U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Advanced Envelope Research for Factory-Built Housing

Download the presentation at: www.buildingamerica.gov/meetings.html

Date: December 14, 2011

Building America U.S. Department of Energy

Building America: Introduction

December 14. 2011

Mike Gestwick

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- 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

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Building America Industry Consortia Industry Research Teams

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The Partnership for Advanced Residential Retrofit

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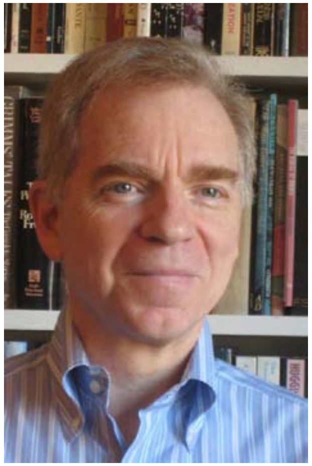
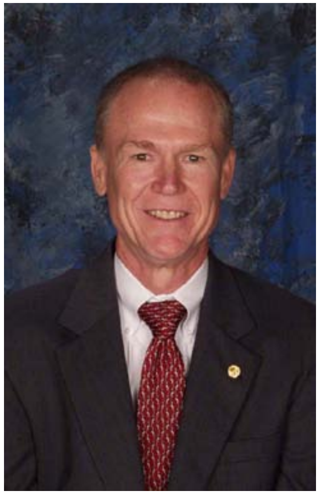
Today’s Speakers



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

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Advanced Residential Integrated Energy Solutions

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- **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

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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

Systems Building Research Alliance (SBRA)

Cavco Industries, Inc.

CertainTeed Saint-Gobain

The New Champion

Clayton homes

Cavalier Homes

NTA Inc.

Bayer

BASF The Chemical Company

JM Johns Manville

The Levy Partnership

MHI Manufactured Housing Institute

Owens Corning

Dow

AFM Corporation

Palm Harbor Homes

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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

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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

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Vetting the Options

Selection criteria

- ✓ System design
- ✓ Manufacturability
- ✓ Energy performance
- ✓ Code compliance
- ✓ Structural properties
- ✓ Cost (development, start up, recurring and maintenance)

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Qualitative Assessment Heat Map

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

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.

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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)

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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

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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.)

