



Home Innovation
RESEARCH LABS™

EXTENDED PLATE & BEAM DEMONSTRATION HOME

FINAL PROJECT REPORT

Prepared For

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Abbreviations

c.i.	Continuous insulation—generally a rigid or semi-rigid board insulation material installed exterior to the wall cavity.
CZ	Climate Zone, as defined by the International Energy Conservation Code
DOE	United States Department of Energy, a federal agency that conducts and solicits research on energy efficiency topics, and includes the Building America program
EP&B	Extended Plate & Beam, a light frame wall system under development at Home Innovation Research Labs
FF	Framing Factor – the percentage of a wall’s area that is made up of lumber that spans the full depth, and forms a thermal bridge from the interior to the exterior. Typical light-framed construction may be made up of as much as 28% lumber by area as viewed in elevation. Advanced framing techniques can reduce this to as little as 15%.
FPIS	Foam Plastic Insulating Sheathing- a rigid foam board typically made from extruded polystyrene (XPS), expanded polystyrene (EPS) or Polyisocyanurate (PIC) and used to provide a layer of continuous insulation for house walls or other components
High-R	Building America program reference to wall systems with high thermal resistance, exceeding energy code minimum requirements
IECC	International Energy Conservation Code
IRC	International Residential Code
MC	Moisture Content, generally reported on a percentage basis by weight (MC%)
o.c.	On center – the measurement for components with dimension, i.e., lumber such as studs, whose 1-1/2-in. width means that 16-in. o.c. installation leaves a 14-1/2-in. stud bay.
OSB	Oriented Strand Board, a manufactured wood sheathing product
PIC	Polyisocyanurate, a type of rigid foam sheathing suitable for use in the EP&B wall system
R-value	Quantitative measure of resistance to conductive heat flow ($\text{hr}\cdot\text{F}\cdot\text{ft}^2/\text{Btu}$)
U-value	Quantitative measure of thermal conductance: $\text{Btu}/(\text{hr}\cdot\text{F}\cdot\text{ft}^2)$ (the inverse of R-value)
VTP	Very top Plate – the final top plate in a wall panel which is used to tie two or more panels together by spanning the joint between them
WRB	Water Resistive Barrier—used to protect the building envelope from liquid water, while allowing the diffusion of water vapor back out
WSP	Wood Structural Panel — the layer of wood sheathing (plywood or OSB) that provides shear and racking strength when properly attached to wall framing
XPS	Extruded Polystyrene, a type of rigid foam sheathing suitable for use in the EP&B wall system

Introduction

This document is the final report for an Extended Plate and Beam (EP&B) demonstration home built in Cazenovia, NY in 2015 using panelized wall sections produced at a nearby manufacturing plant. Other documents provided as a result of this research project include an Energy Analysis (July 2016) and a Construction Guide (August 2016.)

Home Innovation Research Labs previously studied the EP&B wall system for a 2014/2015 NYSERDA research project that included the following tasks:

1. Construction Details
2. Structural Testing
3. Constructability Assessment
4. Code Compliance
5. Cost Effectiveness

Positive results from the 2014/2015 evaluation¹ as well as moisture monitoring of the EP&B wall done in a parallel study in partnership with the Forest Products Research Lab² indicated that a test home project was an appropriate next step in the development of the EP&B system.

Background of High-R Wall Development

The residential building industry has been searching to expand the list of available options for increasing the thermal resistance of walls for several decades. Although multiple high-R wall construction methods have been developed over the last 25 years, the market penetration for high-R walls remains low. The EP&B Wall system is a solution that can be appealing to a large swath of typical builders looking to improve their homes' thermal performance because the system incorporates a layer of nearly continuous rigid foam insulation, while minimizing many of the common risks and concerns associated with high-R envelope systems.

The International Energy Conservation Code (IECC) Table R402.1.1 lists prescriptive thermal performance values for envelope components based on local climate conditions. Figure 1 illustrates the range of each climate zone.

¹ Extended Plate and Beam Wall System, Summary of Initial Assessment

² Characterization of Moisture Performance of Energy-Efficient Light-Frame Wood Wall Systems – Phase II

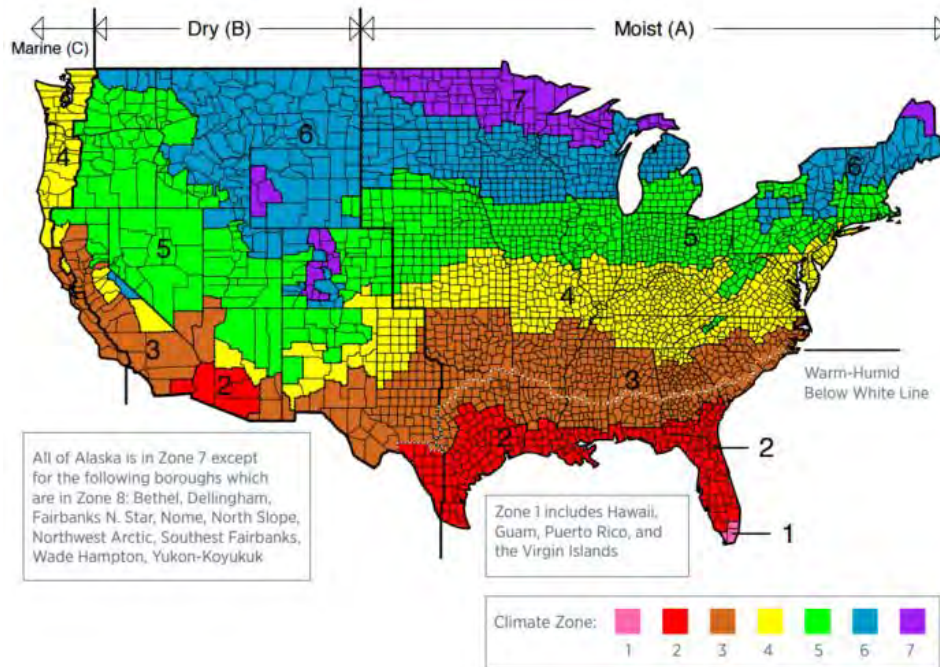
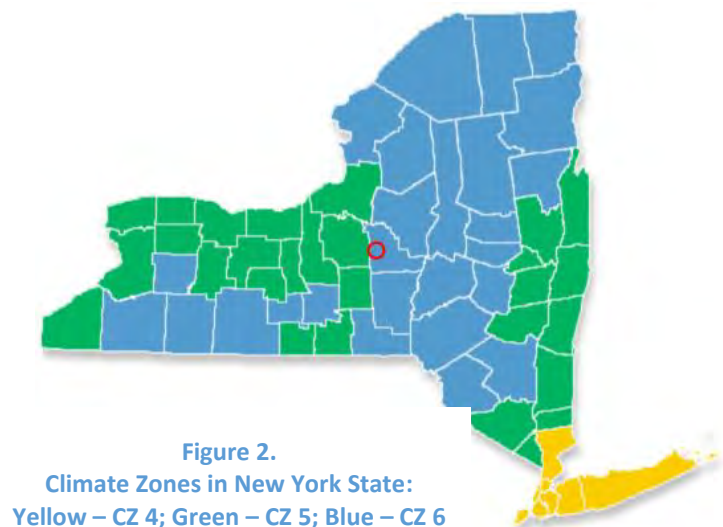


Figure 1. International Energy Conservation Code Climate Regions

The state of New York encompasses three different climate zones: CZ 4A (non-Marine), CZ 5A, and CZ 6A. Cazenovia, New York (the location of the test home) is in Madison County, which is assigned to CZ 6A.

The 2014 supplement to the New York State Energy Conservation Construction Code adopted the 2012 IECC prescriptive and performance minimums for residential energy efficiency.

Compared to IECC 2009, envelope requirements have increased for all major envelope components. An NAHB Research Center report³ determined that the savings resulting from the 2012 IECC energy components baseline compared to the 2006 baseline averaged more than 30% for homes across all eight climate zones.



³ 2012 IECC Cost Effectiveness Analysis

Table 1 shows the trend for several IECC prescriptive insulation and fenestration requirements over the last decade. Changes for the climate zones present in the state of New York compared to previous years are highlighted. Note that these envelope components for the 2015 IECC are the same as for 2012.

Table 1. Evolution of Several IECC Envelope Prescriptive Requirements from 2006 to 2015

	IECC Climate Zone	Fenestration U-Factor	Ceiling R-Value	Wood Frame Wall R-Value ^a	Basement Wall R-value ^b
2006	CZ 4	0.40	38	13	10/13
	CZ 5	0.35	38	19 or 13+5	10/13
	CZ 6	0.35	49	19 or 13+5	10/13
2009	CZ 4	0.35	38	13	10/13
	CZ 5	0.35	38	20 or 13+5	10/13
	CZ 6	0.35	49	20 or 13+5	15/19
2012	CZ 4	0.35	49	20 or 13+5	10/13
	CZ 5	0.32	49	20 or 13+5	15/19
	CZ 6	0.32	49	20+5 or 13+10	15/19
2015	CZ 4	0.35	49	20 or 13+5	10/13
	CZ 5	0.32	49	20 or 13+5	15/19
	CZ 6	0.32	49	20+5 or 13+10	15/19

^a For compound requirements (“+”) first value is cavity insulation, second is continuous insulation or insulated siding
^b For alternate requirements (“/”) first value is continuous insulation on the interior or exterior of the home, second is cavity insulation at the interior of the basement wall

Beginning with IECC 2012, residential builders in CZ 6 can only meet prescriptive above-grade wall insulation requirements by using a layer of continuous insulation (c.i.), either R-5 or R-10, depending on the cavity insulation value. Approximately half of New York State lies in CZ 6.

The standard EP&B configuration (2x4 studs with 2x6 plates) meets or exceeds the prescriptive R-value requirements for all New York State climate zones, and provides an above-code solution for CZ 4 and CZ 5. The configuration can be modified to better than nominal R-30, offering opportunities in all New York climate zones for pursuing several voluntary green building certification programs, and providing an alternative to exterior-applied continuous insulation.

Exterior continuous insulation (c.i.) is commonly seen as Foam Plastic Insulating Sheathing (FPIS) installed at the outside plane of the wood structural panel (WSP); this technique was demonstrated over 40 years ago, and is now standardized as a prescriptive method in the IECC. Yet, it still accounts for only 11% nationwide market penetration in 2015⁴. There are several perceived transition barriers to widespread adoption of this method, such as:

- concern about reducing the ability of the OSB to dry outward, due to the low permeability of most foam plastic insulated sheathing, which is installed directly over the WSP
- lack of a nailing base to support the cladding

⁴ 2016 Annual Builder Practices Survey

- difficulty identifying and detailing a drainage plane
- unusual installation of windows and doors
- atypical attachment of flashing to or through the FPIS

With the steady increase of IECC energy requirements, adoption rates by builders of continuous insulation wall systems will undoubtedly grow. For builders who have not yet transitioned to using FPIS as an exterior option, EP&B offers an alternative location for a layer of continuous insulation.

Project Plan

Objective

This project's main objective is to identify, implement, and publish specific construction details and integration strategies that can be used to support builder transition to the EP&B system. The selected home is used to evaluate the implementation of a panelized EP&B system from plan layout through final testing, including assembly and erection on site. Evaluation of the full implementation process is used to develop system modifications and enhancements. Key benefits and learning curves are documented in this report and, where appropriate, included in the Construction Guide.

System Description

The Extended Plate and Beam (EP&B) wall assembly currently under study is intended to address many of the transition barriers for high-R walls. The method launches from a starting point comfortable for residential builders today – 2x4 light-frame wood construction. The key difference is that the bottom and top plates are one dimension wider than the stud lumber and attached flush to the interior stud plane, creating space on the exterior side of the stud framing that accommodates a 2-in. layer of rigid foam insulation. The single layer of OSB or plywood sheathing is moved outboard for direct attachment to the extended plates, and attachment to the studs through the rigid foam, effectively encasing the c.i.

EP&B walls can be built in various configurations, including 2x4 studs with 2x6 plates (2-in. FPIS), 2x6 studs with 2x8 plates (1- $\frac{3}{4}$ -in. FPIS) and 2x6 studs with 2x7.5*⁵ plates (2-in. FPIS.) This last configuration can be achieved by rip cutting 2x10s to reduce their width. The configuration with 2x7.5* (2x10) plates tends to be less expensive than 2x8 plates (actual lumber dimensions 1- $\frac{1}{2}$ x 7- $\frac{1}{4}$), since FPIS is not available in 1- $\frac{3}{4}$ -in. thickness and must be installed as two layers: 1-in. and $\frac{3}{4}$ -in.

The NYSERDA demonstration home EP&B design utilized 2x4 lumber for the studs and 2x6 lumber for the bottom and second top plates, with 2-in. extruded polystyrene (XPS) rigid foam continuous insulation, OSB exterior structural sheathing, and R-15, 3- $\frac{1}{2}$ -in. thick un-faced fiberglass batts. The initial EP&B innovation specified that only the bottom and second top plate would be extended, maximizing the area for continuous FPIS. Based in part on the results of this study, the recommended configuration has now been modified to extend both top plates for improved strength and constructability. Typical materials and layering are shown in Figure 3.

⁵ The asterisk in 2x7.5* is intended to denote an actual, rather than a nominal width measurement

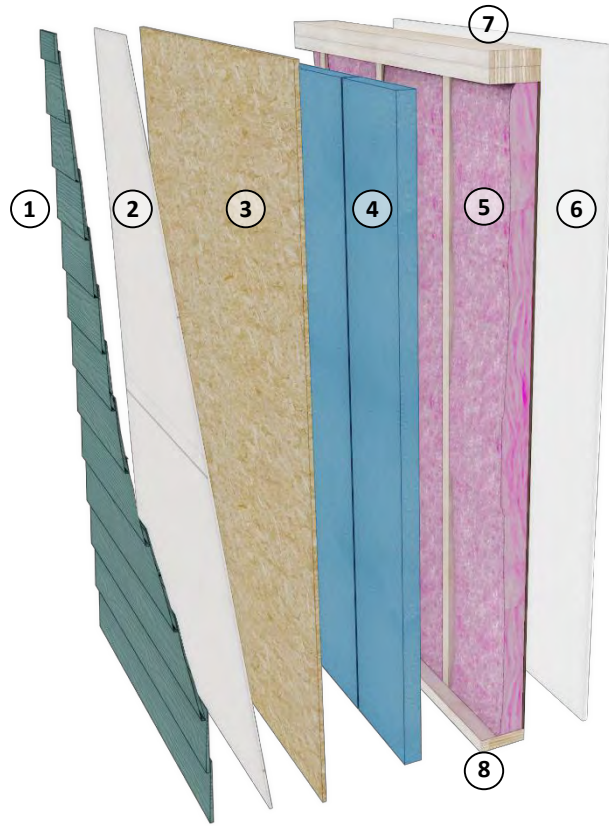


Figure 3. Materials Layering for an Extended Plate and Beam Wall

EP&B components are:

1. Exterior siding
2. Water Resistive Barrier (WRB)
3. Wood Structural Panel Sheathing (WSP)
4. FPIS
5. Framed 2x4 16 in. o.c. wood stud-wall with cavity insulation (and Interior vapor retarder if specified)
6. Interior gypsum dry wall
7. Extended top plates
8. Extended bottom plate

EP&B design features include:

- >95% framing coverage with continuous insulation, to reduce thermal shorts due to framing members
- Exterior WSP sheathing for siding attachment
- WSP sheathing nailed directly to extended bottom and second top plates for shear load resistance
- Wood Structural Panel (WSP) provides a flashing surface for windows and doors, for efficient installation and good durability
- The exterior location of the WSP sheathing allows it to dry to the outside; the FPIS layer behind it protects the WSP from interior moisture diffusion
- Warm stud cavity space to reduce the risk of condensation potential
- Flexibility in the selection of insulation materials
- Flexibility in the use of framing sizes for incremental improvement of wall thermal resistance
- Band beam design to eliminate headers in many wall sections

Energy Benefits

The EP&B wall system has two major thermal advantages as a result of the two inches of foam sheathing: higher overall R-value and a nearly continuous insulation layer which spans over 95% of the wall area.

The thermal bridge of the cantilevered plates in the EP&B wall reduces the wall's thermal performance by approximately 4% compared to a similarly-framed wall which has complete coverage with exterior FPIS. Even considering this slightly reduced performance, the standard EP&B assembly meets or exceeds the minimum prescriptive insulation requirements for 2012/2015 IECC as described in Table 2. Calculated assembly values are shown in parentheses.

