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Extended Plate and Beam Demonstration Home

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Abstract

An extended plate and beam (EP&B) design was developed at Home Innovation Research Labs (Upper Marlboro, Maryland) in an effort to provide traditional light-frame wall construction details that are compatible with continuous insulating sheathing. This would encourage wide-spread adoption of high-R walls and promote greater energy efficiency in new houses. The new wall design provides significant increases in insulation and ensures moisture management while relying on common methods and materials for framing, insulation, and siding attachment. It incorporates the use of foam sheathing uniquely integrated with a structural framing system that allows for the installation of the wood structural panels outside of the foam insulation. The objective of this EP&B home demonstration project was to identify, implement, and publish specific construction details and integration strategies that can help builders transition to the EP&B system. The selected home was used to evaluate the implementation of a panelized EP&B system from plan layout through final testing, including assembly and erection on site. The full implementation process was evaluated to develop system modifications and enhancements. Key benefits and learning curves are documented in this report.

Keywords: EP&B wall system, cost, design, energy efficiency, thermal performance, wall construction, wall erection, continuous insulation, FPIS, energy code envelope, high-R wall

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Contents

English unit	Conversion factor	SI unit
inch (in.)	25.4	millimeter (mm)
square foot (ft^2)	0.092903	square meter (m^2)
pound (lb)	0.45359	kilogram (kg)
British thermal unit (Btu)	0.00105506	megajoule (MJ)
$T_{°F}$	$T_{°C} = (T_{°F} - 32)/1.8$	$T_{°C}$

Nominal lumber size (in.)	Standard lumber size (mm)
2 by 4	38 by 89
2 by 6	38 by 140
2 by 8	38 by 184
2 by 10	38 by 235

Extended Plate and Beam Demonstration Home

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Introduction

An extended plate and beam (EP&B) design was developed at Home Innovation Research Labs (HIRL) (Upper Marlboro, Maryland) in an effort to provide traditional light-frame wall construction details that are compatible with continuous insulating sheathing to encourage wide-spread adoption of high-R walls and promote greater energy efficiency in new houses. The new wall design provides significant increases in insulation and ensures moisture management while relying on common methods and materials for framing, insulation, and siding attachment. It incorporates the use of foam sheathing uniquely integrated with a structural framing system that allows for the installation of the wood structural panels outside the foam insulation. The EP&B wall design can be easily fabricated on site or factory panelized, thus decreasing transition risk to builders.

This document is the final report for an EP&B demonstration home built in Cazenovia, New York, 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 report (HIRL 2016a) and a construction guide (HIRL 2016b).

Home Innovation Research Labs previously studied the EP&B wall system for a 2014–2015 New York State Energy Research and Development Authority (NYSERDA) research project that included the following tasks: (1) construction details, (2) structural testing, (3) constructability assessment, (4) code compliance, and (5) cost effectiveness. Positive results from the 2014–2015 evaluation (HIRL 2014) as well as moisture monitoring of the EP&B wall performed in a parallel study with the USDA Forest Service, Forest Products Laboratory (HIRL 2015), 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

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

The International Energy Conservation Code (IECC) table R402.1.1 (ICC 2011) lists prescriptive thermal performance values for envelope components based on local climate conditions. Figure 1 illustrates the range of each climate zone (CZ).

The State of New York encompasses three different climate zones: CZ 4A (nonMarine), CZ 5A, and CZ 6A. Cazenovia, New York, (the location of the test home) is in Madison County, which is assigned to CZ 6A (Fig. 2). The 2014 supplement to the New York State Energy Conservation Construction Code (NYSDS 2014) adopted the 2012 IECC prescriptive and performance minimums for residential energy efficiency. Compared with IECC 2009 (ICC 2009), envelope requirements have increased for all major envelope components. A National Association of Home Builders (NAHB) report determined that the savings resulting from the 2012 IECC energy components baseline compared with the 2006 baseline averaged more than 30% for homes across all eight climate zones (NAHB 2012).

Table 1 shows the trend for several IECC prescriptive insulation and fenestration requirements during the last decade. Changes for the climate zones in New York compared with previous years are highlighted. The envelope components for the 2015 IECC are the same as for 2012. 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 (CI), 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 (2 by 4 studs with 2 by 6 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