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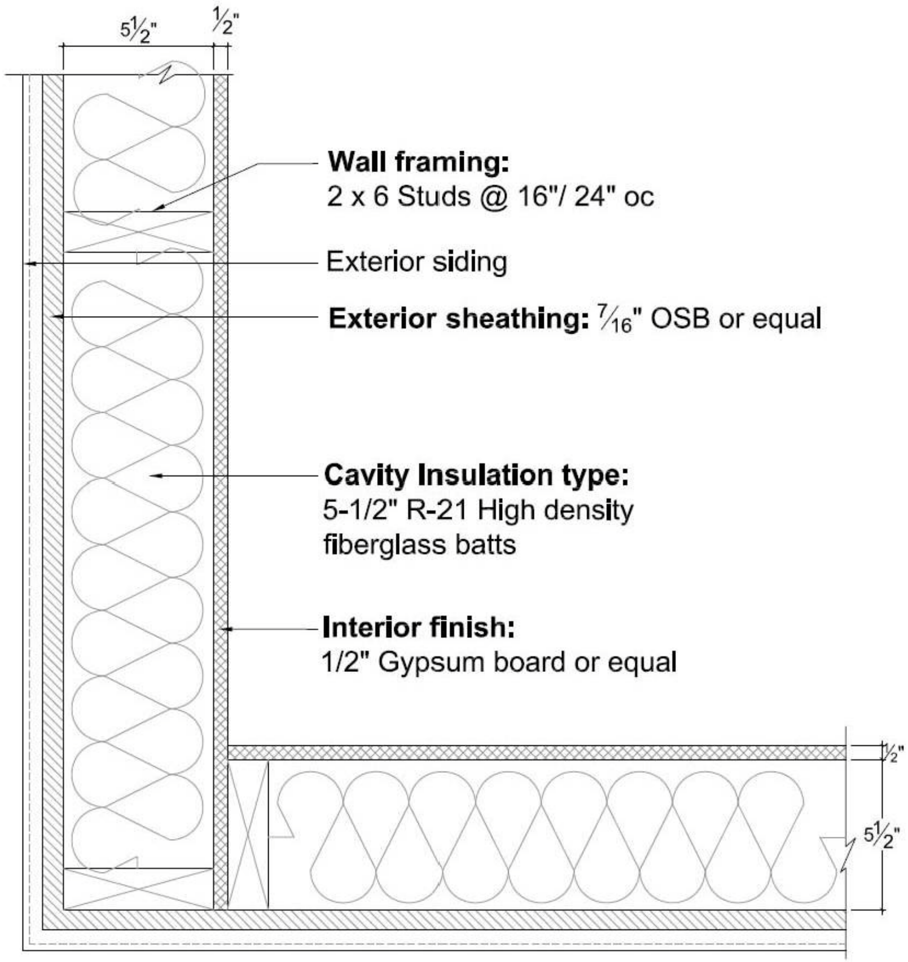
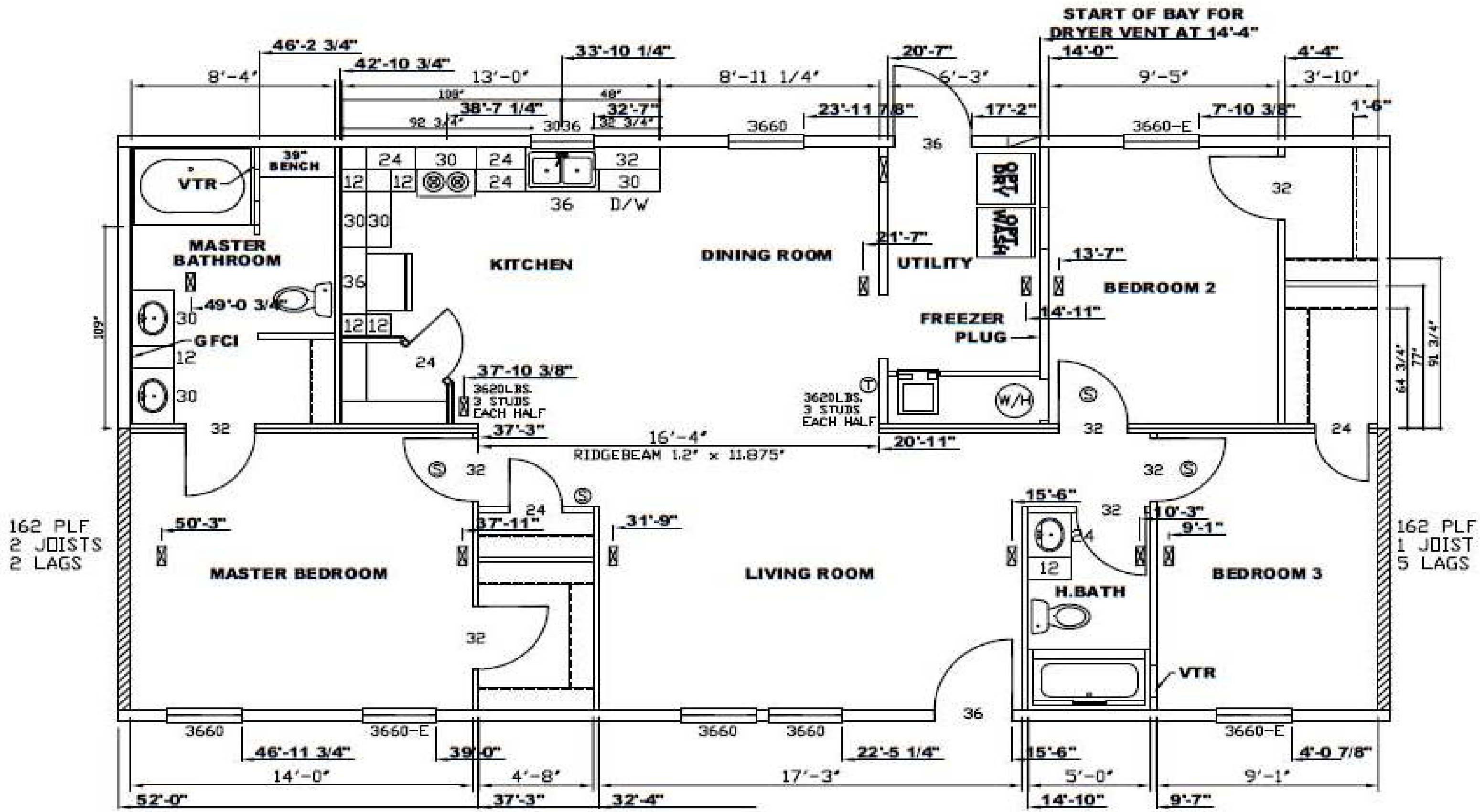
Base case - Design