Table 2. Thermal Performance of EP&B Wall Configurations Compared to IECC Code Requirements

Climate Zone	2012/2015 IECC Prescriptive R-value ^a for Above-Grade Walls (Calculated Assembly Value ^d)	Nominal R-value (Calculated Assembly Value ^d)		
		EP&B 2x4/2x6 Std 16 in. o.c.	EP&B 2x6/2x8 Adv 24 in. o.c.	EP&B 2x6/2x7.5* ^c Adv 24 in. o.c.
Non-Marine 4	20 (16.8) or 13+5 ^b (17.5)	13+10 ^b (21.7)	19+8.75 ^b (26.6)	19+10 ^b (27.8)
5	20 (16.8) or 13+5 ^b (17.5)	or 15+10 ^b (22.8)	or 21+8.75 ^b (29.2)	or 21+10 ^b (29.1)
6	20 + 5 ^b (22.5) or 13+10 ^b (22.7)			

^a R-value in hr·°F·ft² /Btu. A 25% Framing Factor (FF) is assumed.

^b The first value is cavity insulation, the second value is continuous insulation, so “13+5” means R-13 cavity insulation plus R-5 continuous insulation.

^c Plates designated 2x7.5* indicate the actual 7-1/2-in. width, to allow two full inches of rigid foam insulation

^d The calculated assembly value assumes typical wall materials of gypsum drywall, SPF lumber, fiberglass batt insulation, XPS foam sheathing, OSB structural sheathing, water resistive barrier (WRB) and vinyl siding. 16 in. o.c. framing assumes 75%/20.6%/4.4% thermal path ratios (cavity/framing/cantilevered plates); 24 in. o.c. framing assumes 85%/10.6%/4.4% ratios.

The EP&B wall configuration in the test house exceeds code for CZ 4 Non-Marine and CZ 5 by nominal R-7. For climate zone 6, the test house EP&B wall meets the prescriptive requirement for the c.i., and exceeds the prescriptive cavity insulation requirement by nominal R-2.

For houses with two stories, a double rim joist assembly can be used with EP&B walls to eliminate headers and provide space for additional insulation. This “rim beam” can perform the duties of a header in many cases, eliminating typical headers and freeing space for more insulation. The structural capacity of the EP&B wall system has been tested and confirmed for both conditions⁶: 1) a double rim joist located at the exterior plane; and 2) a single rim joist inset by 1 in. to accommodate a layer of FPIS. The NYSERDA test house was single story, and so did not utilize this feature.

Other Benefits

Because the wood structural panel (WSP) is outboard of the foam plastic insulating panel (FPIS), the EP&B wall offers trades a familiar approach to installing windows and the water resistive barrier (WRB). Siding attachment is also straightforward, using the IRC's alternate attachment schedule, R703.3.2 (Table 3) for fastening siding to wood sheathing instead of framing.

⁶ Extended Plate and Beam Wall System, Summary of Initial Assessment

Siding: With EP&B, the nail length for siding installation simply needs to capture the depth of the siding, plus the OSB, plus the required ¼-in. extension – a ¾-in. ring shank nail.

By contrast, a typical prescriptive wall with 2 in. of FPIS on the exterior requires fasteners to be nearly 3-in. long to attach the siding to the wood sheathing through the foam, and nails in excess of 4 in. to attach to framing.⁷ More commonly, furring would be installed outboard of the foam (or let in) to provide a nailing substrate for shorter siding fasteners. However, the furring must still be attached directly to framing with long nails or screws, and requires extra labor and materials.

Table 3. IRC Table R703.3.2 Optional Siding Attachment Schedule for Fasteners Where No Stud Penetration Necessary

APPLICATION	NUMBER AND TYPE OF FASTENER	SPACING OF FASTENERS ^b
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. ^a	Ring shank roofing nail (0.148" min dia.)	12 in. o.c.
	Ring shank nail (0.148" min dia.)	15 in. o.c.
	#6 screw (0.138" min dia.)	12 in. o.c.
Note: Does not apply to vertical siding.	#8 screw (0.164" min dia.)	16 in. o.c.

^a 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.

^b 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 than the manufacturer's minimum recommendations.

Water Resistive Barrier: An EP&B wall has OSB as the exterior layer so traditional sheet-goods WRB can be installed in the usual fashion (staples or cap nails), another similarity with typical, well-known methods.

In a wall with FPIS as the exterior layer the foam sheathing can act as the WRB⁸. The joints between the sheets can be taped and all edges must be detailed for resistance to bulk water intrusion. This approach is common among the cohort of builders already using exterior foam sheathing. Detailing these joints and connections is important both in the long and the short term for moisture durability, and can be more complex than installing sheet goods house-wrap. Not all rigid foam sheathing is approved for such use, so this approach requires advance planning. FPIS can also be covered with a sheet-type WRB.

Window Installation: In an EP&B wall, windows can be framed with 2x4's, preserving the continuous insulation layer of FPIS behind the WSP. The box frame of the window can bear on both the wall framing and the edge of the OSB, or the window can be shimmed at the framing. Nailing the window flange to the OSB layer is generally sufficient; OSB has enough rigidity to bear the wind load. Longer nails can be used to attach the window directly to framing, if additional support is desired.

For windows in a wall with an exterior foam layer, all fasteners must penetrate through the foam to connect with framing. The window frame must be shimmed to avoid bearing on the foam. Alternatively, additional framing can be added at window and door openings.

⁷ Attachment of Exterior Wall Coverings Through Foam Plastic Insulating Sheathing (FPIS) to Wood or Steel Wall Framing.

⁸ Using Rigid Foam As a Water-Resistive Barrier

Window Flashing: Because of the exterior layer of WSP, attaching and shingling the window flashing in an EP&B wall is almost identical to that for a typical wall.

With FPIS as the exterior wall layer, it's often recommended that a reglet be created in the face of the foam above the window head to accept a drip cap, and seams in the FPIS should be avoided.⁹

Panelization: Also unlike a wall with exterior c.i., the EP&B wall lends itself to panelization. The extended plates at the top and bottom of wall sections and the OSB sheathing effectively protect the foam in transit. The FPIS can be cut with the same saws used for lumber, and excess material can be used in header and cripple stud locations, minimizing waste.

Continuous insulation: EP&B walls also provide thermal performance benefits with respect to materials durability. A 2-in. layer of insulating foam exterior to the framing maintains a much warmer temperature in the wall cavity during winter (Table 4.) Should water vapor make its way to the interior plane of the FPIS, it is far less likely to condense; liquid water in building materials is often a precursor to mold and mildew.

Table 4 shows that in typical light-wood framing with 15°F outdoors and 68°F indoors, the temperature in the wall cavity at the interior plane of the WSP is well below freezing. In a wall with a layer of R-10 continuous insulation, the temperature in the cavity remains above freezing.

Table 4. EP&B Provides a Warm Cavity to Prevent Condensation, with Outdoor Temperature of 15°F

Interface/Wall Assembly	EP&B, R13/10	2x4, R13	2x6, R20
Indoor Temperature	68	68	68
Cavity interior face	65.7	64.2	65.2
Cavity exterior face	38.7		
OSB Interior plane	18	20	18.6
OSB Exterior plane	16.6	17.7	16.9
Outdoor Temperature	15	15	15

Thermal comfort: The surface of a poorly-insulated wall can be cold compared to the rest of the space, which can cause occupant discomfort even when the building's heating system is capable of maintaining the room's setpoint air temperature.¹⁰ Continuous insulation exterior to the framing and wall cavity can help maintain more uniform surface temperatures in a space, improving occupant comfort.

Drying capability: 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 came from – exterior to the exterior and interior to the interior (Figure 4.) In an EP&B wall, outward drying of the WSP is facilitated by the use of a high-perm WRB.

Where the OSB is located behind the foam, as with an exterior c.i. configuration, the drying of the wood sheathing primarily occurs to the inside. Inward drying is effective when vapor drive is low, or during

⁹ www.nrel.gov/docs/fy05osti/37583.pdf

¹⁰ www.sciencedirect.com/science/article/pii/S0378778885900064

non-winter seasons when the direction of the vapor drive is also to the inside. Inward drying does not occur in the winter when there is a strong vapor drive in the opposite direction.

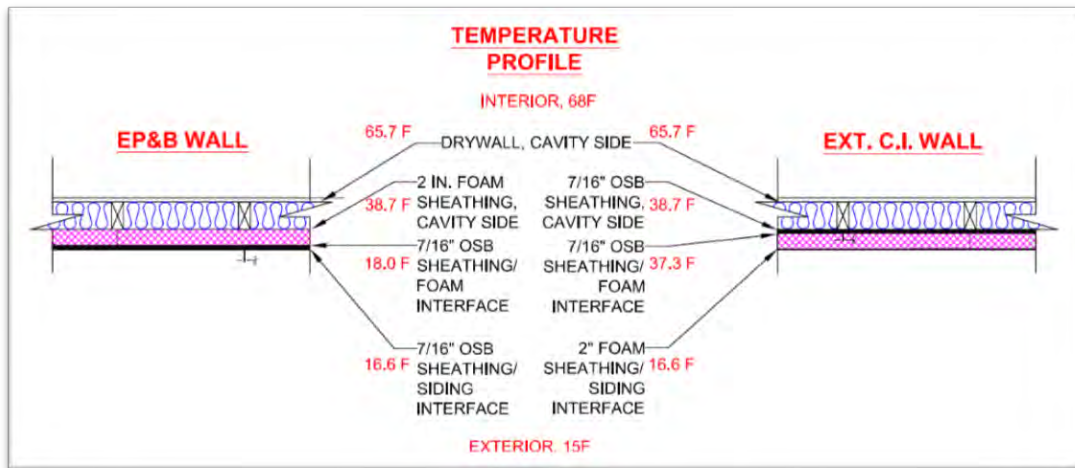


Figure 4. Temperature Profile and Drying Capability: EP&B Wall Compared to Exterior C.I. Wall

An appropriate interior vapor retarder helps prevent accumulation of moisture in the wall cavity due to humid conditions inside the building. The IRC allows a Class III vapor retarder to be used in certain wall configurations which include an FPIS layer, specifically because of the foam insulation’s ability to keep the cavity warmer and reduce the potential for condensation. Interior vapor drive (from inside to outside) is high where outside conditions are cold and dry. A Class II interior vapor retarder is recommended for EP&B walls in CZ 5 and above using a “smart” vapor retarder or Kraft paper to protect the wall assembly against high winter interior vapor and to allow inward drying of the cavity as humidity reduces seasonally, allowing a balanced condition. Extended Plate and Beam walls monitored for a two-year period in controlled test buildings in CZ 4¹¹ showed that in this configuration the OSB performs well with respect to moisture (Figure 5.) OSB sheathing on EP&B walls with vinyl siding and un-faced fiberglass batts remained below 14% Moisture Content (MC) throughout the test period.

Increased air sealing improves thermal performance but potentially reduces drying capability. The EP&B wall with air-sealing in Figure 5 was more resilient to this effect than the kraft-faced batt wall with air-sealing. This is likely due to the location of the FPIS layer which provides a centrally-located vapor plane, allowing the OSB to dry directly to the outside, and protecting it from interior vapor drive.

¹¹ Characterization of Moisture Performance of Energy-Efficient Light-Frame Wood Wall Systems – Phase II, pgs 17-18

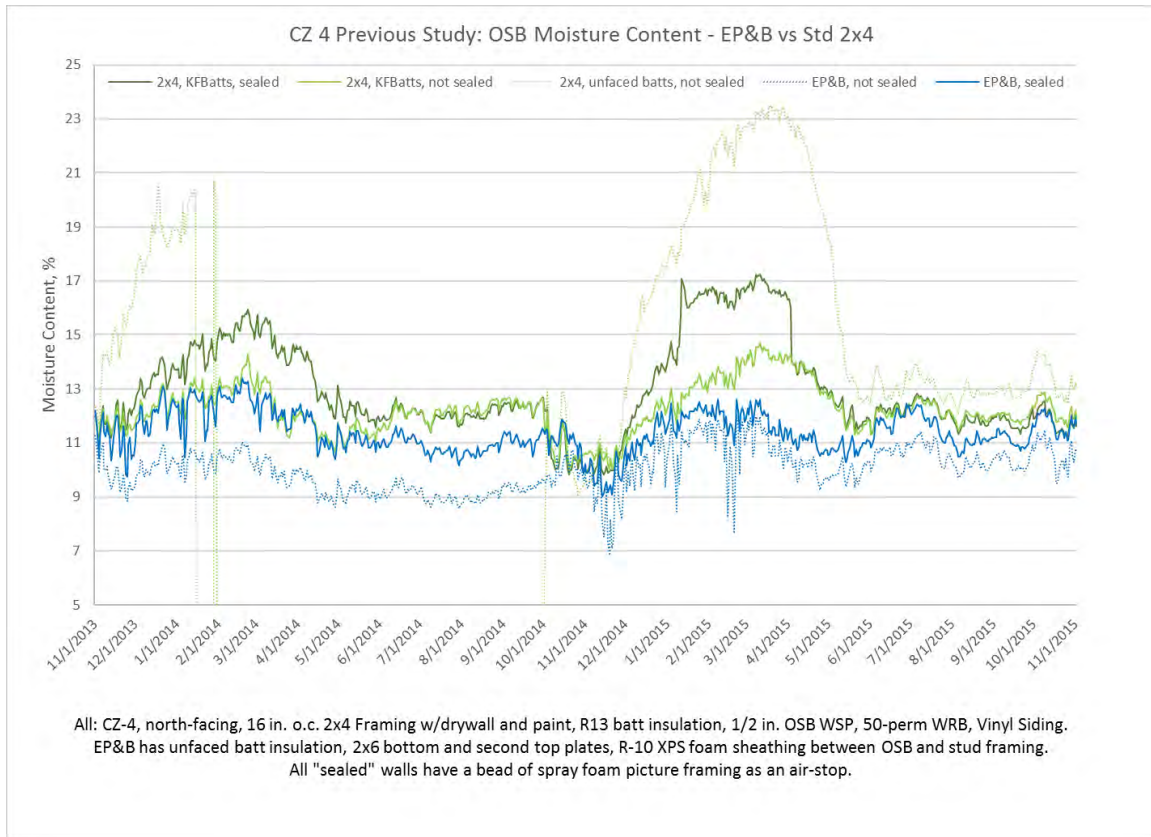


Figure 5. In a Previous Study, the EP&B Walls in CZ 4 Maintained Moisture Levels Below 14% (blue)

Implementation

In this project, the EP&B system is evaluated as part of a panelized construction process where the walls are fabricated in a controlled factory environment and delivered to the site for assembly. The EP&B system provides an opportunity to help panelizers integrate thermal insulation into their fabrication process. It is standard practice for panelizers around the country not to install any insulation, neither cavity nor exterior, at the factory. In fact, the panelizer involved in this study has never installed insulation at their facility in the 50-year history of the company. The purpose of this project is to use the EP&B innovation to demonstrate a path for panelizers to add the energy efficiency component of c.i. to the traditionally structure-only product, and to participate in the high-performance construction market.

Project Team

Table 5. NYSERDA EP&B Test Home Project Team

Organization	Role	Contact
Home Innovation Research Labs	Research and Evaluation	Joe Weihagen, Vladimir Kochkin, Patti Gunderson
NYSERDA	Project Oversight	Dan Farrell, Bob Carver, Megan Bulman
DOW Chemical Company	Industry Partner	Brian Lieburn
Hamilton Building Services	Builder	Mike Quinlen
StarkTruss	Panelizer	Dan Webb
Framing Contractor	Panel Erection, WRB, Window Installation, Roof Trusses and Decking	Cody Warner
LaRocque Business Mgmt Services, LLC	Field representative	Philip LaRocque

Design Documents

This demonstration home was built with EP&B wall panels produced at a building components plant in Whitesboro, NY. The design utilized 2x4 lumber for the studs and 2x6 lumber for the bottom and second top plates, with 2 in. XPS R-10 FPIS, 7/16 in. OSB exterior structural sheathing, and 3.5 in. of R-15 un-faced fiberglass batts in the wall cavity.

Figure 6 shows the front view of the completed home and Figure 7 shows the floor plan of the test house.