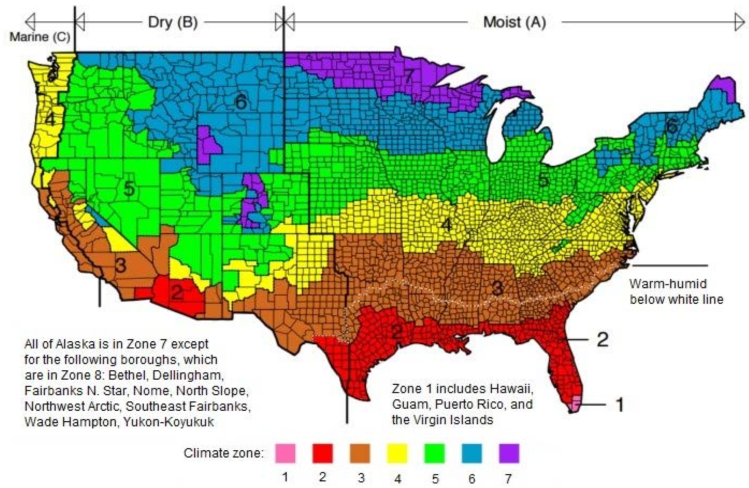


Figure 1—International Energy Conservation Code (IECC) climate regions (Baechler and others 2010).

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 CI.

Exterior CI is commonly applied as foam plastic insulating sheathing (FPIS) installed at the outside plane of the wood structural panel (WSP); this technique was demonstrated more than 40 years ago and is now standardized as a prescriptive method in the IECC. Yet, it had only achieved 11% nationwide market penetration in 2015 (2016 Annual Builder Practices Survey). There are several perceived transition barriers to widespread adoption of this method, such as

- concern about decreasing the ability of the oriented standboard (OSB) to dry outward, because of the low permeability of most FPIS, which is installed directly over the WSP,
- lack of a nailing base to support the cladding,
- difficulty of identifying and detailing a drainage plane,
- unusual installation of windows and doors, and
- atypical attachment of flashing to or through the FPIS.

With the steady increase of IECC energy requirements, adoption rates by builders of CI 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 CI.

Project Plan

Objective

The main objective of this project was 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 was 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 was 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 (HIRL 2016b). Abbreviations pertaining to this report are defined in Appendix A.

System Description

The EP&B wall assembly currently under study is intended to address many of the transition barriers for high-R walls.

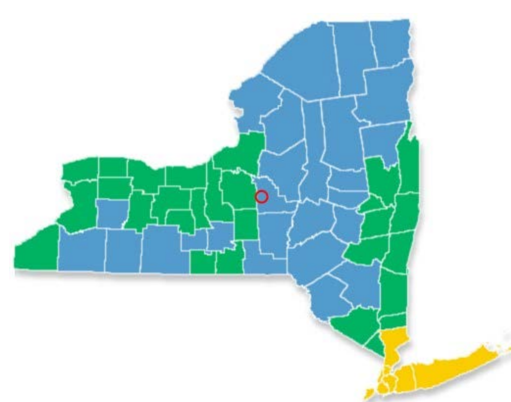


Figure 2—Climate zones (CZ) in New York State: yellow is CZ 4; green is CZ 5; blue is CZ 6 (Baechler and others 2010). Red circle shows location of test house.

Table 1—Evolution of several International Energy Conservation Code (IECC) envelope prescriptive requirements from 2006 to 2015[a]

Year	IECC climate zone	Fenestration U-factor	Ceiling R-value	Wood frame wall R-value[b]	Basement wall R-value[c]
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]Shaded areas show changes for the climate zones present in the State of New York compared with previous years.

[b]For compound requirements ("+"), first value is cavity insulation, second is continuous insulation or insulated siding.

[c]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.

The method launches from a starting point comfortable for residential builders today — 2 by 4 light-frame wood construction. The key difference is that the bottom and top plates are one dimension wider than the stud lumber and are 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 CI. EP&B walls can be built in various configurations, including 2 by 4 studs with 2 by 6 plates (2-in. FPIS), 2 by 6 studs with 2 by 8 plates (1-3/4-in. FPIS), and 2 by 6 studs with 2 by 7.5 plates (2-in. FPIS) (7.5 in. is the actual measurement, not nominal). This last configuration can be achieved by rip cutting 2 by 10s to decrease their width. The configuration with 2 by 7.5 plates tends to be less expensive than 2 by 8 plates (actual lumber dimensions 1-1/2 by 7-1/4 in.) because FPIS is not available in 1-3/4-in. thickness and must be installed as two layers: 1 and 3/4 in.

The NYSERDA demonstration home EP&B design used 2 by 4 lumber for the studs and 2 by 6 lumber for the bottom and second top plates, with 2-in. expanded polystyrene (XPS) rigid foam CI, OSB exterior structural sheathing, and R-15, 3-1/2-in.-thick, unfaced 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.