Plan view

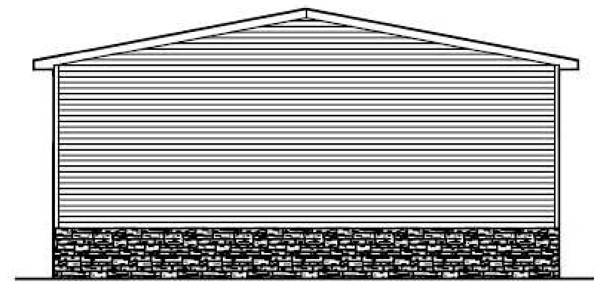


Base case - Typical floor plan



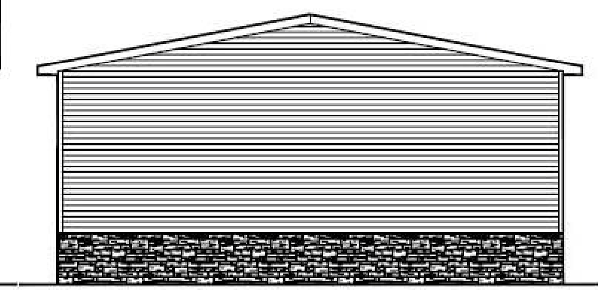
Base case - Elevations

FRONT ELEVATION



LEFT SIDE ELEVATION

REAR ELEVATION



RIGHT SIDE ELEVATION

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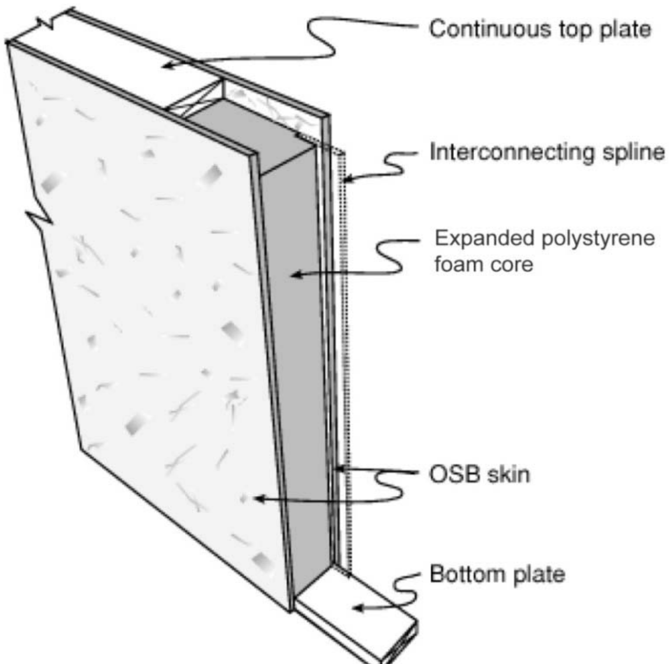
1 - Structural Insulated Panels (SIPs) for Walls

- 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



Structural Insulated Panels

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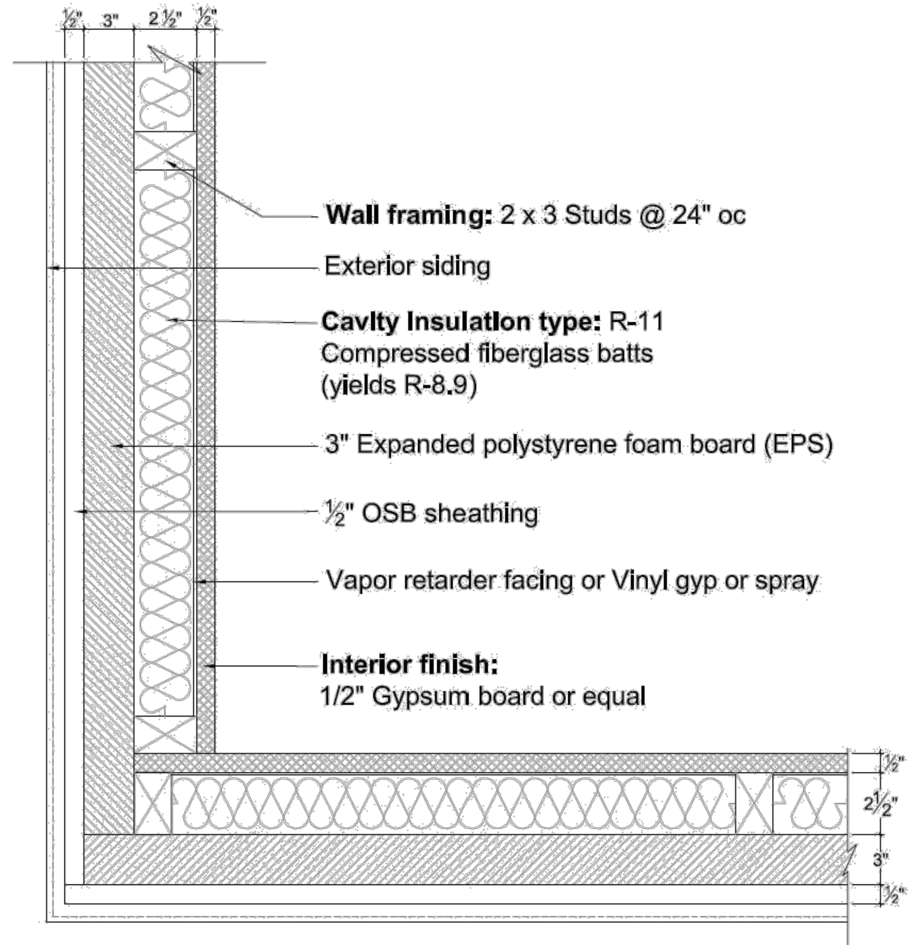
SIPs - Strengths and Weaknesses

- **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.