Figure 6. NYSERDA EP&B Test Home Front View

Descriptions of the energy features, cost comparison, and construction details of the home are included in the companion report, “Extended Plate and Beam Demonstration Home: Energy Simulation Results Analysis,” and its appendices:

- APPENDIX A: Building Summary
- APPENDIX B: Photographs
- APPENDIX C: Typical 200 sf Wall Cost Comparison
- APPENDIX D: Manufacturers’ Cut Sheets
- APPENDIX E: REM/Rate Energy Analysis Report
- APPENDIX F: Construction Documents

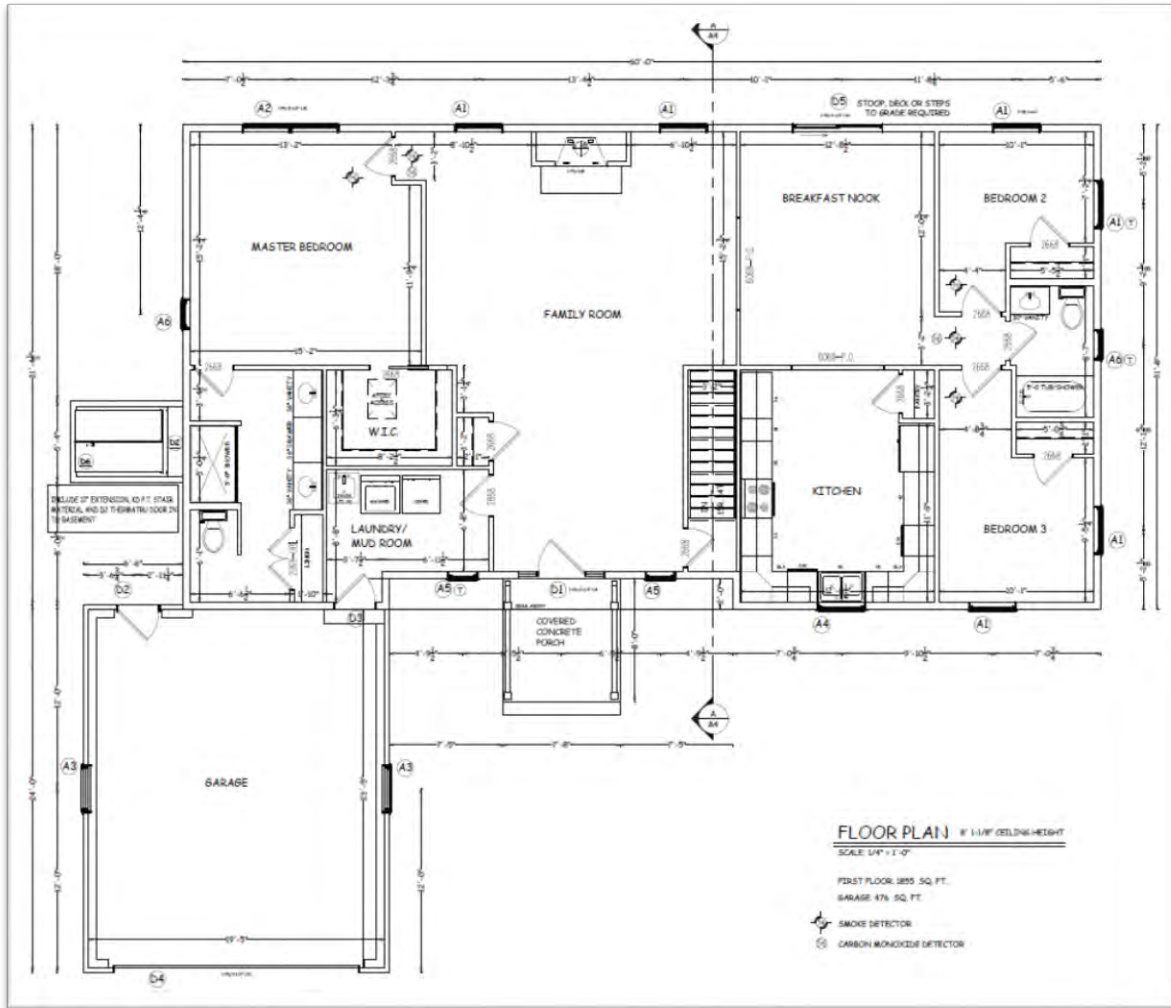


Figure 7. EP&B Test Home Floor Plan

Wall Construction at the Panel Plant

Plant manager Dan Webb stated that the project was outside of this Stark Truss facility’s ordinary assembly work process. This plant was started as a wall panel fabrication plant, but recently has been producing more trusses than wall components. The crew had no experience with the EP&B configuration, nor with rigid foam sheathing.

The designer developed a complete set of shop drawings for all walls, including corners and window and door openings, according to their standard practice. Mr. Webb reported no difficulties in drafting the EP&B wall system. Figure 8 and Figure 9 are representative examples of the schematics provided to the shop crew for assembling the panels, and bundling and marking them for shipment to the project site.

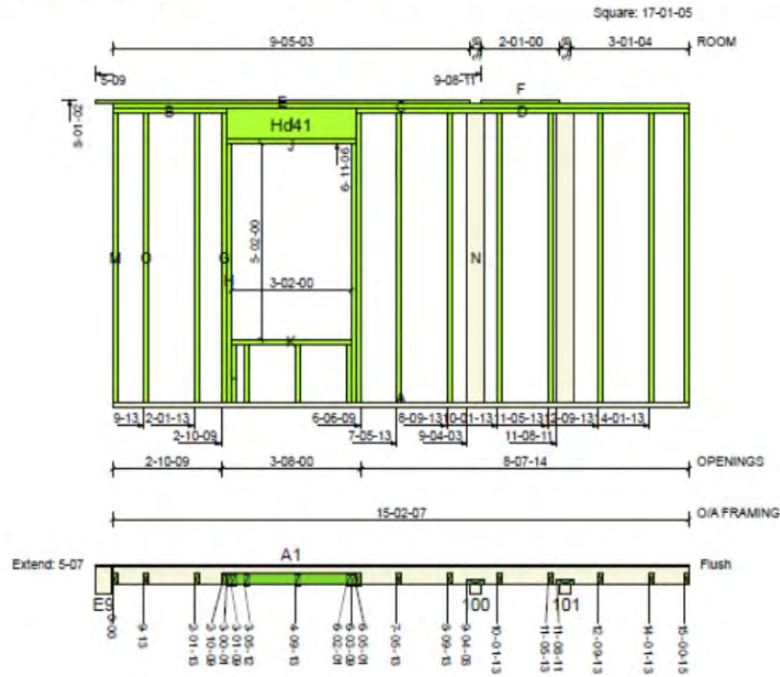


Level: 1st Floor

Bundle: 2

Panel: E8

Stud Spacing 1-04-00
BF 218
Weight 271.00 lb
Production Notes:



Sheathing Standard Material 7/16" 4x8 OSB
Hold/Extend I B L R
-0-06 -0-12 5-08 -

Cutting List

Label	Member	Description	Qty	Length	Width	L Miter	R Miter	L Bevel	R Bevel
A	Bottom Plate	2x6 SPF No.2	(1)	15-02-07	0-00				
B	Top Plate	2x4 SPF No.2	(1)	3-00-01	0-00				
C	Top Plate	2x6 SPF No.2	(1)	15-02-07	0-00				
D	Top Plate	2x4 SPF No.2	(1)	8-09-08	0-00				
E	VTP	2x6 SPF No.2	(1)	9-10-12	0-00				
F	VTP	2x6 SPF No.2	(1)	2-01-00	0-00				
G	King Stud	2x4 SPF No.2	(2)	7-07-02	0-00				
H	Jack Stud	2x4 SPF No.2	(2)	6-09-14	0-00				
I	Header	2x10 SPF No.2	(2)	3-05-00	0-00				
J	Header Sill	2x4 SPF No.2	(1)	3-05-00	0-00				
K	Window Sill	2x4 SPF No.2	(1)	3-02-00	0-00				
L	Sill Cripple	2x4 SPF No.2	(4)	1-06-08	0-00				
M	Stud	2x4 SPF No.2	(2)	7-07-02	0-00				
N	Flat Stud	2x6 SPF No.2	(2)	7-07-02	0-00				
O	Critical Stud	2x4 SPF No.2	(8)	7-07-02	0-00				
P	Sheathing	7/16" 4x8 OSB	(1)	8-00-00	3-10-08				
Q	Sheathing	7/16" 4x8 OSB	(2)	8-00-00	4-00-00				
R	Sheathing	7/16" 4x8 OSB	(1)	8-00-00	3-09-07				

E8

Figure 8. Example of Construction Drawing for Panel Manufacture

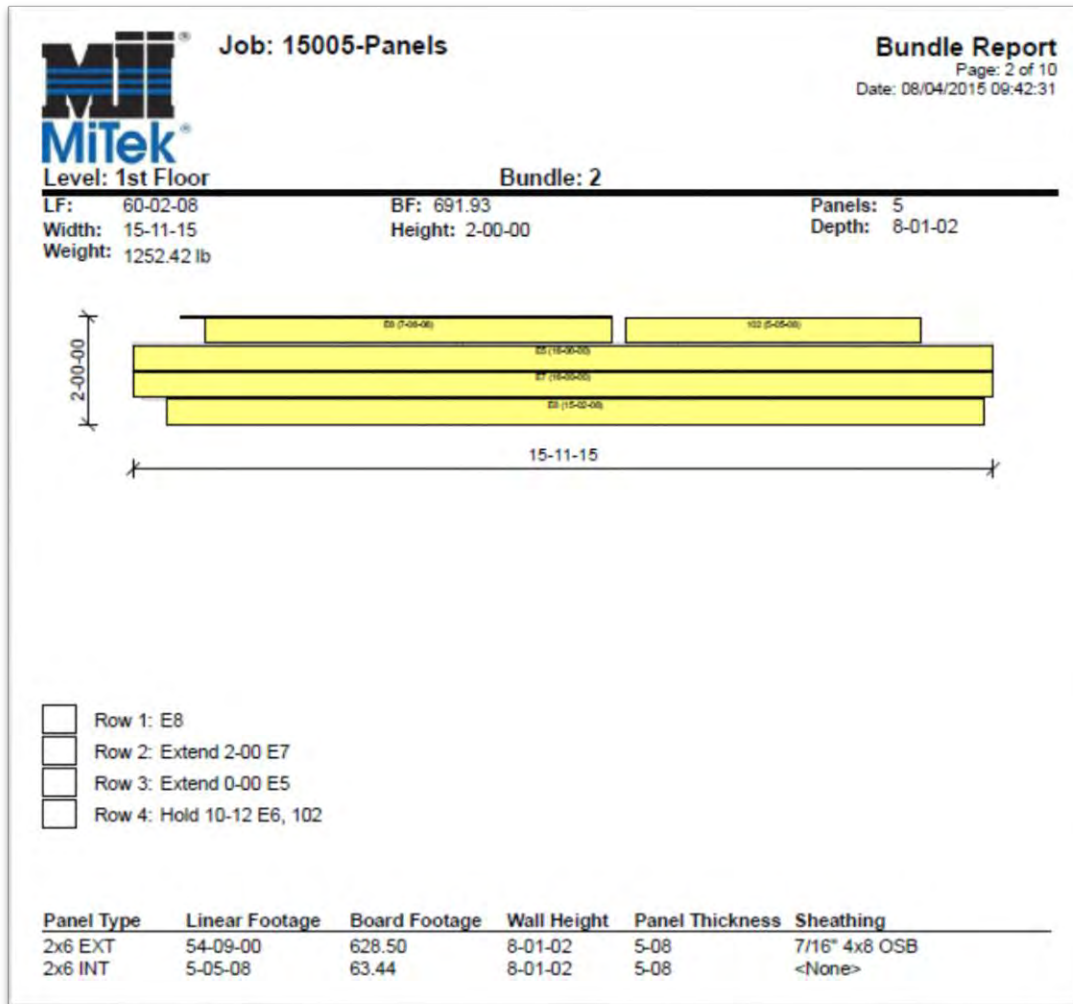


Figure 9. Example of Construction Drawing for Panel Bundling

Mr. Webb said that the addition of the rigid foam board accounted for the largest change to the team's typical process. Experimenting with various tools to cut the XPS took additional time; measuring and installing the foam required a change in work flow. A table saw was used to make long rips in both the OSB and foam, prior to delivering the proper dimensions to the line. To cut the ends of the foam, the crew initially considered hot wire cutters, but did not have the tool or the training. They also worried that melting the XPS might be a health concern. Cutting the foam proved to be the most time-consuming aspect of EP&B wall construction, both during the initial hours when the crew was experimenting to find solutions, and during the actual construction of the panels.

For window and door openings on the line, the crew initially used a hand saw for XPS and a circular saw for OSB. Since the XPS was placed on top of the framing early in the process, there was no circular saw available to use on the foam at that point in the line. The OSB was installed over the top of the foam later along the line.

Typically, a router bit is used when only OSB must be cut for window and door openings. These bits are too short to include the foam layer and so initially the crew cut the two layers independently. The production team was eventually able to locate a router bit that was long enough to span the combined depth of the 2-in. foam and 7/16-in. OSB. This allowed the crew to cut window and door openings at the typical location in the production line, after the foam had been installed over the studs and the OSB had been placed and fastened. Ideally, the bit would include a self-starting tip that can plunge through the OSB and foam into a known opening area, and with enough length to guide the cut along the framing of the opening the full depth of both materials – roughly 2-3/4 in. to 3 in. (Figure 10.) The tool they found had the necessary length but not the self-driving tip – a pilot hole had to be drilled separately. However, once this extra step was accounted for, the router made the cut for each window or door opening in about the same time it would have taken for the OSB without the foam. With that process solved, end-cutting of the foam panels was the step that the manager felt was least optimized. Note that FPIS was originally developed to be installed on the exterior of building walls. The typical 8-ft length spans two plates and the studs, which requires shortening to fit between top and bottom plates for the EP&B configuration.

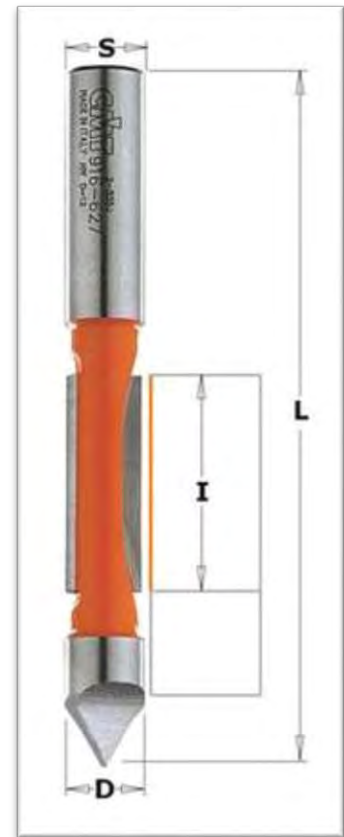


Figure 10. “Pilot Panel Bit” for Cutting OSB and Foam Together

The initial EP&B design used extended plates for only the bottom and second top plate; the first top plate was 2x4. For panelization, using two different lumber sizes for framing required adjustment and planning, and added complexity to the materials staging scheme. Assembly workers found it challenging to ensure that the face of the stud would be flush with the interior face of the plate to provide a good substrate for later drywall installation. The two different widths of the double top plate meant that the OSB could only be fastened to the second top plate. A third top plate was incorporated for tying the panels together in the field. These Very Top Plates (VTPs) were designed, cut and included in the package delivered to the site.

The 4-in. nails and framing gun required for fastening the OSB to the studs through the foam proved to be a challenge. Neither are typical and had to be special ordered. Both the nails and framing gun worked well, but Mr. Webb felt that this requirement might prove to be insurmountable for some crews or plants.

The plant work took two full 10-hour days for a crew of five (excluding supervision and management). This included the EP&B exterior walls and the standard interior partitions. The plant manager and research project field representative both reported that the learning curve appeared to be short, considering that three of the five crew members were new to the job, none had experience working with rigid insulation, and the available tools were not designed for the specific tasks.

The plant manager added some cost to the bid in anticipation of extra time and effort. He noted that it is difficult to compare this job with a typical job, because the major difference was the cost of the foam, which was donated in this research project. He also didn't have to order, source, and compare prices,

tasks which represent administrative time. Though the rigid foam is big and bulky, it is not heavy, and many plants have floor space to spare, including this one. The addition of the VTP meant additional cost, and further complicated the comparison of an EP&B system to a standard light-frame wood configuration.

Mr. Webb estimated that this one-off project required roughly 50%-60% additional time. With proper experience and tooling, Mr. Webb thought that the additional time required for an EP&B project would be 10-15%, specifically for cutting and fitting the foam. In the future, he would plan to budget approximately another \$500 to cover the necessary training and tooling changes to successfully produce an EP&B wall panel project. He predicted that with two, or potentially three EP&B projects in close succession, any wall panel plant could optimize their processes so that little additional fee would be required, other than passing on the cost of the FPIS. Gaps in time or personnel would lengthen this transition. He expressed willingness to do more EP&B projects in the future, and stated that he would likely research and acquire the proper tools to solve the challenges described above if he knew that the EP&B system would be frequently requested. He noted that the ability to include insulation in the panel is a market differentiator.

Figure 11 through Figure 19 show various details of the EP&B wall panel production in the factory.