Design features of EP&B walls include the following:

- >95% framing coverage with CI, which decreases thermal shorts caused by framing members.
- Exterior WSP sheathing for siding attachment.
- WSP sheathing nailed directly to extended bottom and second top plates for shear load resistance.
- WSP provides a flashing surface for windows and doors for efficient installation and durability.
- WSP sheathing dries to the outside because of exterior location and FPIS layer behind it protects the WSP from interior moisture diffusion.
- Warm stud cavity space to decrease the risk of condensation.
- 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 2 in. of foam sheathing: higher overall R-value and a nearly continuous insulation layer that spans more than 95% of the wall area.

The thermal bridge of the extended plates in the EP&B wall decreases the wall's thermal performance by approximately 4% compared with a similarly framed wall that has complete coverage with exterior FPIS. Even considering this slightly decreased performance, the standard EP&B assembly meets or exceeds the minimum prescriptive insulation requirements for 2012–2015 IECC as described in

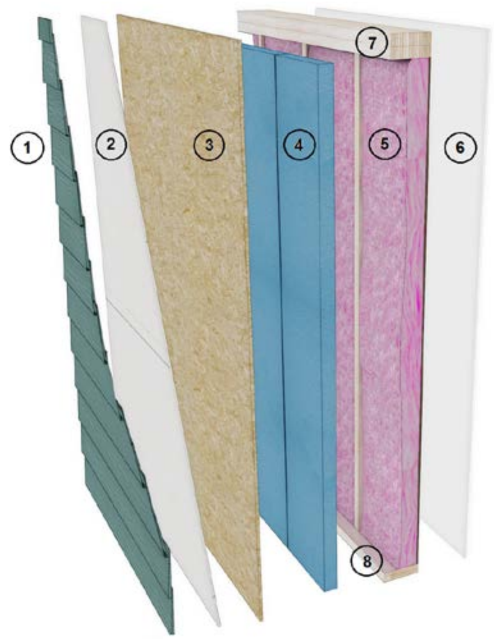


Figure 3—Materials layering for an extended plate and beam (EP&B) wall (1, exterior siding; 2, water-resistive barrier; 3, wood structural panel sheathing; 4, foam plastic insulating sheathing; 5, framed 2 by 4 16-in. o.c. wood stud wall with cavity insulation (and interior vapor retarder if specified); 6, interior gypsum dry wall; 7, extended top plates; 8, extended bottom plate).

Table 2 (calculated assembly values are shown in parentheses).

The EP&B wall configuration in the test house exceeds code for CZ 4 (nonmarine) and CZ 5 by nominal R-7. For CZ 6, the test house EP&B wall meets the prescriptive requirement for the CI 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 conditions: (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 (HIRL 2014). The NYSERDA test house in this project was single story and therefore did not use this feature.

Other Benefits

Because the WSP is outboard of the FPIS, the EP&B wall offers builders a familiar approach to installing windows and the water-resistive barrier (WRB). Siding attachment is also straightforward, using the International Residential Code (IRC) alternate attachment schedule, R703.3.2 (Table 3) for fastening siding to wood sheathing instead of framing.

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 1/4-in. extension (a 3/4-in. ring shank nail is sufficient).

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 requires nails in excess of 4 in. to attach to framing (ABTG 2015). 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.

Water-Resistive Barrier

An EP&B wall has OSB as the exterior layer; therefore, traditional sheet goods such as a WRB can be installed in the usual fashion (staples or cap nails), which is another example of this system being installed with typical, well-known methods.

Table 2—Thermal performance of extended plate and beam (EP&B) wall configurations compared with International Energy Conservation Code (IECC) requirements

Climate zone	2012–2015 IECC prescriptive R-value[b] for above-grade walls (calculated assembly value[a])	Nominal R-value (calculated assembly value[a])		
		EP&B 2 by 4/2 by 6 Std 16 in. o.c.	EP&B 2 by 6/2 by 8 Adv 24 in. o.c.	EP&B 2 by 6/2 by 7.5[c] Adv 24 in. o.c.
NonMarine 4	20 (16.8) or 13 + 5[d] (17.5)	13 + 10 (21.7)	19 + 8.75 (26.6)	19 + 10 (27.8)
5	20 (16.8) or 13 + 5 (17.5)	or	or	or
6	20 + 5 (22.5) or 13 + 10 (22.7)	15 + 10 (22.8)	21 + 8.75 (29.2)	21 + 10 (29.1)

[a]The calculated assembly value assumes typical wall materials of gypsum drywall, spruce–pine–fir lumber, fiberglass batt insulation, expanded polystyrene foam sheathing, oriented strandboard structural sheathing, water-resistive barrier, and vinyl siding. 16 in. o.c. framing assumes 75%/20.6%/4.4% thermal path ratios (cavity/framing/extended plates); 24-in. o.c. framing assumes 85%/10.6%/4.4% ratios.
[b]R-value in h·°F·ft^2/Btu. A 25% framing factor is assumed.
[c]Plates designated 2 by 7.5 indicate the actual 7-1/2-in. width to allow two full inches of rigid foam insulation.
[d]The first value is cavity insulation, the second value is continuous insulation; therefore “13+5” means R-13 cavity insulation plus R-5 continuous insulation.