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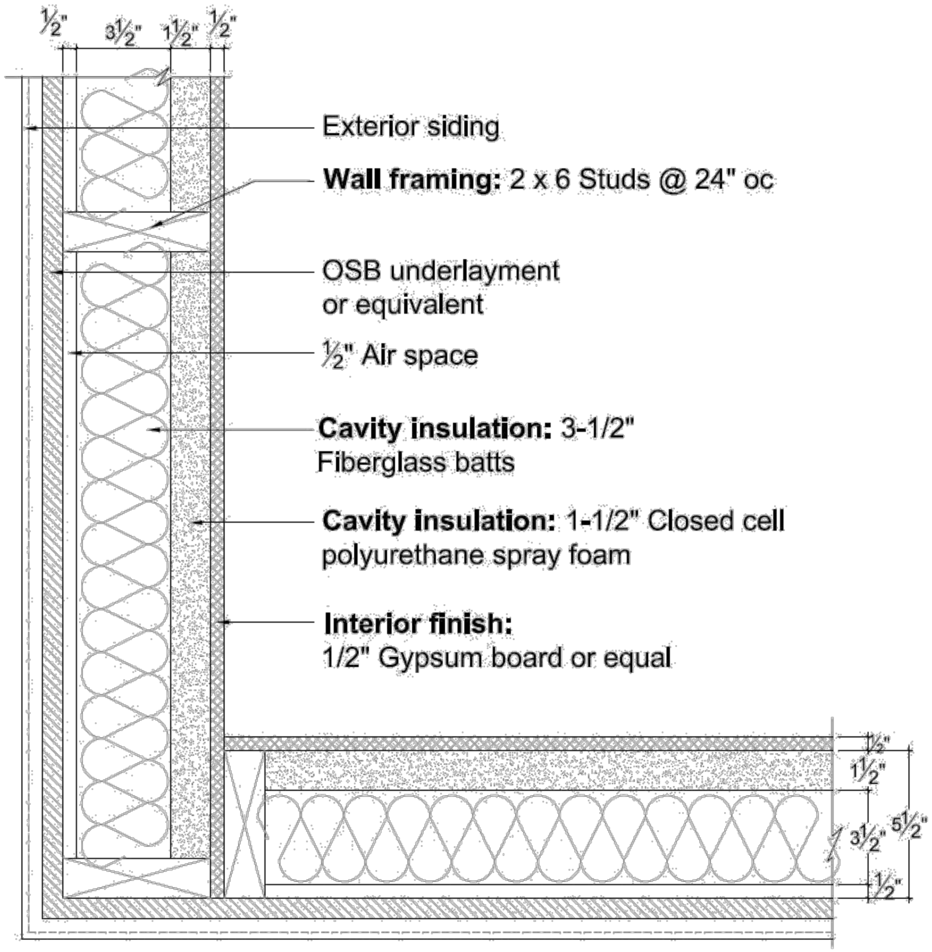
Insulative Sheathing - Strengths and Weaknesses

- **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

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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

Property	BASF		AFM Corporation
	Styropor	Neopor	Foam-Control
Description	Modified expandable polystyrene	Polystyrene granules with a blowing agent for expansion. Raw material that is converted to closed cell rigid foam core for SIPs	Molded, closed cell expanded polystyrene rigid board foam plastic
Application type	General insulation, below grade use, fabrication, flotation, block molding applications, and general packaging	EIFS, interior system, ICF, SIPs, cavity wall and curtain wall systems	Used for all types of industrial, packaging, and construction uses
R-value/inch	3.6	4.5 - 4.6	3.6
Standard thick. (in)	Any	Any	5.5”
Available sizes	Bead size: 0.35 mm - 1.7 mm	Any	4’ x 8’ 4’ x 16’
Density (lbs/cu. Ft.)	0.9 – 4.0	1.15 – 1.8	0.90
Weight (lbs/sq. ft.)	Varies	Varies	Varies

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Thermal Performance

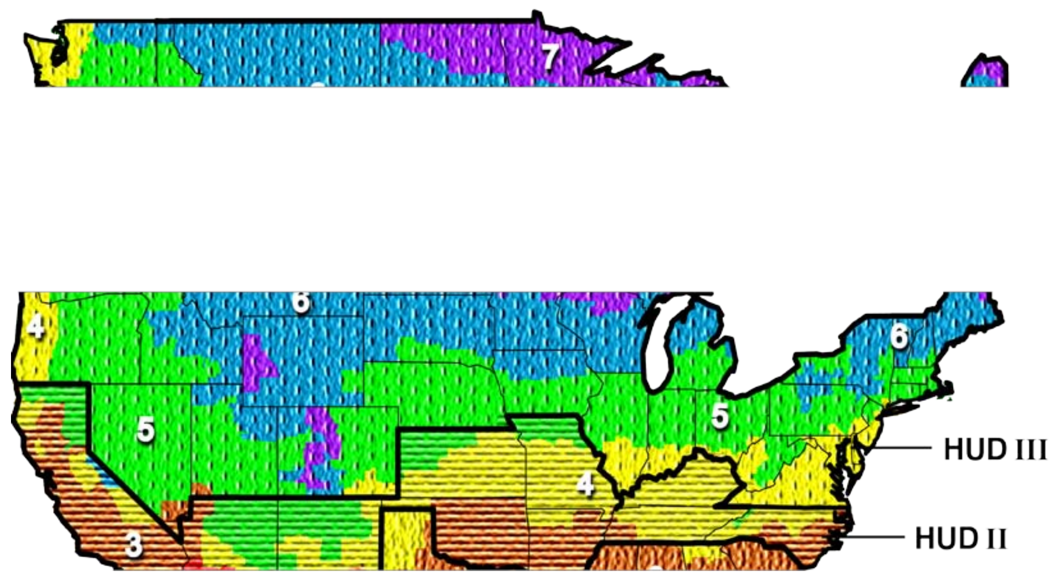
Thermal Performance Standards

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

Research options	U_{wall}-value	ΔU_o-value*
SIPs	0.043	- 0.003
Stud walls with structural insulative sheathing	0.043	- 0.003
Flash and batt wall construction	0.050	- 0.002
Base case	0.052	- 0.002