Figure 11. Studs Nailed to Bottom Plate, leaving 2-in. Gap for Foam



Figure 12. Using Hand Saw to Cut Foam for Windows



Figure 13. A Wall Panel with a Window Opening

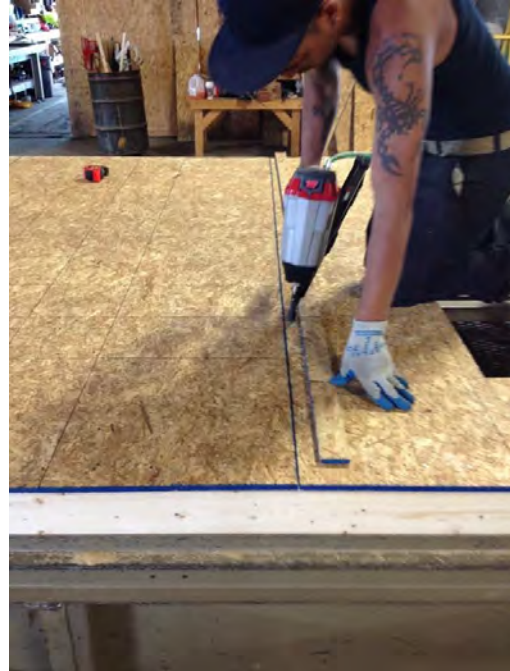


Figure 14. Using a Guide to Attach OSB to 2x4 Studs with 4-in Nails



Figure 15. Cutting XPS on a Table Saw



Figure 16. Grouping Finished Wall Panels for Bundling and Shipping



Figure 17. Completed EP&B Wall Panel Bundles at Plant, Ready to be Loaded onto Flatbed Trailer



Figure 18. EP&B Panels Strapped onto Trailer for Transport to the Project Site



Figure 19. Loading EP&B Wall Panels onto Flatbed Trailer

Wall Erection on Site

The wall panels arrived on site and were moved as required with no apparent damage.

Erection of the wall panels and toe-nailing to the floor deck were both similar to typical wall configurations. Cody Warner, the framing foreman, reported that he would have liked to add a few nails at corner connections (beyond code) but was not able to because the XPS, having been factory-installed, was in the way. Mr. Warner had previous experience with a handful of panelized houses and reported that erection and joining the EP&B system took essentially the same time as any other panelized project, and the crew was able to use their standard tools and techniques. The 6-in. width of the EP&B walls was familiar to the crew since in that area of New York State the most common wall is 2x6 to accommodate code-mandated R-20 cavity fill insulation.

Mr. Warner reported two quality issues with this EP&B project:

1. The air gap between neighboring panels
2. Nails at studs which missed framing

Mr. Warner noted that gaps between neighboring panels are common with any panelized project, and not specific to EP&B. With “stick-built” construction a panel can be built the full length of an uninterrupted wall, limited mostly by the size of the crew to tip it into place. However, sizes from the panel plant tend to be much shorter, which results in more frequent vertical gaps that must be addressed when panels are joined.

In an EP&B wall these connections are slightly different than typical lumber-to-lumber connections. The 2x4's at the panel edges can be drawn tight to each other with nails or screws, but the squared edges of the FPIS and OSB both meet, as well. OSB is intended to be installed with a 1/8-in. gap, but the foam connection works best if the butt ends are pressed together. The wall panels could be constructed with 2x6 studs instead of 2x4's at each panel end to reduce the gap but this adds cost, complexity and dozens of additional thermal bridges due to framing; an important goal of the EP&B wall is to reduce thermal bridging.

Air-sealing was not in Mr. Warner's scope of work; he reported that the general contractor followed the framers and caulked each lumber connection, generally from the inside. This included the sill plate at the deck, the studs at neighboring wall sections and the top plates.

Mr. Warner noted that quite a lot of re-nailing at studs was required since at the factory many nails had missed biting into the framing. This generally occurred at studs where OSB panel edges meet and two rows of nails are placed to capture the sheathing edge for each of the panels which butt at that location. Framers typically shoot these nails at a slight angle in order to provide a safe setback from the WSP edge and still fully engage with the stud lumber. The longer 4-in. nails and the 2-in. offset created by the foam means that the typical nailing angle is a bit too steep, and the nail can actually penetrate through the stud to the other side. Whether the wall panels are being constructed in a plant or on site, accuracy is difficult to determine until the walls are tipped up and examined from the cavity side. Unlike with hand nailing, the framing gun gives no indication of whether or not the lumber was engaged. The framer noted that walls where there was a lot of “blow through” had to be re-nailed on site, often from a

ladder outside the building. This issue is specific to the studs where sheathing panels abut. In the field of the WSP, the nails can be aimed orthogonal to the sheathing and were generally well-placed, with full connection to the stud lumber.

The framer's scope of work included erection and joining of the exterior walls, erection and joining of interior walls, setting trusses and decking the roof, WRB installation, and window installation. He reported no noteworthy differences for any of those activities with respect to the EP&B wall system. Figure 20 through Figure 30 show various details of the EP&B wall system as erected on the test site.

Mr. Warner was asked to compare the EP&B configuration (FPIS sandwiched between the OSB and the stud framing) with the more common application of foam (exterior to the OSB of traditionally-framed 2x4 light-frame wall.) He has previous experience with exterior c.i., and feels comfortable with the necessary adjustments to his construction processes to accommodate the foam layer exterior to the wood sheathing. He does not consider the longer nails for window and siding installation and the addition of framing around window and door openings to be obstacles to using exterior foam, and did not initially see the EP&B system as an advantage. He did express concern about the racking strength of the assembly due to the shifting of the load path away from the framing due to the 2-in. foam layer at the inside of the WSP and the extension of the top and bottom plates. He was satisfied by the laboratory structural test results confirming the performance of the EP&B assembly.

Mr. Warner noted there is some advantage to siding and window installation with EP&B, since shorter nails can be used and less framing is required. He said he would be very willing to accept EP&B projects in the future and would not likely bid or staff the project any differently with respect to labor. He did not make any suggestions for additional or different tools or workflows to accommodate the EP&B configuration.

For any panelized project, whether standard or EP&B, he recommended care with air sealing, especially where wall panels meet. Mr. Warner has used a flash coat of closed cell spray foam on other projects, and suggested that it would also be a good solution for the EP&B wall system.

Mr. Warner said he would readily accept and bid EP&B projects in the future, but noted he would prefer to field-frame the walls. He expressed an opinion that many framers may share: "I like to build." While panelization may provide cost and time benefits, it also changes the inherent nature of framing and building, removing many of the decision-making and creative aspects. This may partially explain the slow penetration into the residential market of panelized wall systems.

Robert Grinrod of Conservation Services Group conducted a site observation and noted that the house design had not been optimized to reduce framing. Several window and door openings fell just shy of 16-in. o.c. spacing locations and required extra jack studs. The effect of this additional framing is minimized in an EP&B wall, where the 2-in. layer of FPIS provides a continuous insulation layer beyond stud framing, as compared to a 2x6 wall with no c.i. layer.



Figure 20. Wall Panels Unloaded on Site



Figure 21. EP&B Panels Tipped up and Braced



Figure 22. Engineered Rim



Figure 23. OSB Filler over Rim (gap was considered too small for FPIS filler)



Figure 24. EP&B Wall Panels Braced in Place



Figure 25. Test Project's Window Openings have 2x4 Framing, Door Openings Have 2x6 Framing



Figure 26. Typical EP&B Window Opening



Figure 27. Connection Between EP&B Wall Panels



Figure 28. Interior Partition Wall Connection



Figure 29. Outside Corner Connection



Figure 30. Inside Corner Connection

Instrumentation

Description of Sensors and Equipment

Monitoring of the walls is accomplished using commercially available sensors and data-loggers from Omnisense. The sensor integrates a wireless transceiver, temperature sensor, humidity sensor, and pin type (resistance) moisture meter and has a battery life which can last up to 15 years. The sensors are permanently embedded into the EP&B wall structures for long term building envelope performance monitoring. A wireless data logger with built-in cellular capabilities (Gateway, also from Omnisense, installed in the garage) collects and transmits that data to the manufacturer’s web site for storage and periodic downloading for analysis. Table 6 lists the accuracy and features of the monitoring equipment used in the project. Figure 31 a and b show the sensor and data logging devices.

Table 6. OMNISENSE Testing and Monitoring Equipment

Function	Range/Accuracy/Details	Equipment/Features
Temperature (T)	T-40 to 185 °F /±0.8 °F, 3.6 °F max	<ul style="list-style-type: none"> • S-1-3.5 wireless sensor • plastic casing ~ 2.5 in. wide, 1.5 in. high, and 1 in. deep • lithium battery
Relative Humidity (RH)	0 to 100%/ ±3.5%, ±5% max	
Moisture Content (MC)	% by weight; measures elec. resistance between the two screws embedded in the material	
Data logger	Stores data to bridge power outage	G-3-C-VZW cellular gateway



a.



b.

Figure 31. Omnisense Gateway Data Acquisition Unit and Omnisense T/RH%/MC% Sensor

Sensor Placement in Building and Walls

Previous simulation and field testing¹² has indicated that most walls have ample opportunity to dry out diurnally and seasonally if they face south or west. Walls with east or north exposures encounter the most challenging moisture conditions, in large part because they get little or no direct sunlight. The north and east walls were defined as primary walls for monitoring; three stud bays on the north and three stud bays on the east were chosen to be instrumented with two sensors each, one for the stud, and one for the OSB. In one bedroom near the outside corner, two pairs of stud/OSB sensors were installed on each of the north and east walls, for redundancy. A pair of stud/OSB sensors were installed in the east wall of the kitchen and in the north wall of the bathroom.

For reference, a west wall and a south wall were chosen for instrumentation, again with two sensors each – one on a stud and one in the OSB. Also on the south wall, the master bathroom received one pair of stud/OSB sensors and the interior of the master bathroom was equipped with an independent sensor to measure ambient air conditions within the space.

A sensor in the great room reports temperature and relative humidity inside the building, and an exterior sensor was installed below the back deck with protection from sun and wind to monitor outdoor ambient conditions.

Table 7 and Figure 32 list sensor IDs and show the final monitoring locations.

Table 7. Sensor IDs and Final Locations

Sensor Id	Name	Type	Direction	Location
1E7000C7	East OSB Bed3 C	OSB	East	Brm 3 C
1E70023F	East OSB Bed3	OSB	East	Brm 3
1E7002FE	East OSB Kitch	OSB	East	Kitchen
1E7001A4	East stud Bed3	Stud	East	Brm 3
1E7001B5	East stud Bed3 C	Stud	East	Brm 3 C
1E700189	East stud Kitch	Stud	East	Kitchen
1696032B	Exterior	Ambient	Exterior	Exterior
1E7000C1	Interior MBath	Ambient	Interior	Interior
1E700103	Interior T-stat	Ambient	Interior	Interior
1E7000C8	North OSB Bath	OSB	North	Bathroom
1E7001A8	North OSB Bed3 C	OSB	North	Brm 3 C
1E7003C8	North OSB Bed3	OSB	North	Brm 3
1E70036E	North stud Bath	Stud	North	Bathroom
1E70014D	North stud Bed3	Stud	North	Brm 3
1E700297	North stud Bed3 C	Stud	North	Brm 3 C
1E700069	South OSB MBath	OSB	South	M Bathrm
1E7003CE	South OSB MBed	OSB	South	M Brm
1E700043	South stud MBath	Stud	South	M Bathrm
1E700391	South stud MBed	Stud	South	M Brm
1E70030D	West OSB MBed	OSB	West	M Brm
1E700273	West Stud MBed	Stud	West	M Brm

¹² Moisture Performance of Energy-Efficient and Conventional Wood-Frame Wall Assemblies in a Mixed-Humid Climate

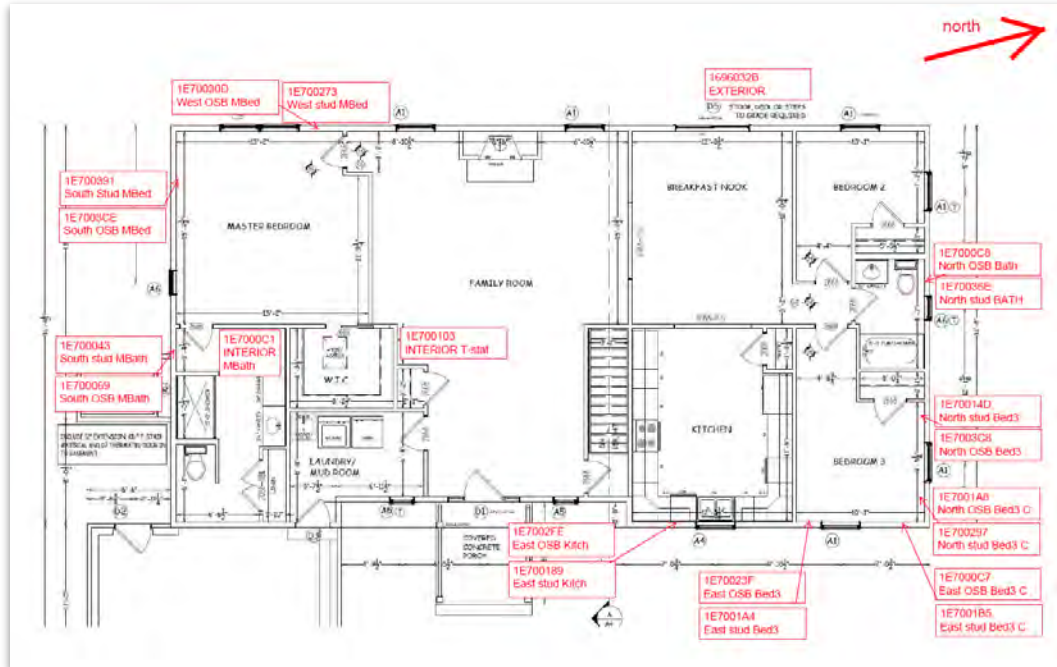


Figure 32. Location of Sensors in Plan

In an EP&B wall, the interior plane of the OSB is coincident and flush with the exterior plane of the rigid foam sheathing. To accommodate the sensor body to measure the moisture content of the OSB, small cubes of the foam layer were removed from the cavity side of the wall (Figure 33a). Once the sensor was placed and the screws inserted into the OSB (Figure 31b), the sensor cabinet was sealed with WRB tape (to avoid moisture damage to the electronic components) and the foam piece was re-inserted into the cavity (Figure 33b). This foam piece stands proud of the foam sheathing layer by approximately 1 in., due to the thickness of the sensor cabinet. The patch in the FPIS is not fully air-tight. The next intended step was to provide an air seal between the foam piece and the foam sheathing panel using either caulk or spray foam. This step was not implemented by the field representative.



Figure 33. Typical Installation of OSB Sensors in the EP&B Wall

The stud sensors were installed approximately 48-in. above the finished floor in the empty stud cavity, and the fiberglass batt insulation was installed over them.

Data Type and Interpretation Methodology

The data collected from the sensors includes the local temperature and relative humidity, and the moisture content of the wood to which they are attached.

The data logger is set to collect data at approximately 15-minute intervals. Data is uploaded continuously to a website for data storage; battery backup allows temporary local storage in the event of a power interruption. The Omnisense acquisition protocol processes this raw data to calculate the dew point and grains of moisture based on the temperature and relative humidity. The moisture content data is calibrated to a standard wood MC% based on the temperature at the wood surface.

The data set stored on the website has been downloaded on a monthly basis and averaged on several different time intervals (hourly to daily) for further analysis and charting.

The EP&B wall system is evaluated based on moisture content, temperature and relative humidity. The data from walls with north and east exposures is especially pertinent, since these orientations represent a “worst-case scenario.”

A key moisture performance characteristic is the fiber saturation point (FSP) – the moisture content (MC, %) at which only the cell walls are completely saturated (all bound water) but no water exists in cell lumina. Thirty-percent moisture content is considered the maximum fiber saturation point for solid wood.¹³ For OSB, the FSP is three to five percentage points below that of solid wood products,¹⁴ approximately 26%. As a design principle, wood and wood-based materials in buildings should be maintained at moisture content levels below the fiber saturation point, preferably with a margin of several percentage points. Above 20% MC there may be a risk for moisture performance problems – actual limits are not well-defined.

The ASTM D4444 Standard Test Method for Laboratory Standardization and Calibration of Hand-Held Moisture Meters was used as a guide for calibrating the Omnisense S-1 pin type (resistance) sensors. The accuracy of the Omnisense moisture content readings was determined by comparing recorded sensor measurements to gravimetric measurements of OSB samples of all readily available wood species mixes, using ASTM D4442 Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials for the same samples. Multiple samples in a variety of combinations of the following conditions were tested:

- Temperature was held constant at 25°C (77°F)
- Relative humidity ranged from 40% to 90%
- Moisture content ranged from 7% to 25%
- The conditioned specimens were considered stable when the difference in mass over a 24-hour period was less than 0.04 grams
- All specimens were weighed on a balance with a precision of 0.01 grams

The sensors record temperature simultaneously with relative humidity. The sensor measures the resistance across the sensor legs (the tips of the screws) to determine moisture content and

¹³ Wood Handbook – Wood as an Engineered Material

¹⁴ Moisture-related properties of wood and the effects of moisture on wood and wood products.

automatically corrects for temperature (because the conductivity of wood increases with increasing temperature.)