Table 3—International residential code Table R703.3.2 optional siding attachment schedule for fasteners where no stud penetration necessary (ICC 2014)

Application	Number and type of fastener	Spacing of fasteners[a]
Exterior wall covering (weighing 3 lb/ft^2 or less) attachment to wood structural panel sheathing, either direct or over foam sheathing a maximum of 2 in. thick[b] (does not apply to vertical siding)	Ring shank roofing nail (0.148 in. min. diameter)	12 in. o.c.
	Ring shank nail (0.148 in. min. diameter)	15 in. o.c.
	#6 screw (0.138 in. min. diameter)	12 in. o.c.
	#8 screw (0.164 in. min. diameter)	16 in. o.c.

[a]Spacing of fasteners is per 12 in. of siding width. For other siding widths, multiply spacing of fasteners by factors of 12, where *s* is the siding width in inches. Fastener spacing shall never be greater than the manufacturer's minimum recommendations.
[b]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. thick.

In a wall with FPIS as the exterior layer, the foam sheathing can act as the WRB (Holladay 2010). 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 builders already using exterior foam sheathing. Detailing these joints and connections is important both in the long and short term for moisture durability and can be more complex than installing a sheet goods house wrap. Not all rigid foam sheathing is approved for such use; therefore, this approach requires advanced planning. FPIS can also be covered with a sheet-type WRB.

Window Installation

In an EP&B wall, windows can be framed with 2 by 4s, preserving the CI 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 the 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 the framing. The window frame must be shimmed to avoid bearing on the foam. Alternatively, additional framing can be added at window and door openings.

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 that seams in the FPIS be avoided (BSC 2005).

Panelization

Also unlike a wall with exterior CI, 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 material 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 CI, the temperature in the cavity remains above freezing.

Thermal Comfort

The surface of a poorly insulated wall can be cold compared with 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 (Fanger and others 1985). CI exterior to the framing and wall cavity can help maintain more uniform surface temperatures in a space, improving occupant comfort.

Table 4—Temperature gradient moving from inside to outside of extended plate and beam (EP&B) construction compared with conventional 2 by 4 and 2 by 6 walls

	Temperature (°F)		
Interface–wall assembly	EP&B, R13/10	2 by 4, R13	2 by 6, R20
Inside space	68	68	68
Cavity interior face	65.7	64.2	65.2
Cavity exterior face	38.7	20	18.6
OSB interior plane	18	20	18.6
OSB exterior plane	16.6	17.7	16.9
Outside	15	15	15

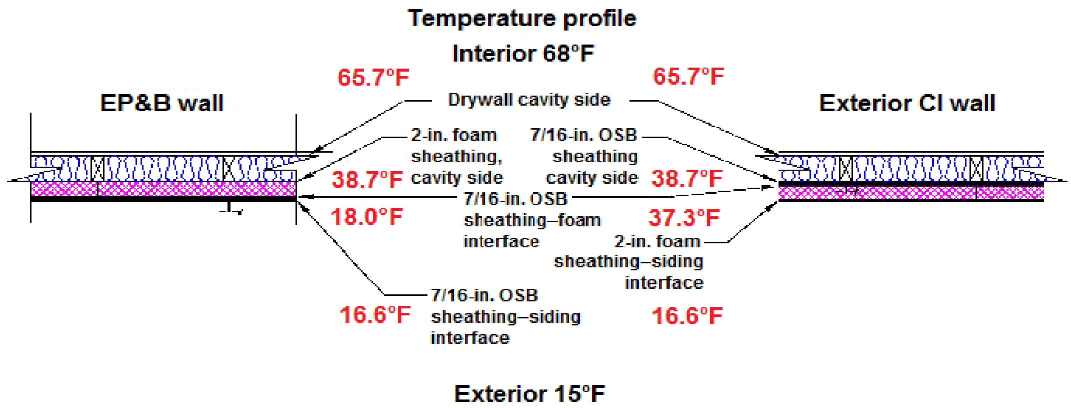


Figure 4—Temperature profile and drying capability: extended plate and beam (EP&B) wall compared with exterior continuous insulation (CI) wall (OSB, oriented strandboard).

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 from which the source moisture came — exterior to the exterior and interior to the interior (Fig. 4). In an EP&B wall, outward drying of the WSP is facilitated by the use of a high-perm WRB.