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

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Thermal Impact of Research

Translating U_o-value impact into cost savings

Option	Example impact on other components	Savings ($/sf)
SIPs *and* Structural insulative sheathing	**Replace R-38** blown cellulose (U-value = 0.029) in ceiling **with R-33 blown** cellulose (U-value = 0.032)	**$ 0.16**
Flash and batt	Same as Base case	----

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Code Compliance and Structural Performance

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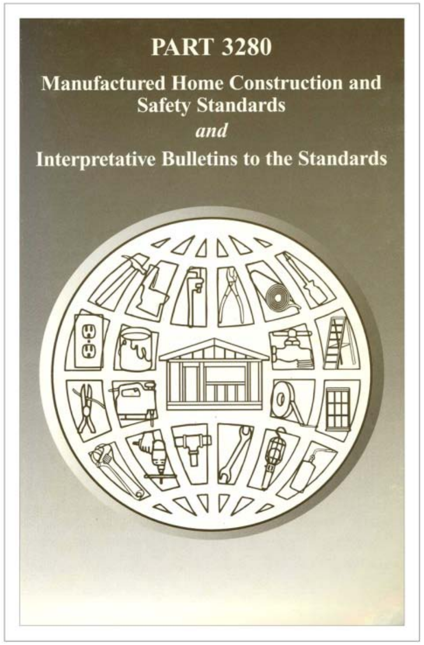
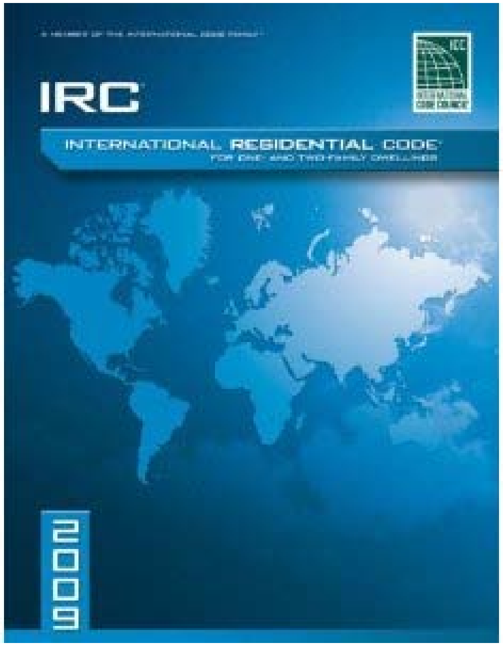
Code Compliance

Research identified testing for code compliance for homes built under the HUDs Standards (MHCSS) and the International Residential Code (IRC)





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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)

