.050</td>
<td>- 0.002</td>
</tr>
<tr>
<td>Base case</td>
<td>0.052</td>
<td>- 0.002</td>
</tr>
</tbody>
</table>

*Assumes $U_{ceiling}$ = 0.030 and $U_{floor}$ = 0.033, as per IECC 2009 code for CZ 5
Thermal Impact of Research

Translating $U_o$-value impact into cost savings

<table>
<thead>
<tr>
<th>Option</th>
<th>Example impact on other components</th>
<th>Savings ($/sf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIPs and Structural insulative sheathing</td>
<td>Replace R-38 blown cellulose (U-value = 0.029) in ceiling with R-33 blown cellulose (U-value = 0.032)</td>
<td>$0.16</td>
</tr>
<tr>
<td>Flash and batt</td>
<td>Same as Base case</td>
<td>----</td>
</tr>
</tbody>
</table>
Code Compliance
and
Structural Performance
Research identified testing for code compliance for homes built under the HUDs Standards (MHCSS) and the International Residential Code (IRC)
Manufacturing and Process Analysis
Producibility - Key Factors

- **Safety**: risk of injury when performing operations, using equipment and handling material
- **Quality**: likelihood of scrap, rework, delays in the factory and, worst of all, service calls
- **Flow**: risk of disrupting continuous production flow
- **Cost**: total cost associated with producing the product (space, equipment, supplies and labor)
Plant-level VSM for Norris Plant
(Note: Wall-related activities are highlighted)
1 - Structural Insulated Panels

- Three SIPs used to build each sidewall:
  - 2 custom 8’ x 24’ SIPs
  - 1 shorter custom SIP

- Smaller 8’ x 14’ custom SIP used to build each end wall
SIPs - Key Features & Advantages

• Each custom SIP built to order
  - Cut-to-size
  - No EPS in window and door openings
  - No OSB on one side of opening

• Advantages
  - Reduces parts handled and assembled at wall build
  - Reduces joints
  - Large SIP readily handled
  - Omitting EPS in openings reduces material waste
  - OSB on 1 side of each opening adds strength for handling
SIPs - Production

Wide Aisle Needed to Handle SIPs & OSB
Or Standard Aisle using Cart or Sideloader

Standard Aisle
SIPs - Build Exterior Walls

Labor savings in wall build: 0.7 labor hours per home
SIPs - Summary

- Labor

<table>
<thead>
<tr>
<th>Activity</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut window components</td>
<td>-0.4</td>
</tr>
<tr>
<td>Build window openings</td>
<td>-0.5</td>
</tr>
<tr>
<td>Build exterior walls</td>
<td>-0.7</td>
</tr>
<tr>
<td>Set exterior walls</td>
<td>0.5</td>
</tr>
<tr>
<td>Install rough electric in ext. walls</td>
<td>0.8</td>
</tr>
<tr>
<td>Sheath walls</td>
<td>-1.4</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>-1.7</strong></td>
</tr>
</tbody>
</table>
SIPs - Summary

• Safety
  - Large components, but safely handled with existing equipment
  - Hot wire used to cut foam

• Flow
  - SIP production problem can delay line
  - Must produce and inspect custom SIPs in advance

• Quality
  - SIPs must be produced correctly
  - Fewer parts and joints reduce risk of errors during wall assembly
  - Monolithic structure reduces service problems, such as gypsum board cracking
SIPs - Challenges

• SIP production
  - Precise EPS and OSB cutting in advance
  - Timely layup of SIPs (within “open time”)

• Rough wiring
  - Aligning electric wall devices on standard vertical chases
  - Creating custom vertical chase
2 - Structural Insulative Sheathing

- **Key features**
  - 2” x 3” framing, 24”oc
  - 3” EPS board added under OSB

- **Producibility**
  - Comparable to base case
  - Potential challenge - 2” x 3” framing may result in increased service problems from gyp board cracking
Insulative Sheathing - Production Impacts

• Wall build
  - 26% reduction in studs (saving 0.5 labor hours per home)

• Sheathing
  - Continuous layer of 3” EPS installed in wall cavity before OSB installed
  - EPS and OSB installed by same team during same production cycle
  - Add 1.4 labor hours per home
3 - Flash and Batt wall construction