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

An appropriate interior vapor retarder helps prevent accumulation of moisture in the wall cavity caused by humid conditions inside the building. The IRC allows a Class III vapor retarder to be used in certain wall configurations that include an FPIS layer, specifically because of the foam insulation's ability to keep the cavity warmer and decrease the potential for condensation. Interior vapor drive (from inside to outside) is high when 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 decreases seasonally, allowing a balanced condition. EP&B walls monitored for a 2-yr period in controlled test buildings in CZ 4 (HIRL 2015) showed that, in this configuration, OSB performed well with respect to moisture (Fig. 5). OSB

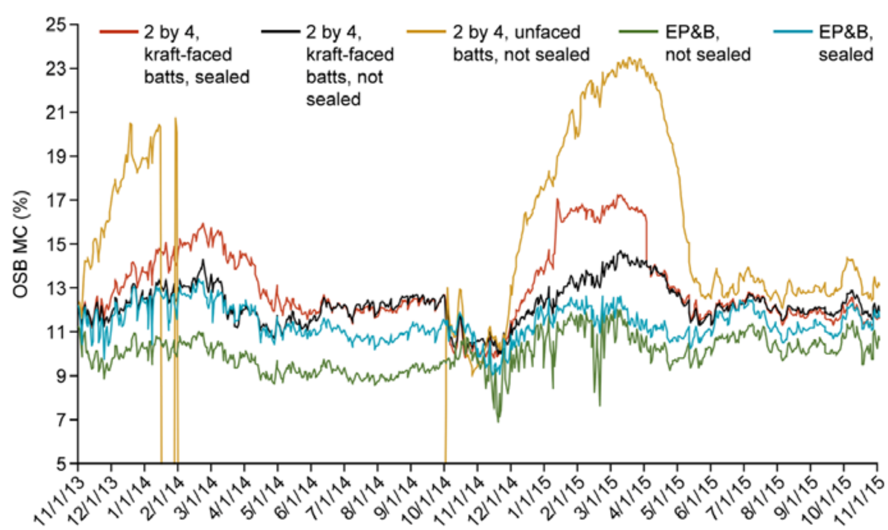


Figure 5—In a previous study (HIRL 2014), the extended plate and beam (EP&B) walls in climate zone 4 maintained moisture content (MC) levels below 14% (blue and green lines) (all construction configurations were climate zone 4, north-facing, 16-in. o.c. 2 by 4 framing with drywall and paint, R13 batt insulation, 1/2-in. oriented strandboard (OSB) wood structural panel, 50-perm water-resistive barrier, and vinyl siding. EP&B had unfaced batt insulation, 2 by 6 bottom and second top plates, R-10 extruded polystyrene foam sheathing between OSB and stud framing. All sealed walls had a bead of spray foam picture framing as an air-stop).

sheathing on EP&B walls with vinyl siding and unfaced fiberglass batts remained below 14% moisture content (MC) throughout the test period.

Increased air sealing improves thermal performance but potentially decreases drying capability. The EP&B wall with air sealing in Figure 5 had more drying capability than did the kraft-faced batt wall with air sealing. This was probably because of 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.

Implementation

In this study, the EP&B system was evaluated as part of a panelized construction process in which the walls were 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 study was to use the EP&B innovation to demonstrate a path for panelizers to add the energy efficiency component of CI to the traditionally structure-only product and to participate in the high-performance construction market.

Figure 6—Extended plate and beam (EP&B) test house front view.

Design Documents

The demonstration home was built with EP&B wall panels produced at a building components plant in Whitesboro, New York. The design used 2 by 4 lumber for the studs and 2 by 6 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 unfaced 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.