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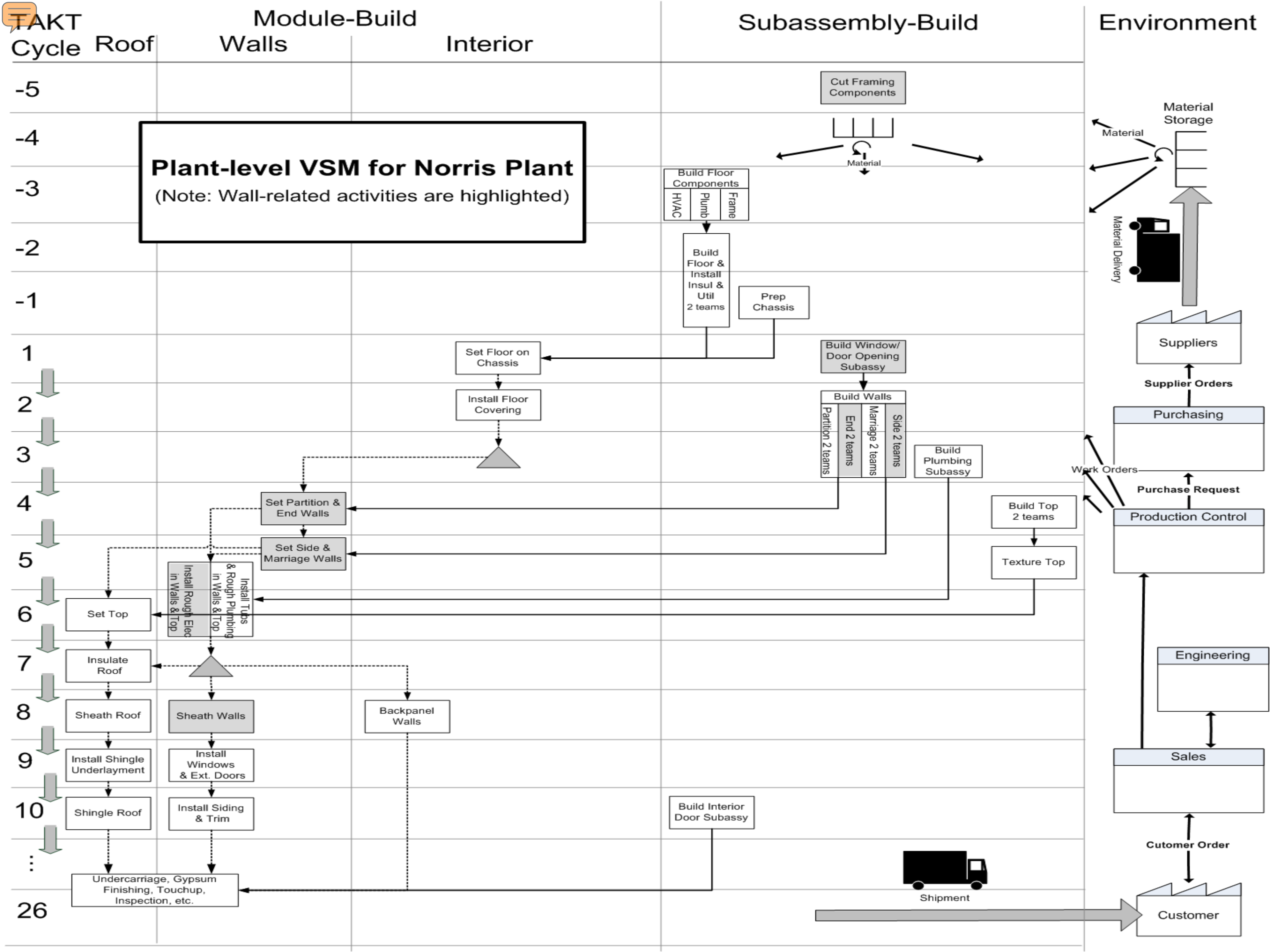
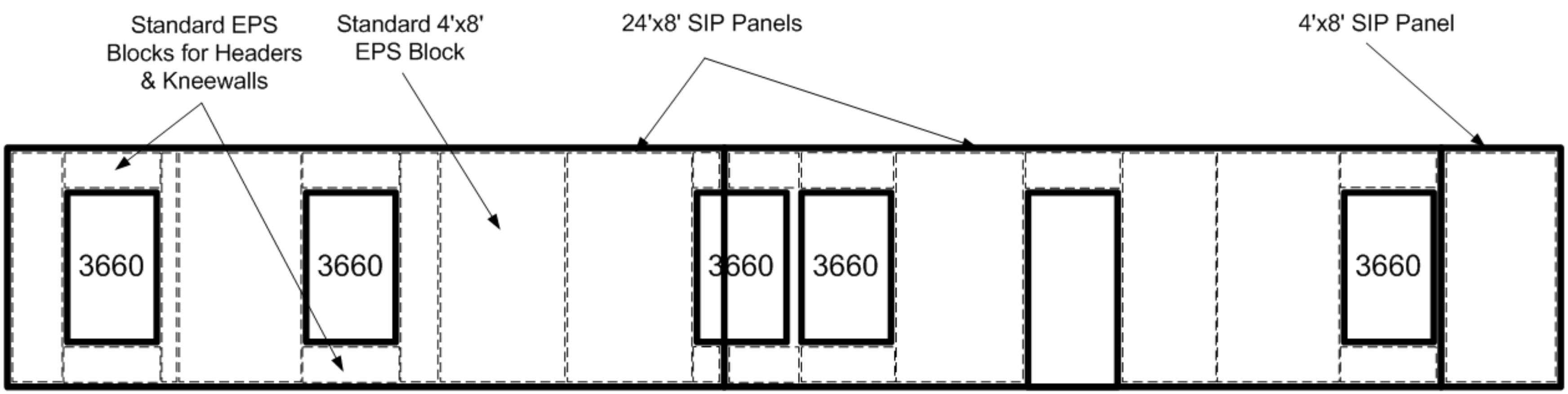


TAKT Cycle
Module-Build
Roof
Walls
Interior
Subassembly-Build
Environment
-5
-4
-3
-2
-1
1
2
3
4
5
6
7
8
9
10
26
Plant-level VSM for Norris Plant
(Note: Wall-related activities are highlighted)
Cut Framing Components
Material
Material Storage
Material
Build Floor Components
HVAC
Plumb
Frame
Material Delivery
Build Floor & Install Insul & Util 2 teams
Prep Chassis
Suppliers
Set Floor on Chassis
Build Window/ Door Opening Subassy
Supplier Orders
Install Floor Covering
Build Walls
Partition 2 teams
End 2 teams
Marriage 2 teams
Side 2 teams
Purchasing
Build Plumbing Subassy
Work Orders
Purchase Request
Set Partition & End Walls
Build Top 2 teams
Production Control
Set Side & Marriage Walls
Texture Top
Install Rough Elec in Walls & Top
Install Tubs & Rough Plumbing in Walls & Top
Set Top
Insulate Roof
Engineering
Sheath Roof
Sheath Walls
Backpanel Walls
Install Shingle Underlayment
Install Windows & Ext. Doors
Sales
Shingle Roof
Install Siding & Trim
Build Interior Door Subassy
Cutomer Order
Shipment
Undercarriage, Gypsum Finishing, Touchup, Inspection, etc.
Customer