• Production limitations
  - Hazardous substance during spraying
  - Perpendicular application
  - Material heated
<table>
<thead>
<tr>
<th>Material Bridge</th>
<th>Material Bridge</th>
<th>Sidewall Table</th>
<th>E Rack Studs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batts</td>
<td>Wall Staging, SPF Spray &amp; Batt Installation</td>
<td>SPF Spray Tanks</td>
<td>48'-3&quot;</td>
</tr>
<tr>
<td>Material Bridge</td>
<td>Material Bridge</td>
<td>Sidewall Table</td>
<td>E Rack Studs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tops</th>
</tr>
</thead>
</table>
F&B - Summary

• Safety
  - SPF is a hazardous material when spraying. Protective gear required
  - Worker spraying SPF must be elevated horizontally or vertically

• Quality
  - Demonstrated reduction in service problems such as gypsum board cracking due to loading, shipping, set and settling
  - Demonstrated tighter envelope

• Flow
  - Problem with spray gun, system or materials can disrupt flow. Need equipment spares and possibly inventory of completed walls
F&B - Summary

• Opportunity – optimizing process by eliminating gypsum board screws might save 5.6 labor hours per home

• Challenges
  - Strength of wall system
  - SPF cure time before batt installation
  - SPF cure time before movement
  - SPF creep under frame and bowing gypsum board
  - Fastening gypsum board to wider framing
# Production Summary - Grading the Options

<table>
<thead>
<tr>
<th>Quality</th>
<th>SIPs</th>
<th>Insulative sheathing</th>
<th>Flash &amp; batt</th>
<th>Optimized flash &amp; batt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>+</td>
<td>0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Quality</td>
<td>++</td>
<td>0</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Flow</td>
<td>–</td>
<td>0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Challenges/ opportunities</td>
<td>–</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Overall grade</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
</tbody>
</table>

“o” denotes equivalent to base case
Cost of Implementation
## Comparison of fixed costs

<table>
<thead>
<tr>
<th>Option</th>
<th>Capital costs ($)</th>
<th>Annualized capital costs ($/year)</th>
<th>Fixed operating costs ($/year)</th>
<th>Total ($/year)</th>
<th>Production related costs ($/home)</th>
<th>300</th>
<th>650</th>
<th>1,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural insulated panels</td>
<td>$560,000</td>
<td>$133,573</td>
<td>$130,240</td>
<td>$263,813</td>
<td>$879</td>
<td>$406</td>
<td>$264</td>
<td></td>
</tr>
<tr>
<td>Structural insulative sheathing</td>
<td>$14,915</td>
<td>$3,558</td>
<td>$0</td>
<td>$3,558</td>
<td>$12</td>
<td>$5</td>
<td>$4</td>
<td></td>
</tr>
<tr>
<td>Flash and batt</td>
<td>$54,864</td>
<td>$13,086</td>
<td>$10,022</td>
<td>$23,108</td>
<td>$77</td>
<td>$36</td>
<td>$23</td>
<td></td>
</tr>
</tbody>
</table>
## Marginal costs by production volume

### Production volume

<table>
<thead>
<tr>
<th>Cost ($/sf)</th>
<th>300</th>
<th>650</th>
<th>1,000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SIPs</td>
<td>IS</td>
<td>F&amp;B</td>
</tr>
<tr>
<td>Materials</td>
<td>$0.70</td>
<td>$0.14</td>
<td>$0.42</td>
</tr>
<tr>
<td>Direct labor</td>
<td>-$0.03</td>
<td>$0.02</td>
<td>$0.01</td>
</tr>
<tr>
<td>Fixed costs</td>
<td>$0.80</td>
<td>$0.01</td>
<td>$0.07</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$1.47</strong></td>
<td><strong>$0.17</strong></td>
<td><strong>$0.50</strong></td>
</tr>
</tbody>
</table>
Committee Prioritization of Options

Decisions and Actions

• Technical review and assessment was conducted to evaluate the potential of the options
• The three technologies were ranked in terms of their design, production feasibility and marketability
• Two options selected to move forward to Phase 3
  - **Stud walls with structural insulative sheathing**
  - **Flash and batt wall construction**
• Conduct a preliminary feasibility study of using SIPs for floor construction
Phase 3: Implementation and Testing

Going Forward, Phase 3 (2012)

1. Development and full-scale evaluation of a manufacturing plan for the two wall options

2. Conduct essential testing needed for code approvals and related verification

3. Preliminary design/development of a new floor design
For Further Information

• Review the detailed technical report at:
  www.levypartnership.com/AdvancedEnvelopeResearch.pdf

• Contact:
  Emanuel Levy, President
  The Levy Partnership, Inc.
  1776 Broadway, Suite 2205
  New York, NY 10019
  (212) 496 0800 x 140
  elevy@levypartnership.com