The data and fitted curve for the Home Innovation OSB moisture sensor calibration study are shown in Figure 34:

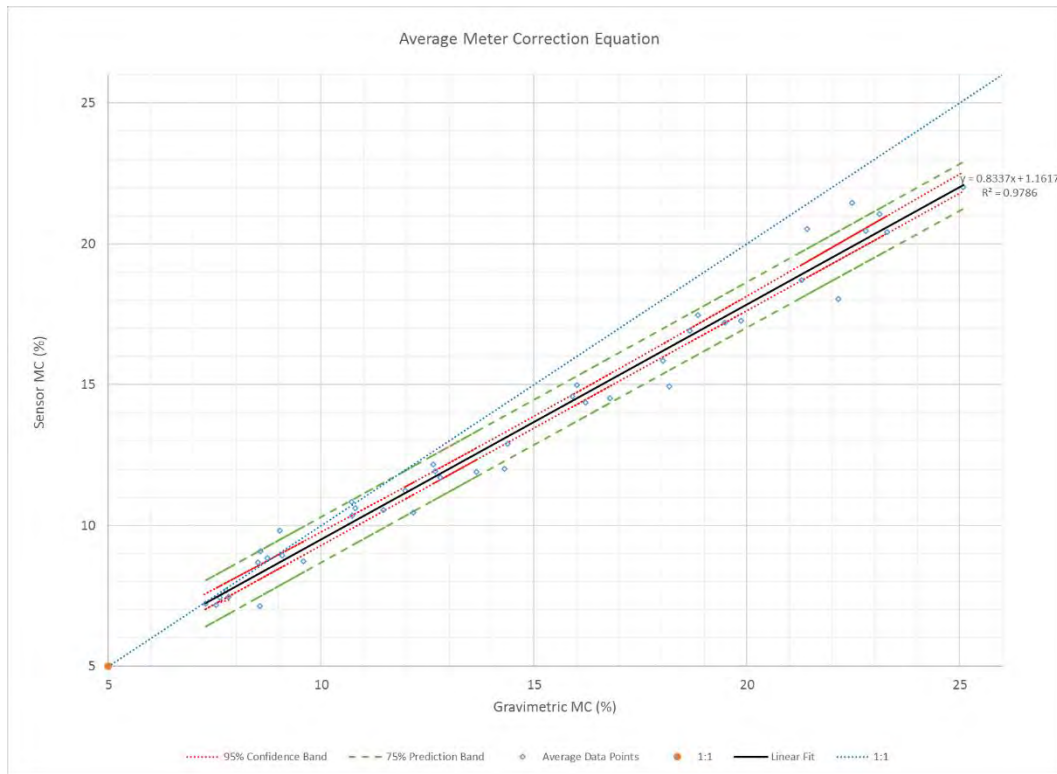


Figure 34. Curve Fit Chart for Moisture Content Sensor Calibration for All OSB Data Points

All wood moisture content (MC) values for OSB in this report have been corrected according to the following equation:

$$MC_{actual} = 0.83 \times MC_{recorded} + 1.16$$

The moisture content of the lumber and WSP in the demonstration house was documented over time to determine MC trends in relation to seasonal temperature and relative humidity (indoor and outdoor).

Two previous research efforts indicated that the EP&B wall assembly performs well with typical interior latent loads.^{15,16} The baselines from those projects are used for comparison to the OSB moisture data gathered here, in addition to WUFI simulation for heat and moisture transiency.

¹⁵ Advanced Extended Plate and Beam Wall System in a Cold-Climate House

¹⁶ Characterization of Moisture Performance of Energy-Efficient Light-Frame Wood Wall Systems – Phase II

Analysis

Construction

Both the manager of the plant where the test house EP&B walls were manufactured and the framer managing the crew that erected the walls at the site agreed that the construction requirements of the EP&B wall system were achievable and reasonable.

This field test of the EP&B wall system has prompted some changes to the recommended configuration:

Framing

Initially the double top plates were to be two different sizes, to minimize the thermal bridge due to framing. With a first top plate of 2x4 and a second top plate of 2x6, the calculated thermal bridge is 3.7% of opaque wall area in a typical wall section. With all three plates as 2x6 (bottom and two top) the thermal bridge is about 4.4% of opaque wall area. This change in framing results in a calculated whole wall R-value difference of only 0.15, and a reduction of thermal performance compared to a code wall with exterior c.i. of just under R-1. The advantages associated with this modification are:

1. Simplification of lumber ordering and sorting. Whether the framing occurs on-site or at a manufacturing facility, all 2x4's can be pre-cut stud lengths, and all 2x6's will be framing lumber lengths. Mistaking studs for general framing lumber can be time-consuming and costly.
2. The first top plate (instead of the second top plate) can accept the sheathing fastener, and the VTP can be omitted. This allows the panelizer to leave gaps in the second top plate (or tack in filler 2x6 lengths) which the framers on site can utilize to tie the panels together. The 2x6 lumber saved by the omission of the VTP is the full perimeter of the structure. This does not affect lumber quantity if the EP&B walls are field-framed, since in that case the VTP would not be included. An example of the VTP is shown in Figure 35.
3. In a field-framed situation, the top plate connection is simplified. In an EP&B wall with a 2x4 first top plate, only the 2x6 second top plate has a physical connection with the sheathing. By making both top plates 2x6, there are ample opportunities to attach the OSB with full engagement with one of the plates and always meet the manufacturer's edge-spacing requirement.

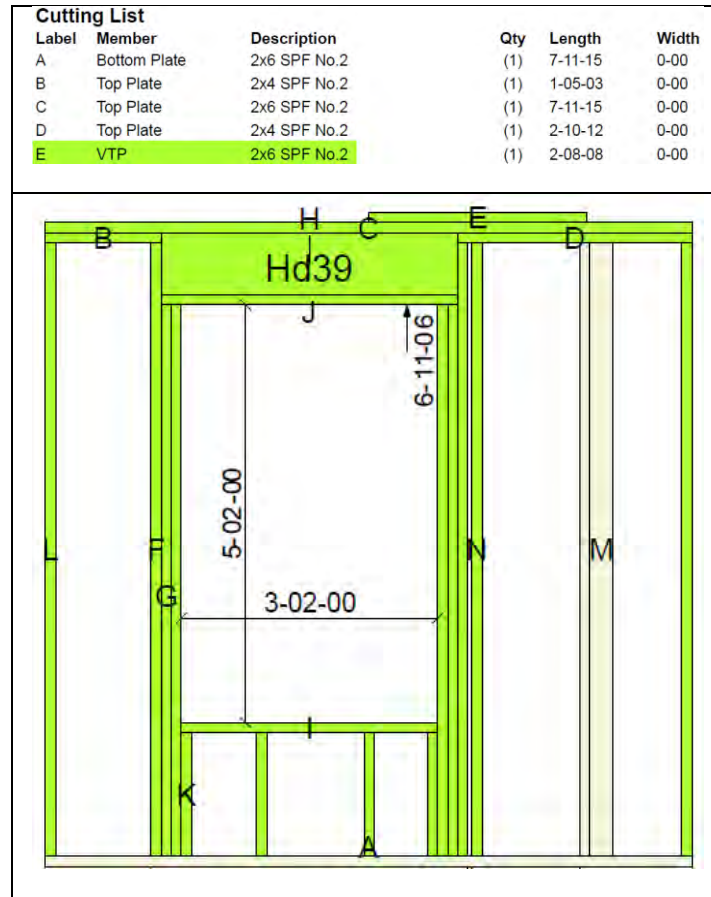


Figure 35. The Very Top Plate (VTP) Added to Tie Panels Together on Site

Fastening Schedule

In the test house, 4-in. nails were used at 6-in. spacing along the studs, and 2.5-in. nails were used at 3-in. spacing along the plates. The manager of the panelization plant reported the 4-in. nails to be a major hurdle in the wall assembly process, based on the cost and availability of the nails and the nailing gun. A subsequent, separately-funded study tested and confirmed an acceptable alternate schedule of 3.5-in. nails for all sheathing attachment locations at 3-in. spacing for the perimeter of the sheathing panel (panel and opening edges) and 6-in. spacing for the field of the panel (at studs without OSB joints.) The advantages associated with this modification are:

1. 3.5-in. nails are readily available at local supply stores and cost substantially less than 4-in. nails;
2. 3.5-in. nails fit most standard framing guns, without modification;
3. The perimeter/field pattern is already a common approach, familiar to framers; and
4. The 3-in./6-in. frequency is familiar to framers because it's a common stapling spec

Lower cost and greater availability of the nails, more common sizing that allows the use of existing nail guns, and a more typical nailing schedule are all likely to improve chances for adoption of the EP&B wall.

Panelization

The additional time that the EP&B wall system required at the panel plant could be reduced with four changes:

1. Standard wall heights, which would allow the use of pre-cut stud lengths (this was not an EP&B design issue);
2. 2x6 first top plate, which allows complete enclosure of the FPIS at the factory, and adjustment of the second top plate in the field, to join panels;
3. FPIS available from the manufacturer in the necessary dimensions, to reduce the number of cuts; and
4. Full-depth router bits with self-sinking tips, to cut window and door openings in OSB and FPIS in a single pass (this solution would also work well for field-framed EP&B projects)

Site erection

The process of joining the factory-built EP&B panels on the job site remains a challenge for air sealing and is true for any wall panel system.

Field-framed wall sections can be much longer than those built in a panel factory, reducing the number of connections. Framers can stagger the two sheathing materials (FPIS and OSB) by the width of one stud bay so that the vertical joints of the two types of sheathing are never coincident – a good first-line-of-defense for air sealing. Even at the end of a wall section, field-framers can add the last section of OSB from outside the wall once the connection is made. Leaving the end portion of a wall panel unfaced with OSB sheathing at the factory is not recommended because it leaves the FPIS and wall panel edges susceptible to damage during shipment.

For all walls, whether panelized or field-framed, best practice air sealing techniques should be employed, such as:

- WRB tape at the OSB joint between wall panels (e.g. Siga Wigluv or other, applied with a pressure roller over a primer)
- A bead of foam-compatible caulk at the vertical stud/FPIS joint on each adjacent panel, prior to connection (this prevents both a direct and serpentine air path)
- A spray-on sealant (e.g. Knauf EcoSeal or other) along the interior framing joints prior to installing the cavity insulation
- A flash coat of closed cell spray foam on the inside of stud bays prior to installing the cavity insulation

Cost

Detailed cost information is in Appendix C of the companion Energy Simulation Results Analysis report. The conclusion of the study is that the NYSERDA test home EP&B wall configuration, as built, cost approximately \$0.55 per square foot less to build than a code-minimum wall for Climate Zone 6: 2x4 16 in. o.c. standard framing with R-13 cavity + R-10 continuous exterior insulation. The EP&B wall requires additional materials (WRB and 2x6 plates), which cost more than for a c.i. wall, but the reduced complexity of window and siding installation – due to the nailing substrate provided by the exterior layer of OSB sheathing – more than offsets those costs.

Table 8. Cost Comparison of Wall Types

Wall Type		R-Value Nominal	R-Value Calculated	Total Cost ^a	Cost/ SF	Cost per Nominal R-Value per SF	Cost per Calc'd R-Value per SF
Std EP&B	EP&B 2x4/2x6 R-13 w/ 2 in. XPS	23	21.8	\$3,936	\$19.68	\$0.86	\$0.90
Test EP&B	EP&B 2x4/2x6 R-15 w/ 2 in. XPS	25	22.8	\$3,988	\$19.94	\$0.80	\$0.87
Max EP&B	EP&B 2x6/2x7.5* R-21 w/ 2 in. XPS	31	30.3	\$4,096	\$20.53	\$0.66	\$0.68
CZ 6 Code	2x4 std. 16 in. o.c. R-13 w/ 2 in. XPS	23	22.6	\$4,098	\$20.49	\$0.89	\$0.91

^a Total Cost for 200 SF wall section, rim, 3050 dbl window, interior/exterior finishes; see Appendix F

Using the most basic comparison, a 2x4/2x6 EP&B wall with R-13 cavity insulation meets International Energy Conservation Code minimum prescriptive R-values for all climate zones in the state of New York, and costs no more than a code-minimum wall with fully exterior c.i. Depending on the comparison code wall's complexity, the EP&B wall can be considerably less.

Energy

The companion Energy Simulation Results Analysis report describes the details of the test home's construction and the methodology for simulating energy use using REM/Rate software and includes comprehensive discussion of results and conclusions. Major topics and final conclusions are summarized here. The EP&B walls were part of a high-performance envelope package including windows and basement walls.

A blower door test measured infiltration of 2.2 air changes per hour, measured at 50 Pascals pressure. IECC 2012 code minimum for CZ 6 is 3 ACH₅₀.

The REM/Rate analysis indicates that for Climate Zone 6A the envelope of the home as designed exceeds prescriptive 2012 IECC Building UA Compliance Section 402 requirements by 17.0% (Figure 36). The home's energy performance exceeds the reference home 2012 IECC Energy Cost Compliance Section 405 requirements by 9.7% (Figure 37). The HERS Index Target for ENERGY STAR v3.0 is 60; the calculated HERS index for the house as designed is 54, qualifying it for certification (Figure 38).

Elements	Insulation Levels	
	2012 IECC	As Designed
Shell UA Check		
Ceilings:	48.2	43.0
Above-Grade Walls:	68.5	64.8
Windows and Doors:	73.3	64.3
Basement Walls:	82.8	54.4
Overall UA (Design must be equal or lower):	272.8	226.5

Figure 36. 2012 Building UA Compliance for CZ 6

Annual Energy Cost	\$/yr	
	2012 IECC	As Designed
Heating	1329	1135
Cooling	157	160
Water Heating	476	476
SubTotal - Used to Determine Compliance	1963	1772
Lights & Appliances	1066	1043
Photovoltaics	-0	-0
Service Charge	195	195
Total	3223	3010

Figure 37. 2012 IECC Energy Cost Compliance for CZ 6

Normalized, Modified End-Use Loads (MMBtu/yr)		
	ENERGY STAR	As Designed
Heating	29.7	27.7
Cooling	4.8	4.8
Water Heating	12.7	10.8
Lights and Appliances	30.6	26.6
Total	77.8	69.9
HERS Index of Reference Design Home	60	54 HERS Index w/o PV
HERS Index Target (SAF Adjusted)	60	54 HERS Index
Size Adjustment Factor	1.00	

ENERGY STAR v3.0 Mandatory Requirements	
X	Duct leakage at post construction better than or equal to ENERGY STAR v3.0 requirements.
X	Envelope insulation levels meet or exceed ENERGY STAR v3.0 requirements.
X	Slab on Grade Insulation must be > R-5, and at IECC 2009 Depth for Climate Zones 4 and above.
X	Envelope insulation achieves RESNET Grade I installation, or Grade II with insulated sheathing.
X	Windows meet the 2009 IECC Requirements - Table 402.1.1.
X	Duct insulation meets the EPA minimum requirements of R-6.
X	Mechanical ventilation system is installed in the home.
X	ENERGY STAR Checklists fully verified and complete.


	<p>This home MEETS or EXCEEDS the energy efficiency requirements for designation as an EPA ENERGY STAR Version 3 Qualified Home.</p> <p>HERS Index w/o PV <= HERS Index of Reference Design Home AND HERS Index <= HERS Index Target to comply.</p>
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Figure 38. Project ENERGY STAR 3.0 Report and HERS Rating

Compared with a 2012 IECC code home, the test home would be expected to save approximately \$200 annually in utility bills, due almost entirely to better efficiency during the heating season. The test home saved 14.6% in heating energy compared to the 2012 reference home. This was due to several better-than-code envelope choices, including the windows, foundation walls and the above-grade walls (EP&B).

Table 9. Test House Annual Energy Cost Savings vs 2012 IECC Reference House

Annual Energy Costs (\$/yr)	2012 IECC	Test Home	Savings	%Saved
Heating	\$1,329	\$1,135	\$194	14.6%
Cooling	\$157	\$160	-\$3	-1.9%
Water heating	\$476	\$476	\$0	0.0%
Lights & Appliances	\$1,066	\$1,043	\$23	2.1%
Service Charges	\$195	\$195	\$0	0.0%
Total	\$3,223	\$3,010	\$214	6.6%
Average Monthly (\$/month)	\$269	\$251	\$18	6.6%

Table 10. Test House Annual Energy Consumption Savings vs 2012 IECC Reference House

Annual Energy Consumption (MMBtu/yr)	2012 IECC	Test Home	Savings	%Saved
Heating	52.2	44.6	7.6	14.6%
Cooling	3.8	3.9	-0.1	-1.9%
Water heating	11.6	11.6	0	0.0%
Lights & Appliances	27.1	26.6	0.5	2.0%
Total	94.7	86.7	8	8.5%

The single largest energy end-use in the home is the category of *Heating*, accounting for 51% of annual energy use, followed by *Lights and Appliances* and then domestic *Water Heating*.