1 - Structural Insulated Panels

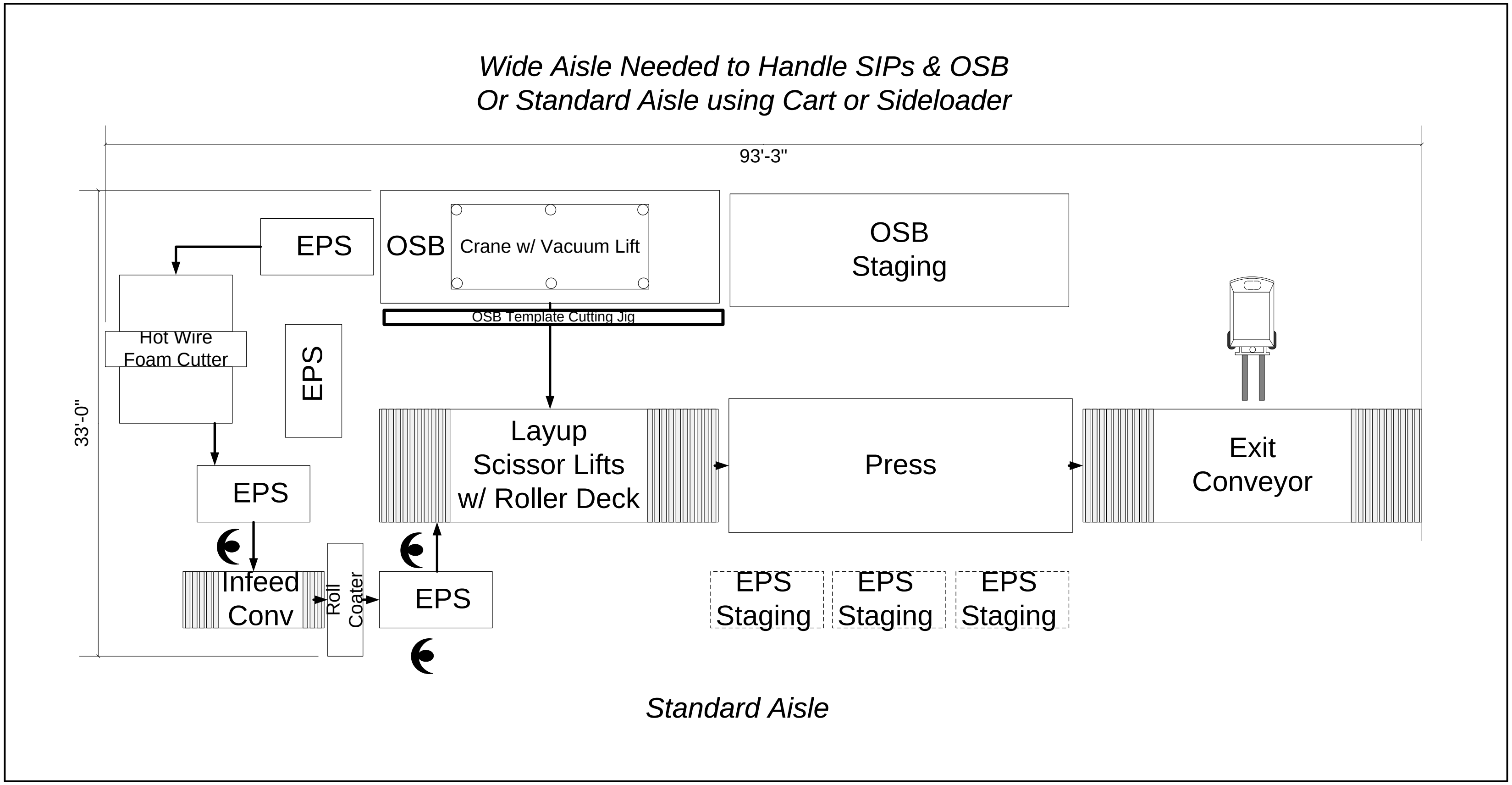
- Three SIPs used to build each sidewall:
  - 2 custom 8’ x 24’ SIPs
  - 1 shorter custom SIP
- Smaller 8’ x 14’ custom SIP used to build each end wall