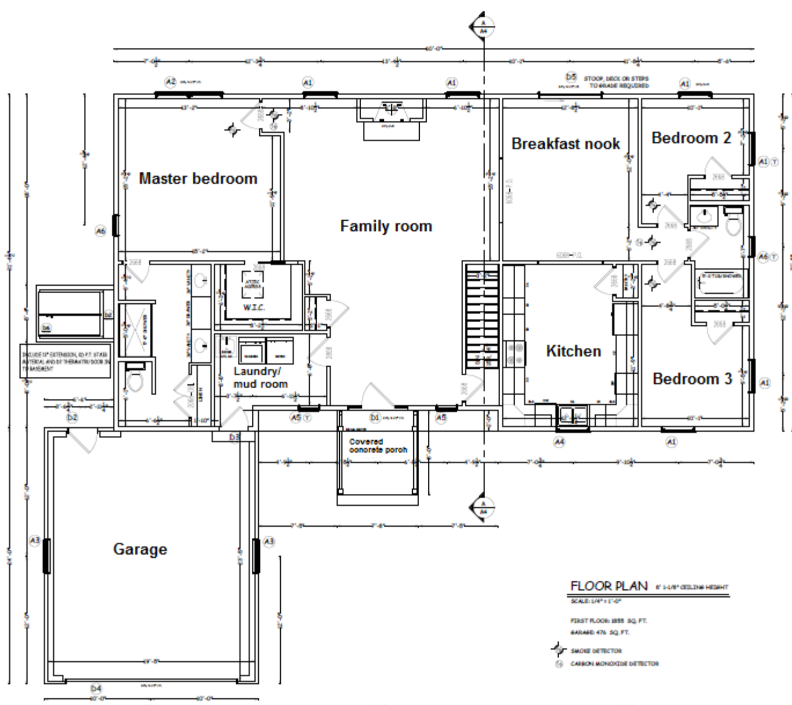


Figure 7—Extended plate and beam (EP&B) test house floor plan.

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 (HIRL 2016a) (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).

Wall Construction at the Panel Plant

Plant manager Dan Webb stated that the project was outside of the 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. Figures 8 and 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.

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. Because 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 on 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 therefore, initially, the crew cut the two layers independently. The production team was

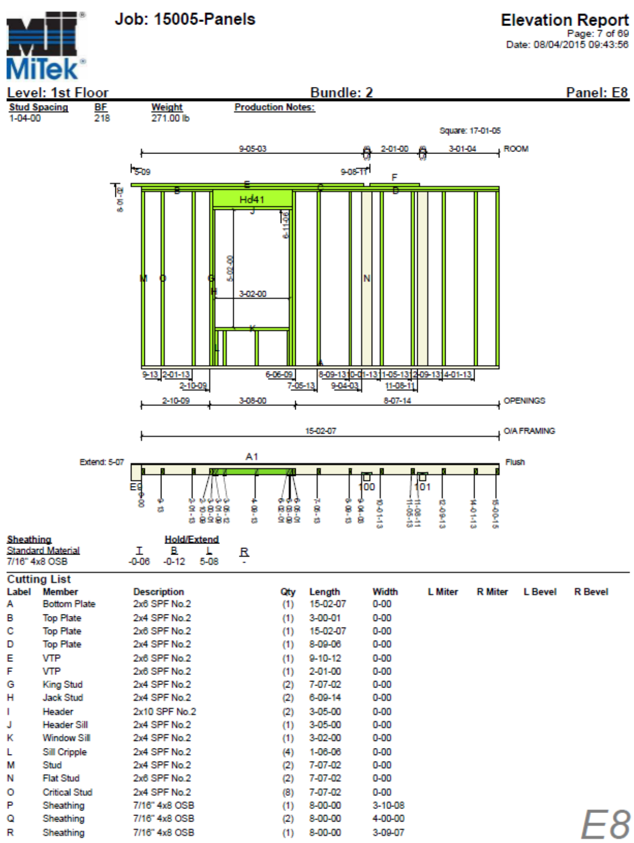
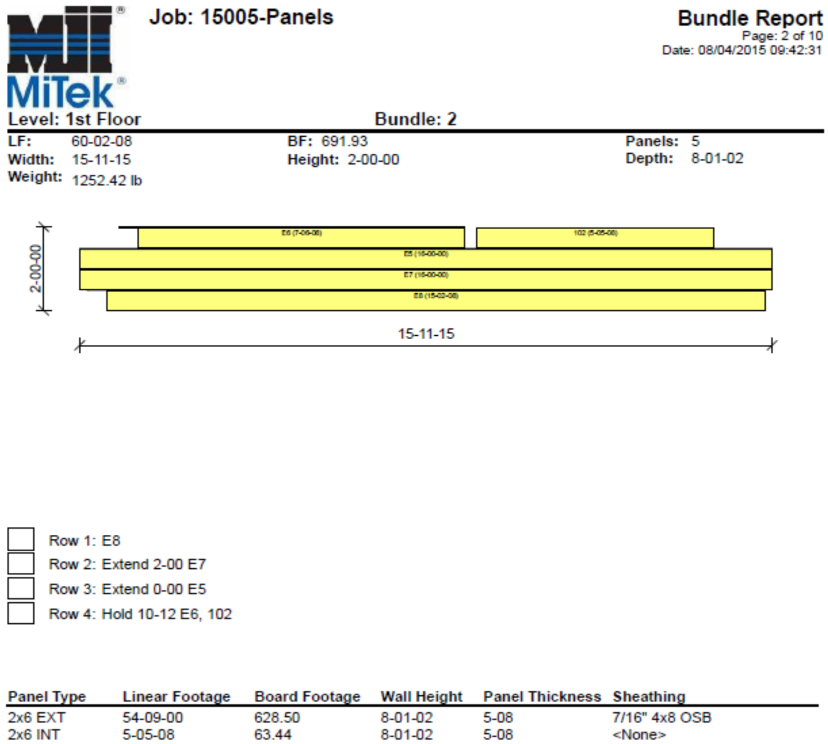


Figure 8—Example of construction drawing for panel manufacture (used with permission from Stark Truss Company, Inc., Whitesboro, New York).