Note that in cold climates the seasonal cooling load is relatively small, less than 5%. In fact, where seasonal cooling demands are small, internal loads (people, lights, appliances) constitute a disproportionate amount of the cooling load in summer. Very tight, heavily-insulated buildings do not reject heat effectively. In this case, because the cooling load is so small, no cooling equipment was installed, and the value listed for “annual energy costs” for the category of cooling (-3\$ per year, in this case) are not a useful metric.

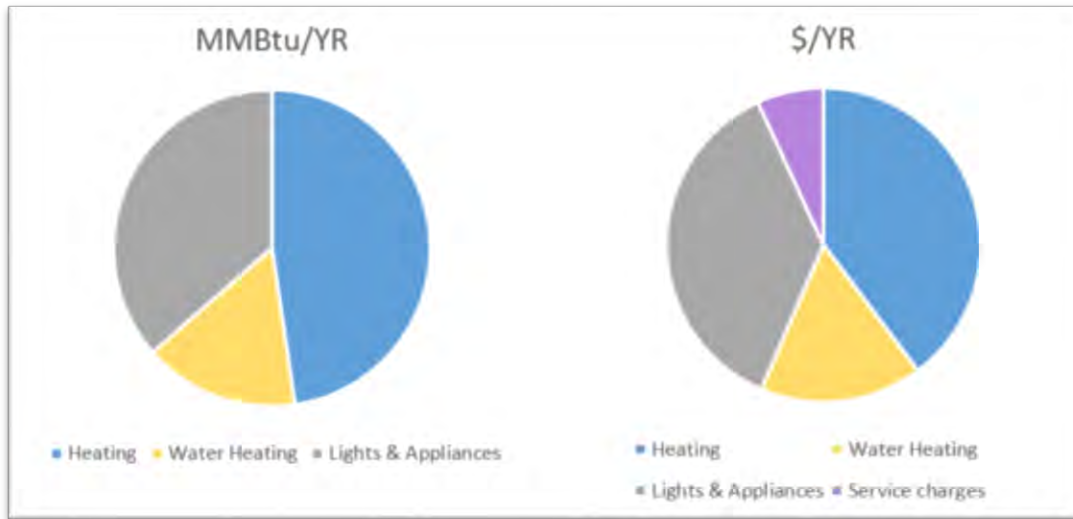


Figure 39. Proportional Annual Heat Energy Consumption and Annual Energy Cost by All End Uses

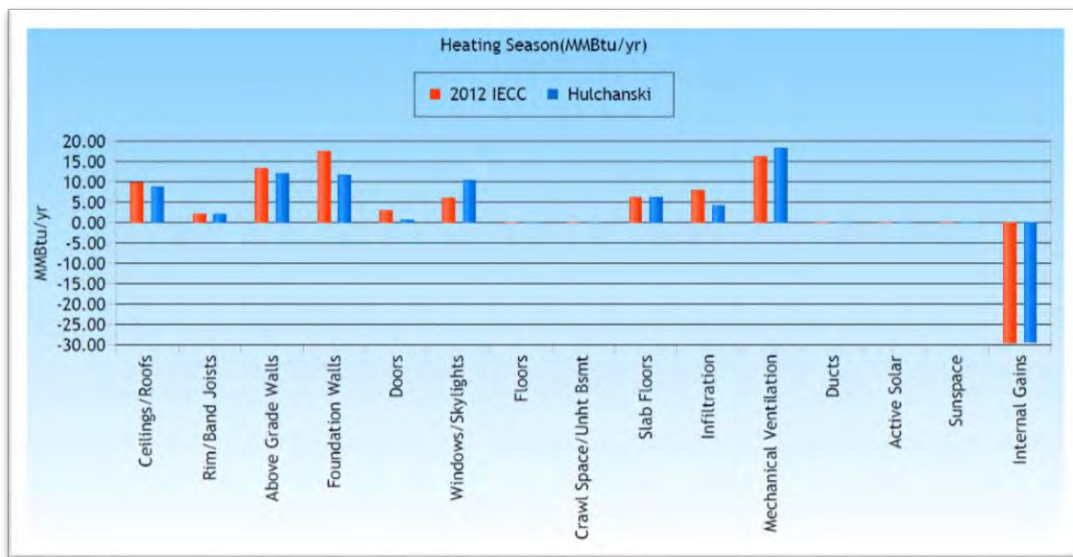


Figure 40. Comparison of Building Component Heating Energy Consumption: Ref (red) vs Test (blue)

The standard EP&B configuration used in the NYSERDA test house (2x4/2x6 with R-15+10 insulation) is a lower total installed cost (\$0.55/sf wall for either field-framed or panelized construction) compared to a CZ 6 code-minimum wall with exterior c.i. EP&B contributed, with improved windows and basement walls, to a projected whole-house energy cost saving of 6.6% - \$214 annually. The advanced-framed EP&B wall configuration (2x6/2x7.5* with R-21+10 insulation) would cost essentially the same as a CZ 6 code-minimum wall, and would increase the annual predicted whole-house savings to 8.5% in energy costs, approximately \$271 per year compared to the code-minimum configuration.

Durability

Moisture Data Results

Data acquisition began November 5, 2015, soon after occupancy. Interior and Exterior ambient temperatures and relative humidity are within typical, expected ranges (Figure 41) for winter and spring.

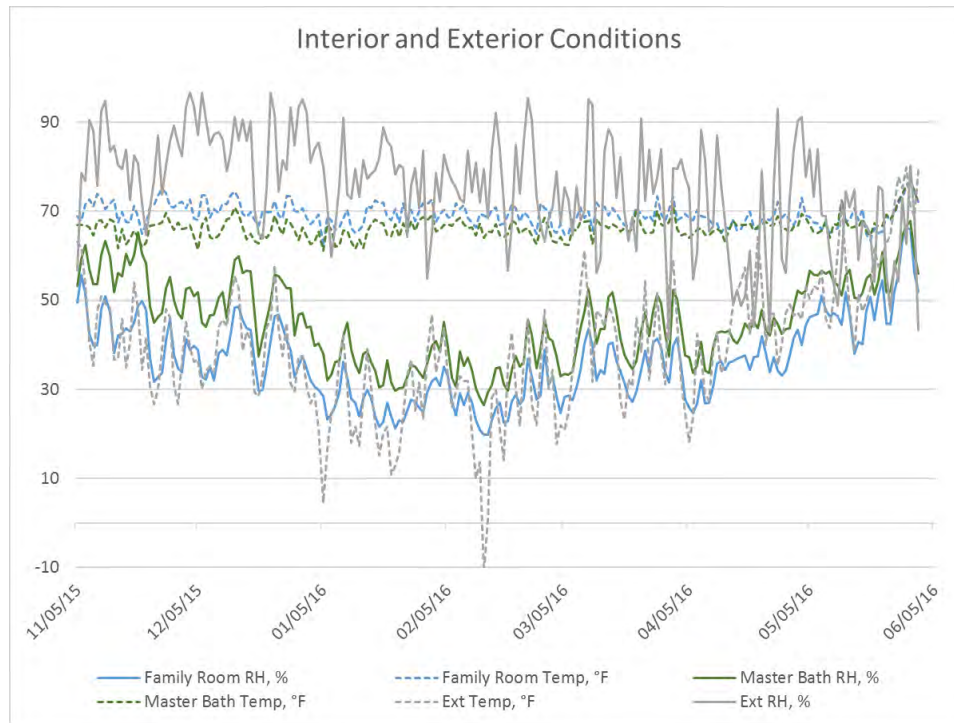


Figure 41. Test House Ambient Conditions

Moisture content (MC) in the studs and in the OSB are analyzed with reference to two different baselines:

1. The “fiber saturation” point (FSP) of each: a maximum of 30% MC for studs and 26% MC for OSB.
2. The MC found in studs and OSB in previous EP&B studies, particularly the two years’ worth of data from the study done in CZ 4 in controlled test buildings on Home Innovation’s campus.¹⁷ That study measured maximums of 11% MC for studs and 14% MC for OSB.

The EP&B studs in the NYSERDA test house are performing well. In all orientations, average stud MC from November through May never exceeded 13%. Studs in south-facing walls never exceeded 11% MC. Wood moisture content for EP&B studs in all directions is shown in Figure 42.

¹⁷ Characterization of Moisture Performance of Energy-Efficient Light-Frame Wood Wall Systems – Phase II

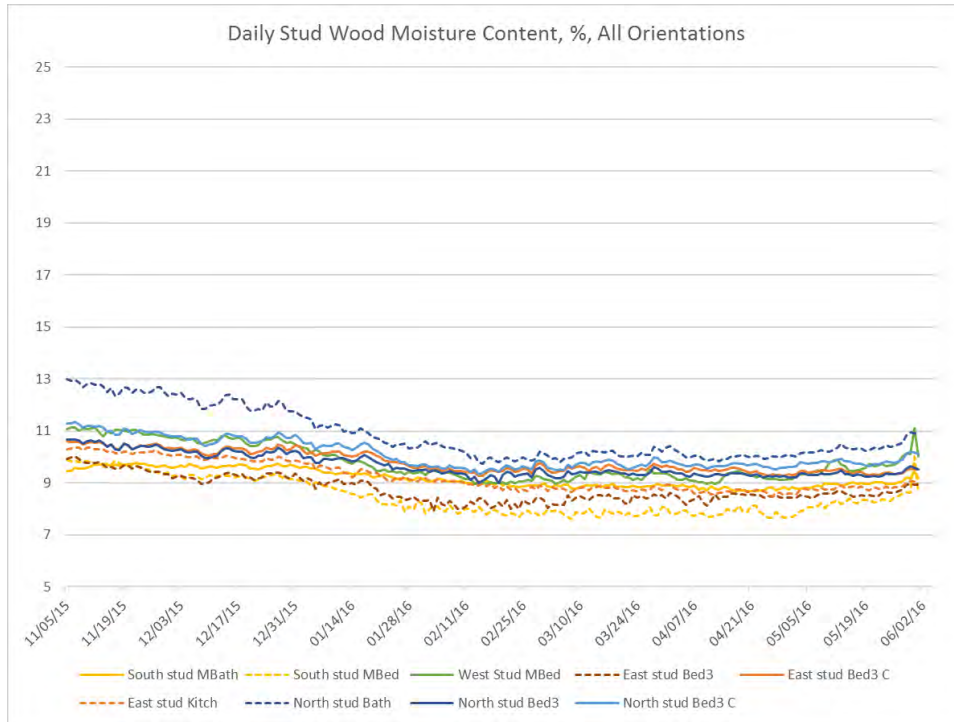


Figure 42. Daily Average Stud Wood Moisture Content, %, All Orientations

All EP&B OSB sensors in the NYSERDA test house reported daily average MC above 15% for at least one week early in the study period. Most OSB sensors recorded peak MC in the first week of February, followed by a steep drying period with occasional fluctuations (Figure 43.) These unusually high readings indicate a deviation from previous studies.

Two sensors, South OSB Bath and North OSB Bath, exceeded 21% MC; the OSB fiber saturation point is 26%. The sensor in the north bathroom wall became inactive during that period, so it is unknown whether the OSB reached fiber saturation, or how long it may have stayed above 21% MC. This sensor had a large gap in data before recording a single, final data point of 12% MC on May 9. If this reported value is accurate, it indicates that the wall did eventually dry to an acceptable moisture content. Two other sensors (east and west walls) experienced two periods of a day or two above 19% MC. The remaining five sensors monitoring OSB remained below 19% for the duration of the study.

The three active sensors which continue to report MC into the spring indicate that the OSB began to dry relatively quickly: the south master bathroom, an east bedroom and a west bedroom are all reading at or below 11% MC since the second week of April (Figure 43.)

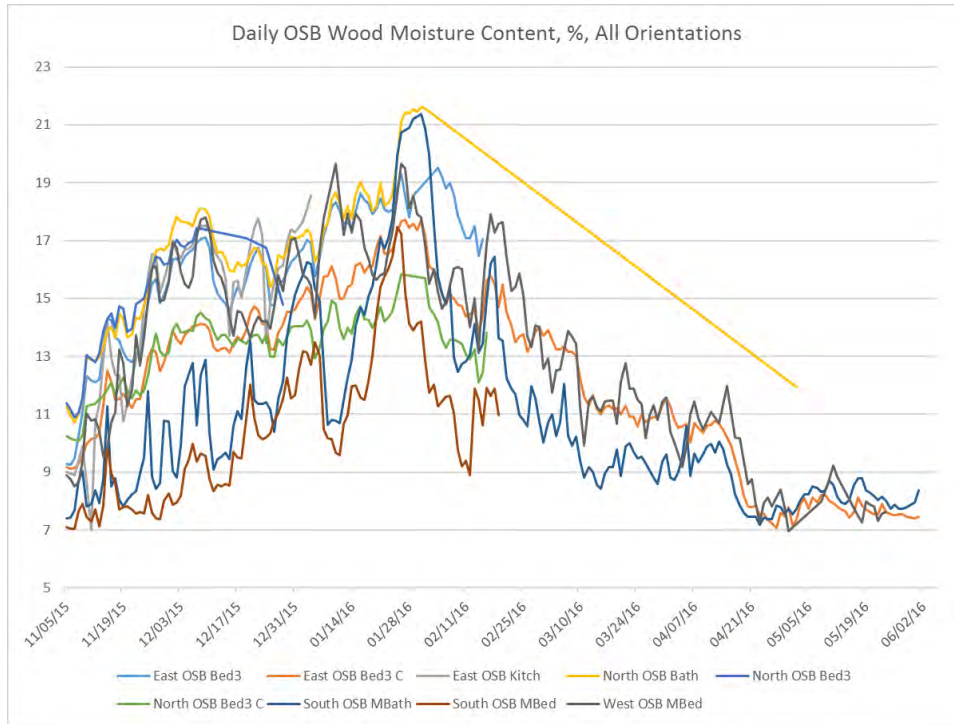


Figure 43. Daily Average OSB Wood Moisture Content, %, All Orientations

Between December 28, 2015 and February 19, 2016 six of the nine OSB sensors have become inactive and a seventh sensor stopped transmitting data in July (Table 11.) Possible explanations are discussed later in this section.

Table 11. Inactive Project Sensors

ID	Name	Last Activity	Status	Type	Direction	Location
1E70023F	East OSB Bed3	16-02-14 11:05:52	Inactive	OSB	East	Brm 3
1E7002FE	East OSB Kitch	16-01-03 12:24:46	Inactive	OSB	East	Kitchen
1E7000C8	North OSB Bath	16-01-31 18:54:28	Inactive	OSB	North	Bathroom
1E7001A8	North OSB Bed3 C	16-02-16 07:11:12	Inactive	OSB	North	Brm 3 C
1E7003C8	North OSB Bed3	15-12-28 01:15:08	Inactive	OSB	North	Brm 3
1E7003CE	South OSB MBed	16-02-19 07:00:08	Inactive	OSB	South	M Brm
1E70030D	West OSB MBed	16-07-13 08:56:52	Inactive	OSB	West	M Brm

Because so few OSB sensors continue to transmit, it is difficult to make definitive conclusions about long-term moisture performance.

For reference, a simulation was used to calculate the heat and moisture transiency in the EP&B walls of the NYSERDA test house using software developed by The Fraunhofer Institute for Building Physics: Wärme Und Feuchte Instationär (WUFI, German for “transient heat and moisture”). The actual ambient conditions in the test house resulting from occupancy during the test period were simulated in the WUFI model with sine curves to approximate the recorded real-time temperature and relative humidity. A WUFI simulation from November through June for a north-facing EP&B wall in CZ 6 (Figure 44) with

similar conditions (Table 12) yields a similarly-shaped curve for OSB MC, except that the spikes from December through February are much shallower than the MC recorded in the NYSERDA test house (Figure 45). For the WUFI model, the MC never rises above 12%, inconsistent with the data from the sensors monitoring the OSB at the NYSERDA house. (Figure 45) The WUFI simulation results illustrated in Figure 44 for conditions matching the NYSERDA test walls shows good moisture performance. The OSB sensors in the NYSERDA test house recorded generally acceptable (though higher) moisture content by percent up until the middle of January.