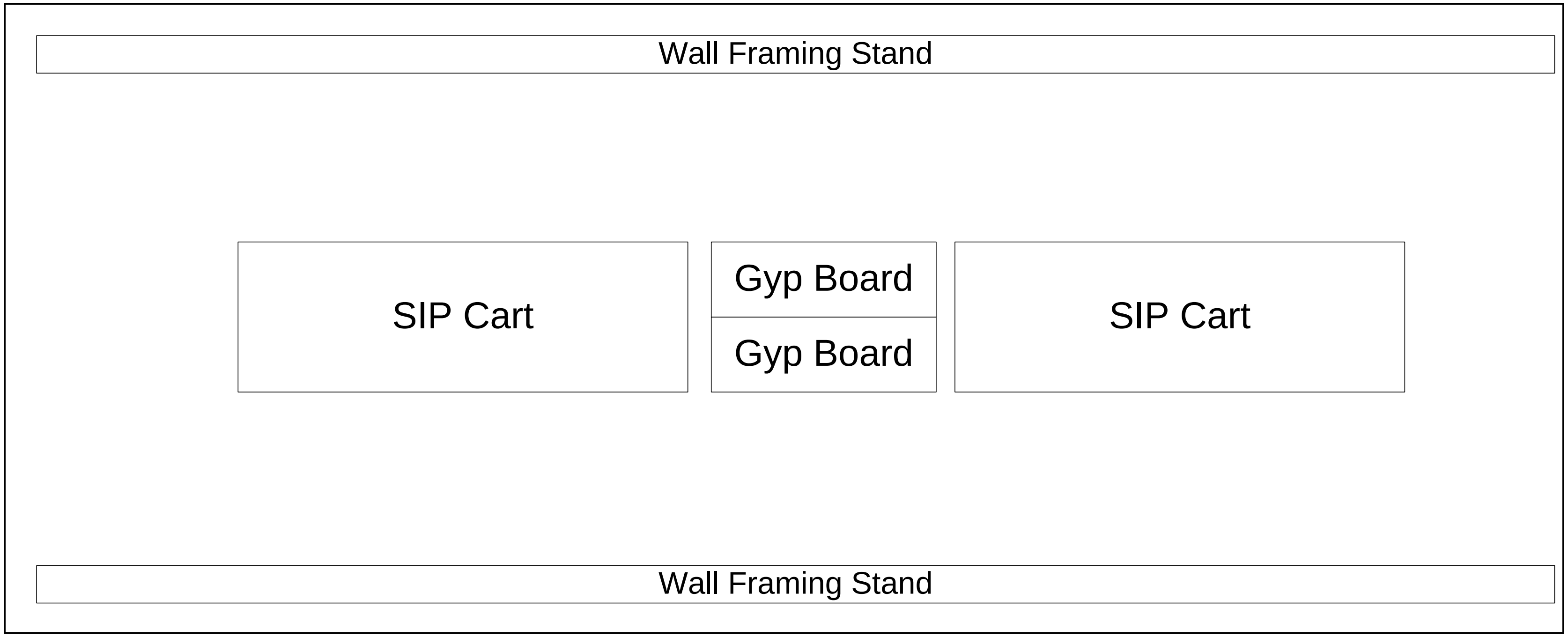
SIPs - Key Features & Advantages

- 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



SIPs - Build Exterior Walls



Labor savings in wall build: 0.7 labor hours per home

SIPs - Summary

- Labor

Marginal labor/home	
Activity	**Hours**
Cut window components	-0.4
Build window openings	-0.5
Build exterior walls	-0.7
Set exterior walls	0.5
Install rough electric in ext. walls	0.8
Sheath walls	-1.4
Other	0
Total	**-1.7**

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

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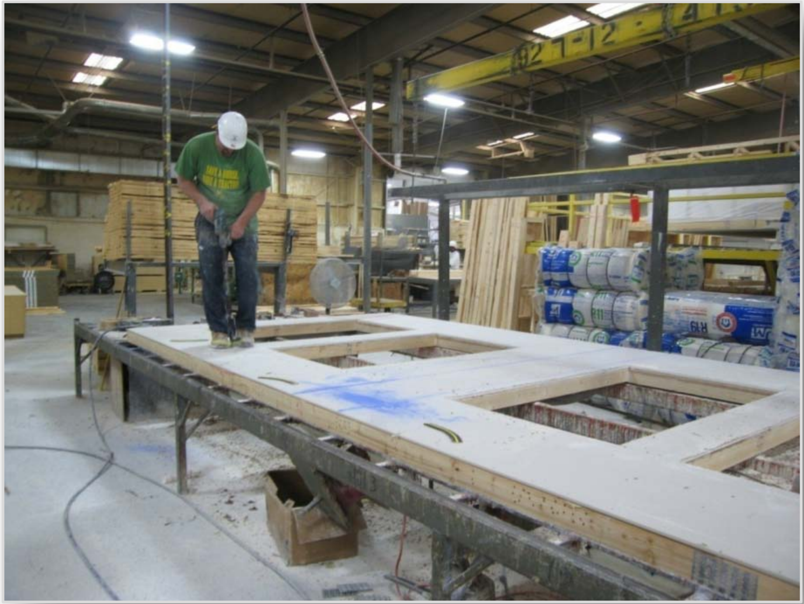
2 - Structural Insulative Sheathing

- 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

F&B - Build Exterior Walls

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

Quality	SIPs	Insulative sheathing	Flash & batt	Optimized flash & batt
Safety	+	o	–	–
Quality	++	o	+	++
Flow	–	o	–	–
Challenges/ opportunities	–	o	o	o
Overall grade	**+**	**o**	**o**	**+**

"o" denotes equivalent to base case

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Cost of Implementation

Comparison of fixed costs

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

Marginal costs by production volume

Production volume

Cost ($/sf)	300			650			1,000		
	SIPs	IS	F&B	SIPs	IS	F&B	SIPs	IS	F&B
Materials	*$0.70*	*$0.14*	*$0.42*	*$0.70*	*$0.14*	*$0.42*	*$0.70*	*$0.14*	*$0.42*
Direct labor	*-$0.03*	*$0.02*	*$0.01*	*-$0.03*	*$0.02*	*$0.01*	*-$0.03*	*$0.02*	*$0.01*
Fixed costs	*$0.80*	*$0.01*	*$0.07*	*$0.37*	*$0.00*	*$0.03*	*$0.24*	*$0.00*	*$0.02*
Total	***$1.47***	***$0.17***	***$0.50***	***$1.04***	***$0.16***	***$0.46***	***$0.91***	***$0.16***	***$0.45***

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

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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

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For Further Information

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

- Contact:

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