Job: 15005-Panels

Bundle Report
Page: 2 of 10
Date: 08/04/2015 09:42:31

Level: 1st Floor | Bundle: 2

LF: 60-02-08 | BF: 691.93 | Panels: 5
Width: 15-11-15 | Height: 2-00-00 | Depth: 8-01-02
Weight: 1252.42 lb

Row 1: E8
Row 2: Extend 2-00 E7
Row 3: Extend 0-00 E5
Row 4: Hold 10-12 E6, 102

Panel Type	Linear Footage	Board Footage	Wall Height	Panel Thickness	Sheathing
2x6 EXT	54-09-00	628.50	8-01-02	5-08	7/16" 4x8 OSB
2x6 INT	5-05-08	63.44	8-01-02	5-08	<None>

Figure 9—Example of construction drawing for panel bundling (used with permission from Stark Truss Company, Inc., Whitesboro, New York).

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 (Fig. 10). 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 to 3 in. The tool they found had the necessary length but not the self-driving tip. Therefore, 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 the least optimized. FPIS was originally developed to be installed on the exterior of building walls. The typical 8-ft length spans two plates and the studs. Shortening is required to fit between top and bottom plates for the EP&B configuration.

The initial EP&B design used extended plates for only the bottom and second top plate; the first top plate was a 2 by 4. 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.

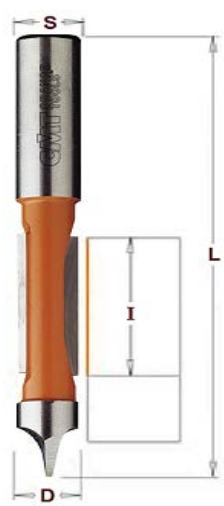


Figure 10—Pilot panel bit for cutting oriented strandboard and foam together (used with permission from CMT, Greenville, South Carolina).

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 both 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-h 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 was 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 source, compare prices, and order, tasks which represent administrative time. Although 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% to 60% additional time. With proper experience and tooling, Mr. Webb thought that the additional time required for an EP&B project would be 10% to 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 probably research and acquire the proper tools to solve the challenges previously described 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.

Appendix B shows various details of the EP&B wall panel production in the factory.

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 preferred 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 several 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 because in that area of New York State, the most common wall is 2 by 6 to accommodate code-mandated R-20 cavity fill insulation.

Mr. Warner reported two quality issues with this EP&B project: The air gap between neighboring panels and nails at studs that missed framing.

Mr. Warner noted that gaps between neighboring panels are common with any panelized project and are 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 2 by 4s 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 must 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 2 by 6 studs instead of 2 by 4s at each panel end to decrease the gap, but this adds cost, complexity, and dozens of additional thermal bridges caused by framing; an important goal of the EP&B wall is to decrease 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 renailing at studs was required because 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 that butt at that location. Framers typically shoot these nails at a slight angle 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 for which there was a lot of “blow through” had to be renailed on site, often from a ladder outside the building. This issue was specific to the studs where sheathing panels abut. In the field, the nails used on the WSP can be aimed orthogonally 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, 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. Appendix C documents 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 a traditionally framed 2 by 4 light-frame wall). He has previous experience with exterior CI and feels comfortable with the necessary adjustments to his construction processes to accommodate the foam layer exterior to the wood sheathing. He did 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 because of the shifting of the load path away from the framing caused by 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 that there is some advantage to siding and window installation with EP&B, because 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 probably would not 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 that he would prefer to field-frame the walls. He expressed an opinion that many framers may share: “I like to build.” Although 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 decrease framing. Several window and door openings fell just shy of 16-in. on center spacing locations and required extra jack studs. The effect of this additional framing is minimized in an EP&B wall, in which the 2-in. layer of FPIS provides a CI layer beyond the stud framing, compared with a 2 by 6 wall with no CI layer.

Instrumentation

Description of Sensors and Equipment

Monitoring of the walls was accomplished using commercially available sensors and data loggers from OmniSense LLC (Lady's Island, South Carolina). The sensor integrates a wireless transceiver, temperature sensor, humidity sensor, and pin-type (resistance) moisture meter and has a battery life that can last up to 15 years. The sensors were 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) collected and transmited data to the manufacturer’s web site for storage and periodic downloading for analysis. Table 5 lists the accuracy and features of the monitoring equipment used in the project. Figure 11 shows the wireless sensor and wireless data logger used.