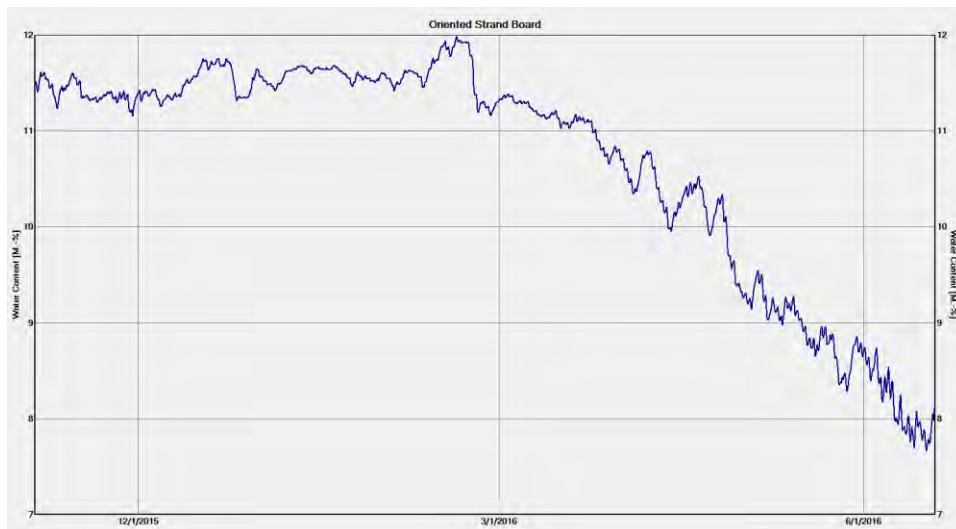


Figure 44. WUFI Simulation of the Moisture Performance of the EP&B North Wall OSB

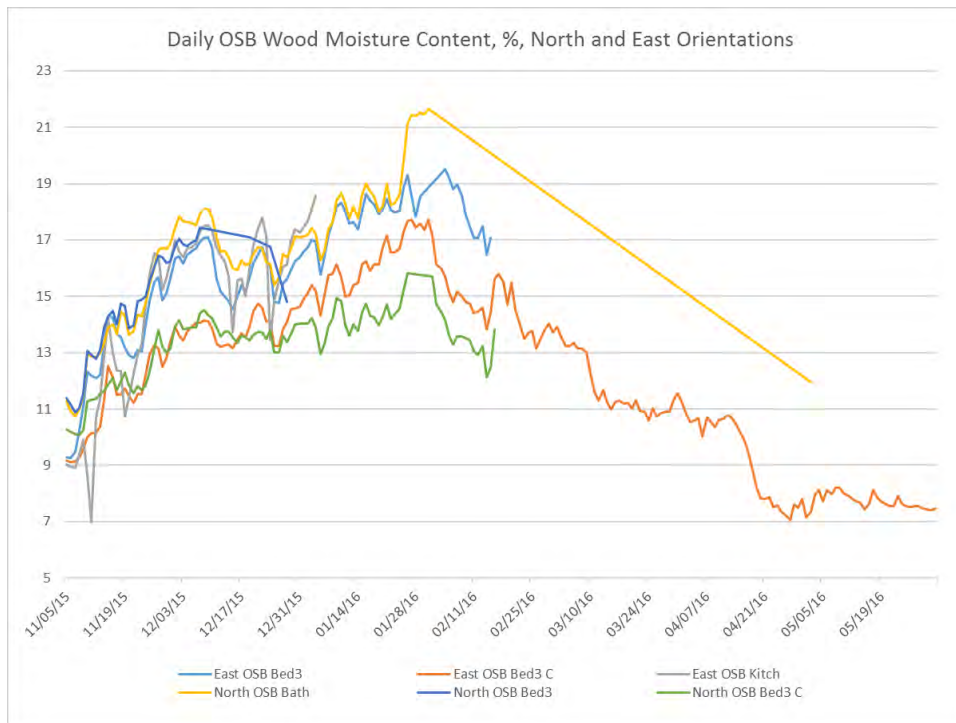


Figure 45. Moisture Performance of the EP&B North & East Wall OSB in the NYSERDA Test House

Table 12 compares the configuration of the NYSERDA test house EP&B walls to the WUFI simulation inputs that generated the graph in Figure 44.

Table 12. Comparison of Previous, Simulated and Current EP&B Test Wall Configurations

Component	NYSERDA Test House	WUFI Simulation
Climate Zone	CZ 6	CZ 6
Interior Air Conditions	As recorded, per Figure 41	Sine Curve for RH and T to match Figure 41
Exterior Air Conditions	As recorded, per Figure 41	TMY3 Syracuse, NY
EP&B Framing	2x4/2x6	2x4/2x6
Cavity Insulation	R-15 unfaced fiberglass batts	R-15 unfaced fiberglass batts
Foam Sheathing	R-10 2-in. XPS	R-10 2-in. XPS
Wood Structural Sheathing	½-in. OSB	½-in. OSB
Air Sealing	Caulked at framing connections	N/A
Water-Resistive Barrier	Non-perforated, ~ 12 perm	Non-perforated, ~ 12 perm
Start of Operation	Early November, 2014	Early November, 2014

Home Innovation has concluded that the NYSERDA test house data obtained from the sensors in the OSB of the EP&B walls is not entirely reliable. The following circumstances are considered relevant:

- The sensors monitoring the OSB were installed in an opening of the FPIS without being sealed, allowing air transport from the warm wall cavity to the cold surface of the OSB. The measured moisture content is likely to be reflective of a unique condition associated with the testing procedure, and not indicative of the typical OSB performance in the NYSERDA test house EP&B walls
- Results from previous test buildings where the sensors were installed in a manner that maintained the continuity of the air barrier provided by the FPIS do not corroborate the NYSERDA OSB MC readings
- Results from WUFI modeling (simulation of heat and moisture transiency) with similar indoor and outdoor air conditions do not corroborate the NYSERDA OSB MC readings
- The two sensors monitoring OSB in bathroom walls exhibited the highest MC readings, and both of these monitors became inactive

The sensor functionality ranges are advertised as -40°F to 185°F and 0% to 100% RH. Nevertheless, the bulk of the sensors which became inactive seem to have done so during the period of highest humidity (likely presence of liquid water) and lowest temperature (below freezing) which indicates the possible formation of ice. (Figure 46)

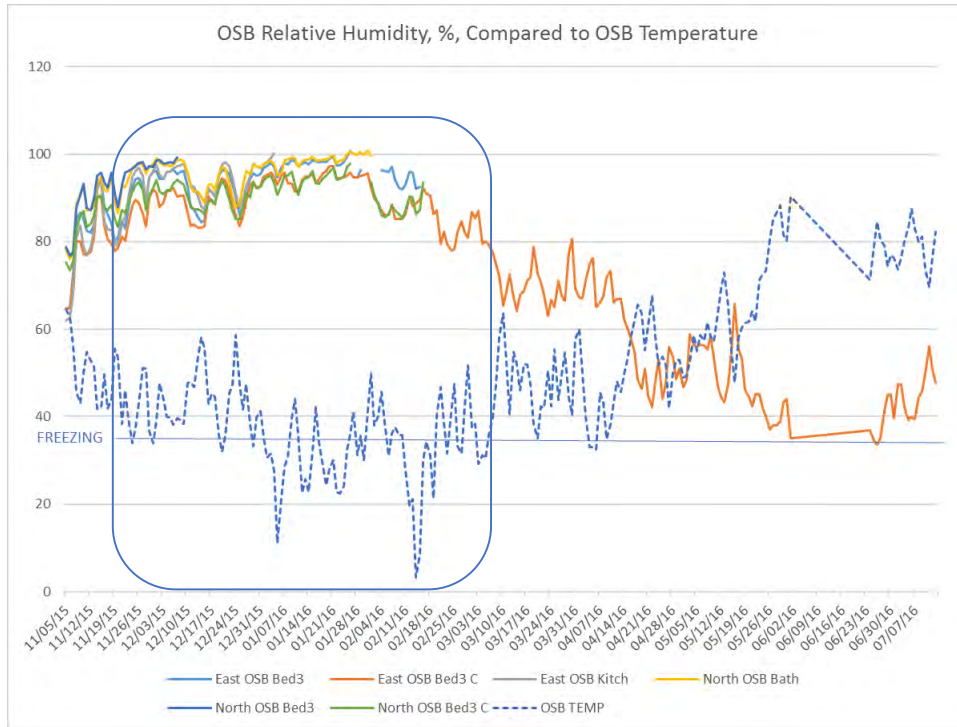


Figure 46. Sensors Malfunctioned When Ice Was Likely Present

The NYSERDA data for the stud moisture performance appears to follow the trends of previous test walls and the WUFI moisture simulation. All are well within safe MC% ranges. The installation of the stud sensors did not deviate from previous tests. (Figure 47)

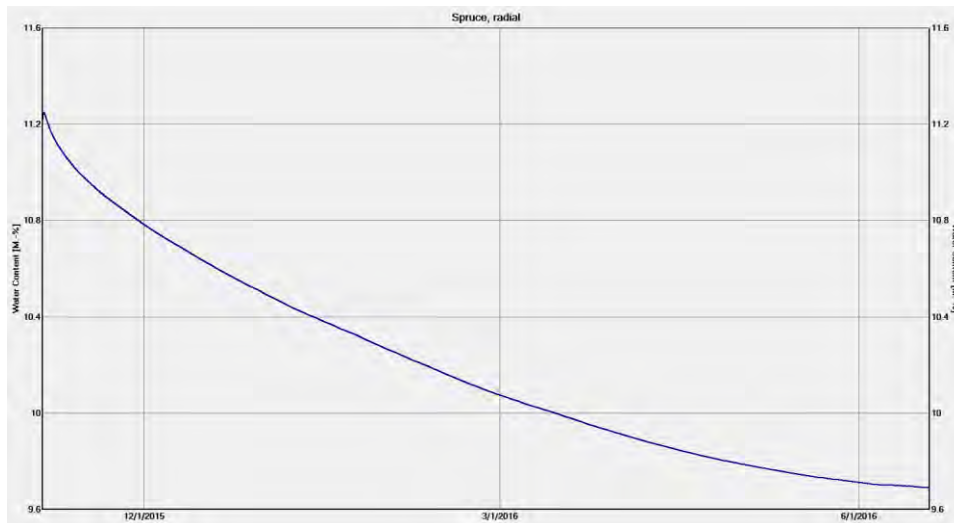
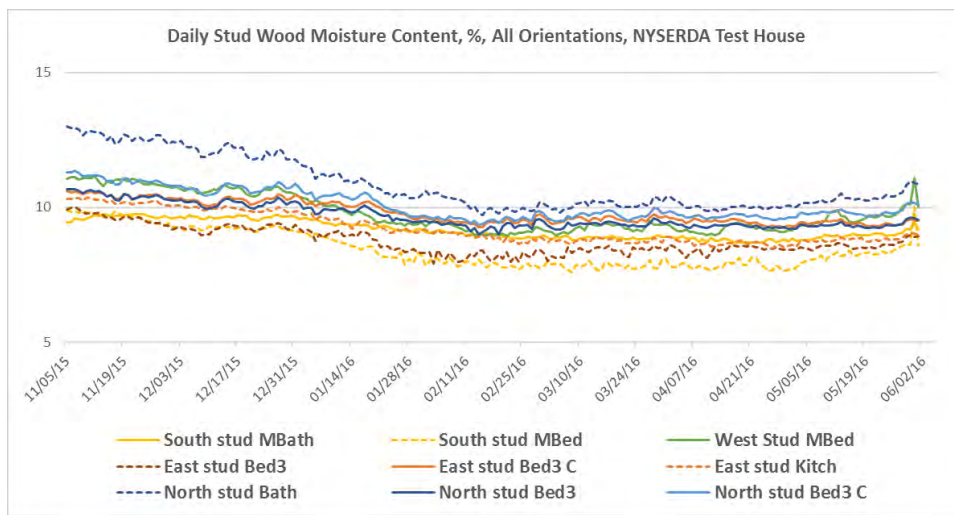
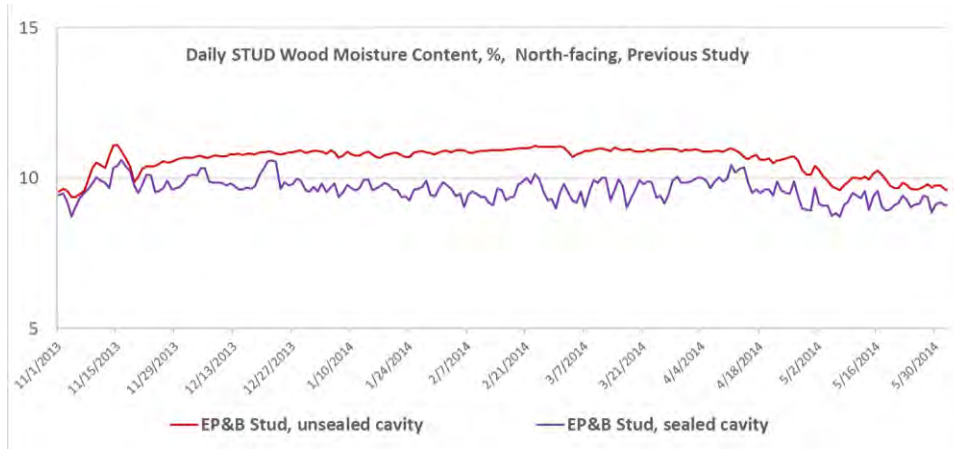


Figure 47. EP&B Wall Stud MC% for Previous Study (top), NYSEDA Test House (middle) and WUFI Moisture Simulation (bottom). All Show Good Correlation

Discussion of Results and Conclusions

Moisture Performance

Previous study of the EP&B wall, including both simulation and field tests, indicates good moisture performance for all components. A WUFI simulation with inputs matching the NYSERDA test house predict good moisture performance for all components. The data in this study confirmed that conclusion for the studs in an EP&B configuration in CZ 6.

The results for OSB moisture performance in this study are somewhat inconclusive, due to lack of data. Seven out of nine sensors assigned to OSB sheathing (78%) became inactive during the study. The faulty installation of the sensors – in a cavity of the FPIS which was not air-sealed – likely allowed moist air to migrate past the foam layer and contact the cold OSB. This would account for early spikes in the relative humidity and moisture content readings at the OSB which were higher than indicated by both 1) the previous field test in CZ 4, and 2) the WUFI heat and moisture transiency simulation designed to mimic the conditions of this test house in CZ 6. This moist air migration would also be a reasonable explanation for the sensor failures, which occurred during periods of 100% RH (liquid water present) and freezing temperatures in the OSB (likely formation of ice).

The three OSB sensors which continue to transmit data seem to indicate good moisture performance, with MC between 7% and 8% during spring and summer; however, the gap resulting from the faulty sensor installation could represent a path for moisture in both directions, allowing atypical drying under certain conditions, as well as the apparently atypical moisture accumulation. These sensors are monitoring OSB in walls with three different orientations: west, east and south. The highest measured moisture content readings – between 19% and 21% - occurred for limited time of less than a week during the coldest periods. Of the two walls with OSB MC readings which spiked above 21%, both were in bathrooms. The sensor in the south bathroom wall remains active, settling in at around 7% MC by spring. The sensor in the north bathroom wall is inactive.

The available data shows that all monitored OSB stayed below 20% for the duration of the test period except for one north-facing bathroom wall; the OSB in that wall spiked to just over 21% MC for a minimum of one week and a maximum of three months, when a single data point recorded a recovery to less than 8% MC.

These results confirm the recommendation that an interior vapor retarder would be beneficial in climates with high interior vapor drive in the wintertime. No interior vapor retarder was installed in the NYSERDA test house. The results also bolster the recommendation for best practices air sealing to prevent the migration of moist air from the building's interior to the OSB sheathing.

Energy

The field test and energy modeling has confirmed that the EP&B wall system can contribute to a building envelope that meets or exceeds both prescriptive and performance energy code requirements, and can aid in qualifying the home for voluntary energy-efficient program certification.

With the advent of stricter thermal performance requirements in the 2012 and 2015 IECC, builders who have resisted transition to exterior continuous insulation, citing construction and detailing complexities, may be prompted to consider this alternative. The extended plates which are integral to the design of the EP&B wall do constitute a thermal bridge and will always result in wall assembly R-values slightly lower than a similar wall with fully-exterior rigid foam. However, the thermal performance penalty of approximately R-1 may be a reasonable price to pay for the EP&B wall's simplicity, durability and flexibility. This project's companion Construction Guide provides builders who utilize either panelized or field-framed methods with the details they need to make an informed decision.

Design

The location of the rigid foam layer in an EP&B wall is a deliberate choice to reduce construction complexities and spur adoption in the market, helping more builders transition to high-performance wall assemblies that provide better-than-code thermal performance, accompanied by good first-step air-tightness, moisture resilience and structural performance which meets IRC requirements.

The information gathered from the field test supports modifications to make the wall system less complex and more affordable than it was previously:

- All plates are should be specified to be the same dimension
 - reduces complexity (takeoffs, ordering, staging)
 - reduces opportunity for error
 - improves the structural connection
 - streamlines wall assembly whether in a panel plant or on site
- Nails for fastening the OSB to the framing should be adjusted to be
 - readily available
 - reasonably-priced
 - fit in typically available framing nail guns in the market
- Nailing pattern should follow a more typical pattern of perimeter/field

All panelized walls require extra care in air sealing. When neighboring wall sections are joined, there is no continuous sheathing connection, and a vertical gap through the full thickness of the wall must be addressed:

- FPIS should be installed vertically, with panel joints alternating with OSB joints, providing first line-of-defense air-tightness by avoiding coincident gaps
- Best practices air sealing techniques should be utilized, such as
 - air-sealing FPIS panel edges at the stud with caulk, elastomeric spray sealant or spray foam; or
 - applying WRB sheathing tape with roller and primer

The panel plant crew in this field test discovered a tooling solution not previously considered: a self-tapping router bit that can cut the combined depth of the OSB sheathing and the FPIS without increasing task time. This solution would likely work for field-framed projects, as well.

The framing crew voiced concerns about nailing accuracy at studs. Factory QA protocols should be instituted to ensure nails consistently engage with framing. When EP&B walls are field-framed, crews should carefully examine the construction from the interior and re-nail as necessary, prior to the installation of WRB.

The framing crew found that window and door installation and flashing required no changes to the methods they typically employ with standard 2x4 or 2x6 framing.

If FPIS manufacturers determined that a large enough market sector of builders might adopt the EP&B innovation, they could offer foam sheathing in lengths to fit between the extended top and bottom plates, saving time and materials for both panelized and field-framed projects.

The thermal performance and moisture durability of an EP&B wall can be aided by

- Careful air sealing
- Use of an interior vapor retarder in CZ 5 and up, and anywhere that interior vapor drives are relatively high
- Close attention to construction drying

The companion publication: “A Builder’s Guide: Extended Plate and Beam Wall System,” includes instructions and final recommendations for EP&B construction. Appendix A contains CAD drawings illustrating the modification to extend both top plates.

Cost & Marketability

A field-framed EP&B wall costs the same as or less than a code minimum wall with exterior c.i. when considering the entire system, including windows and siding. Panelizers will price the wall panels according to actual material costs, which naturally includes the additional lumber of 2x6 plates, instead of 2x4. The builder can expect to realize savings as the house is detailed and closed in, due to the reduced complexity associated with window and siding installation over exterior wood sheathing, compared to FPIS.

The EP&B savings are likely to increase as a result of the design improvements developed from this study, including the use of a router tip to cut both OSB and FPIS for window and door openings in a single step, and modification of the design to include extended lumber for both top plates, simplifying takeoffs and assembly. Effective air-sealing methods should be applied between adjacent panels, as with any panelized wall system.

Building component manufacturers should expect to invest approximately \$500 in training and tooling and roughly 50%-60% additional time for the first two to three projects. After this, the additional time required for an EP&B project is estimated to be less than 15%, which can be passed on to the builder. This installation time is transferred to the plant from the site, as is the additional cost of materials. These premiums are later offset on site with savings associated with reduced complexity for siding and window installation, netting a total savings of about \$0.55 per sf compared to a CZ 6 code wall with 2-in. exterior c.i. For a small additional production fee, panelizers would be able to differentiate themselves in the market by offering a high-performing, code-compliant wall which incorporates 2 in. of FPIS in a nearly continuous layer.

The suitability of EP&B walls to panelization represents a potential new product offering in the market for wall panelizers, and an opportunity for framers to incorporate FPIS as continuous insulation without adding risk or significantly changing their field practices.

Because the extended top and bottom plates and the exterior wood sheathing effectively protect the FPIS, an EP&B wall can be assembled in controlled factory conditions and safely and cost-effectively shipped to a construction site. Wall panelization is well-known to provide time and materials savings through economy of scale and the opportunity to fully utilize waste materials and avoid construction delays and damage due to weather.

As a non-proprietary system with an incremental R-value expansion opportunity and proven performance, EP&B provides the builder with the flexibility, control and confidence to meet and exceed IECC energy requirements for above-grade walls.

References

ABTG (2015) Attachment of Exterior Wall Coverings Through Foam Plastic Insulating Sheathing (FPIS) to Wood or Steel Wall Framing. ABTG Research Report No. 1503-02. p 3.

ASHRAE. ANSI (2009) ASHRAE Standard 160-2009, Criteria for Moisture-Control Design Analysis in Buildings. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2009, including Addendum C, June 2012.

Building Science Corporation (2005) Installing Windows with Foam Sheathing on a Wood-Frame Wall. Subcontract report NREL/SR-550-37583.

Carll, C.; Wiedenhoef, A.C. 2009. Moisture-related properties of wood and the effects of moisture on wood and wood products. In: Trechsel, H.R.; Bomberg, M.T., eds., Moisture control in buildings: the key factor in mold prevention, 2nd ed. West Conshohocken, PA: ASTM International, Chapter 4, pp.54-79.

Fanger, PO; Ipsen, BM; Langkilde, G; Olesen, BW; [Christensen](#), NK; [Tanabe](#) S (1985) Comfort limits for asymmetric thermal radiation. [Energy and Buildings](#) 8(3): 225-236.

Glass, S., Kochkin, V., Drumheller, S., & Barta, L. (2015). Moisture Performance of Energy-Efficient and Conventional Wood-Frame Wall Assemblies in a Mixed-Humid Climate. *Buildings*, 5(3), 759-782. doi:10.3390/buildings5030759

Holladay M (2010) Using Rigid Foam As a Water-Resistive Barrier. Green Builder Advisor. www.greenbuildingadvisor.com/blogs/dept/musings/using-rigid-foam-water-resistive-barrier (Accessed on October 26, 2016)

Home Innovation Research Labs (August, 2015). Extended Plate and Beam Wall System, Summary of Initial Assessment, www.homeinnovation.com/trends_and_reports/featured_reports/extended_plate_and_beam_wall_system_-_summary_of_initial_assessment (Accessed on October 26, 2016)

Home Innovation Research Labs (December, 2015). Characterization of Moisture Performance of Energy-Efficient Light-Frame Wood Wall Systems – Phase II www.homeinnovation.com/trends_and_reports/featured_reports/test_hut_report_2011-2013 (Accessed on October 26, 2016)

Ed Hudson (2013). Home Innovation Research Labs (2013) 2013 Annual Builder Practices Survey. www.homeinnovation.com/about/blog/cost_is_not_always_king (Accessed on October 26, 2016)

Home Innovation Research Labs (August, 2016). A Builder's Guide: Extended Plate and Beam Wall System, www.HomeInnovation.com/EPBBuildersGuide (Accessed on October 26, 2016)

Mallay, D., Wiehagen, J., Kochkin, V. (January, 2016). Advanced Extended Plate and Beam Wall System in a Cold-Climate House, http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/extended-plate-beam-wall-cold.pdf (Accessed on October 26, 2016)

NAHB Research Center [Now Home Innovation Research Labs] (May 24, 2012) 2012 IECC Cost Effectiveness Analysis,
www.homeinnovation.com/~media/Files/Reports/Percent%20Energy%20Savings%202012%20IECC%20Cost%20Effectiveness%20Analysis.PDF (Accessed on October 26, 2016)

Forest Products Laboratory (FPL), U.S. Department of Agriculture Forest Service. (2010). Wood Handbook – Wood as an Engineered Material, FPL, Madison, WI.

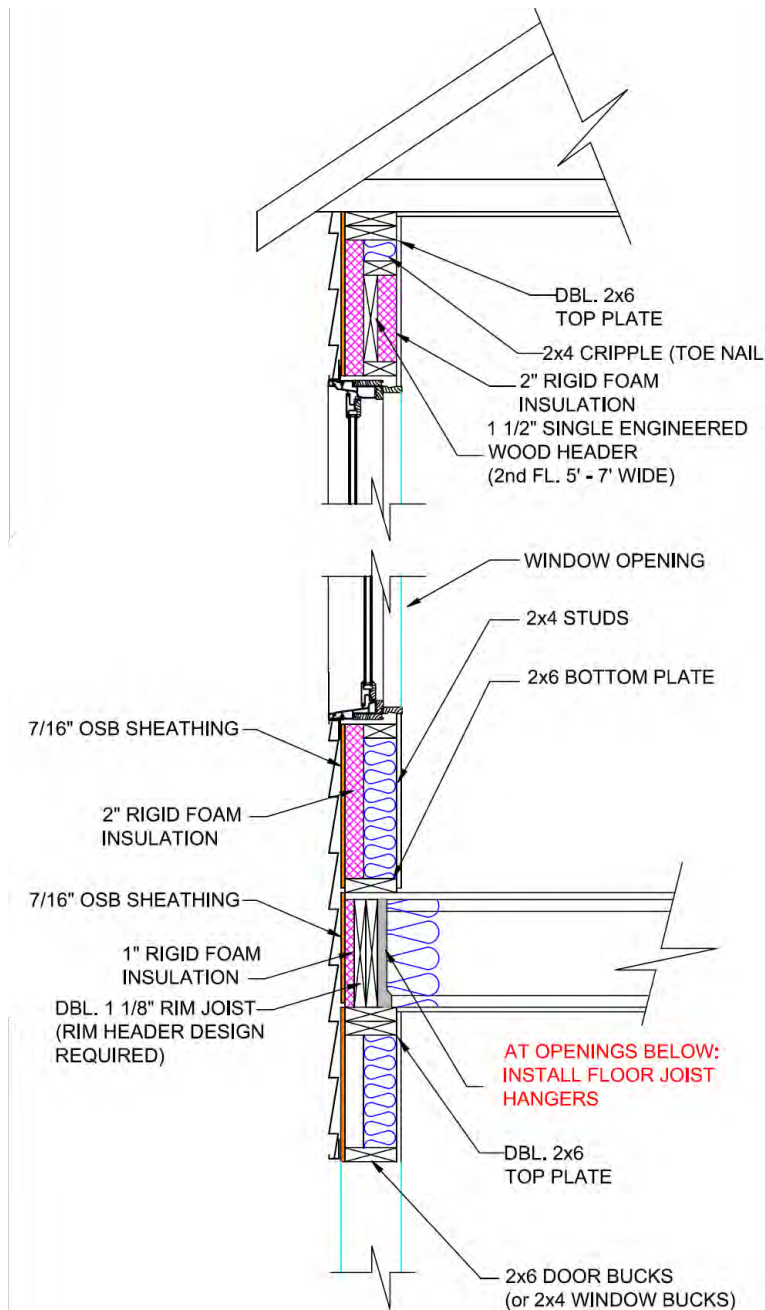
Appendix A: Recommended Modifications

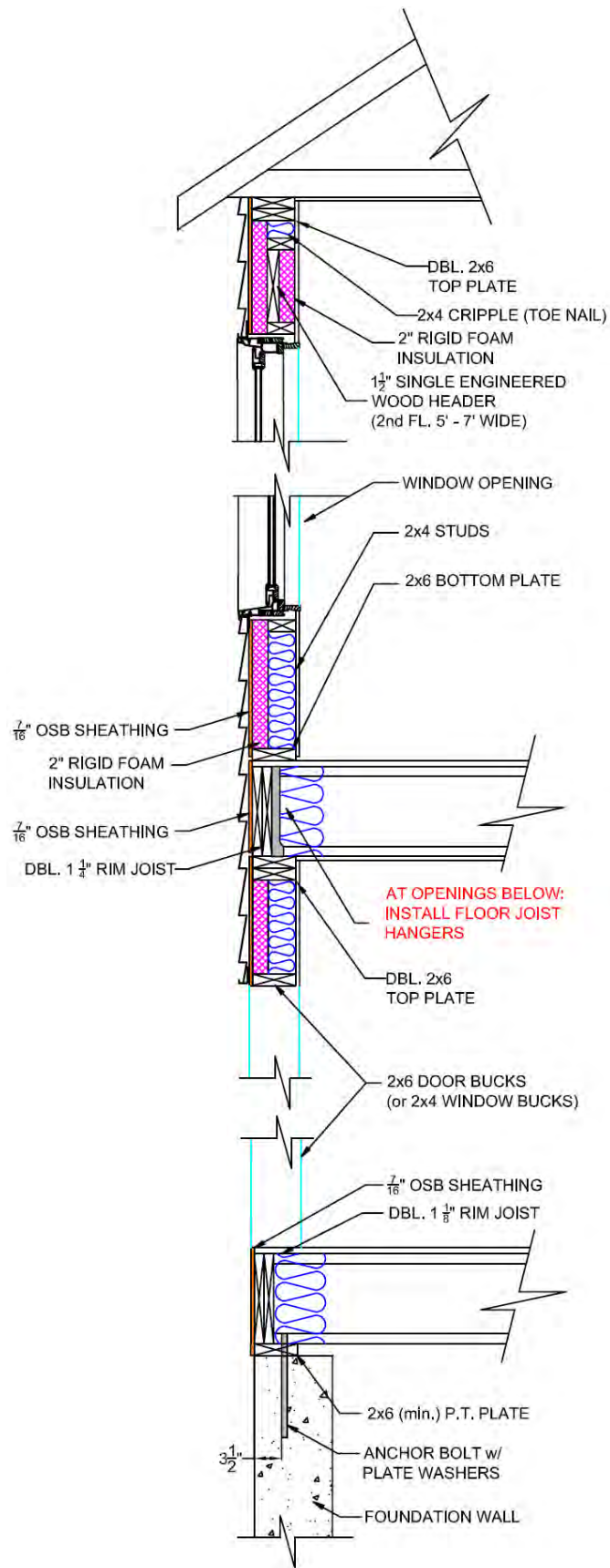
Nailing pattern:

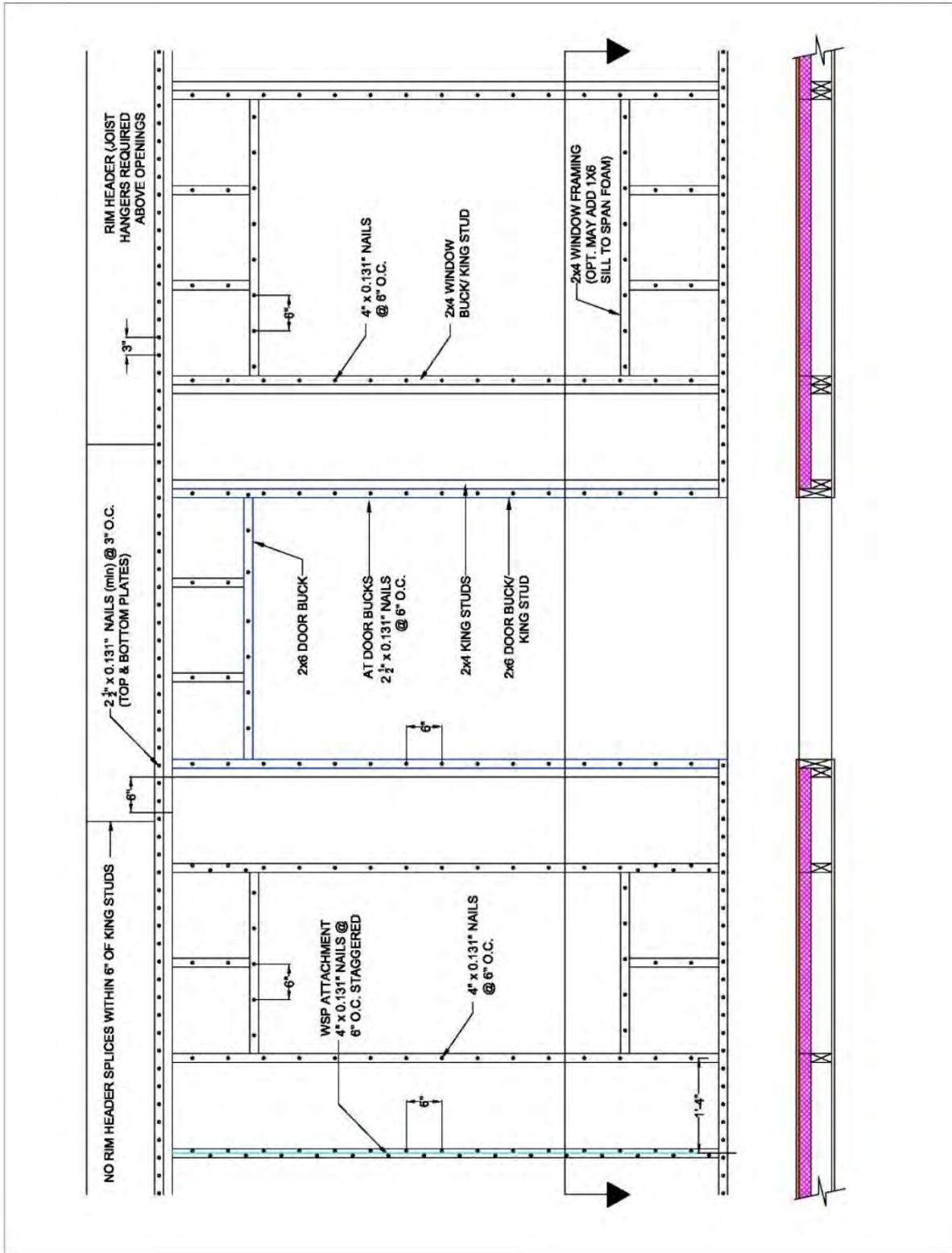
- 3-1/2-in. nails @6-in. o.c. in field
- 3-1/2-in. nails @3-in. o.c. in edges

Plates:

- Bottom and both top plates extended









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