Sensor Placement in Building and Walls

Previous simulation and field testing (Glass and others 2015) 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

Table 5—Accuracy and features of the OmniSense testing and monitoring equipment

Function	Range/accuracy/details	Equipment/features
Temperature	–40 to 185 °F /±0.8 °F, 3.6 °F max	S-1-3.5 wireless sensor
Relative humidity	0 to 100%/ ±3.5%, ±5% max	Plastic casing ~ 2.5 in. wide, 1.5 in. high, and 1 in. deep
Moisture content	Percentage by weight; measures electric resistance between the two screws embedded in the material	Lithium battery
Data logger	Stores data to bridge power outage	G-3-C-VZW cellular gateway

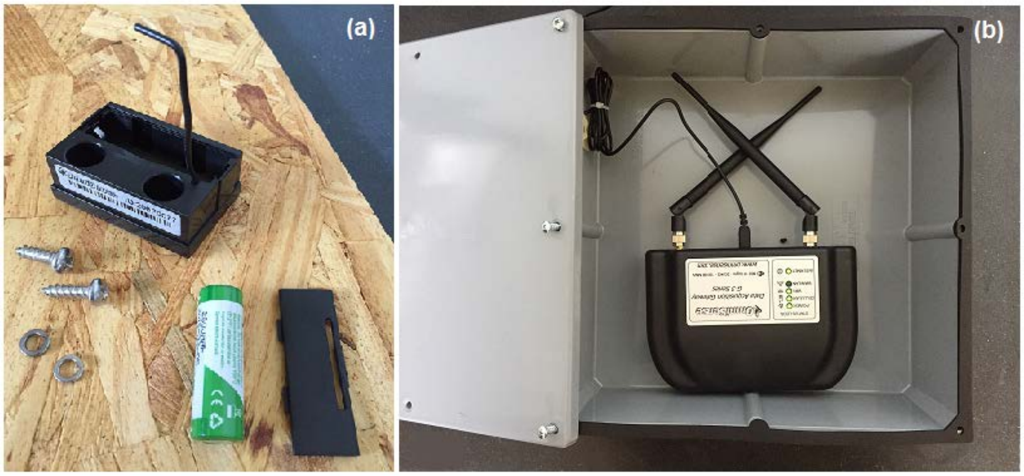


Figure 11—OmniSense (a) wireless sensor (S-1 temperature, relative humidity, wood moisture equivalent) and (b) wireless data logger (gateway data acquisition unit) installed in the test house.

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, one on the north wall and one on the east wall, for redundancy. A pair of stud–OSB sensors were installed in the east wall of the kitchen and another pair 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 reported 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 6 and Figure 12 list sensor IDs and show the final monitoring locations in the test house.

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 (Fig. 13a). After the sensor was placed and the screws inserted into the OSB, the sensor cabinet was sealed with WRB tape (to avoid moisture damage to the electronic components) and the foam piece was reinserted into the cavity (Fig. 13b). This foam piece protruded from the foam sheathing layer by approximately 1 in., because of the thickness of the sensor cabinet. The patch in the FPIS was not fully airtight. 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.

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 included the local temperature and relative humidity and the moisture content of the wood to which they were attached. The data logger was set to collect data at approximately 15-min intervals. Data were uploaded continuously to a website for data storage; battery backup allowed temporary local storage in the event of a power interruption. The OmniSense acquisition protocol processed these raw data to calculate the dew point and grains of moisture based on the temperature and relative humidity. The moisture content data were calibrated to a standard wood MC (%) based on the temperature at the wood surface. The data set stored on the website was 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 was evaluated based on moisture content, temperature, and relative humidity. The data from walls with north and east exposures were especially pertinent because these orientations represent a "worst-case scenario."

A key moisture performance characteristic is the fiber saturation point (FSP), which is the MC (%) at which only the cell walls are completely saturated (all bound water) but no water exists in cell lumina. The maximum FSP for solid wood is considered to be 30% MC (FPL 2010). For OSB, FSP is three to five percentage points below that of solid wood products (approximately 26%) (Carll and

Table 6—Sensor IDs and locations at the test house[a]

Sensor ID	Name	Type	Direction	Location
1E7000C7	East OSB Bdrm3 C	OSB	East	Bdrm 3 C
1E70023F	East OSB Bdrm3	OSB	East	Bdrm 3
1E7002FE	East OSB Kitch	OSB	East	Kitchen
1E7001A4	East stud Bdrm3	Stud	East	Bdrm 3
1E7001B5	East stud Bdrm3 C	Stud	East	Bdrm 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 Bdrm3 C	OSB	North	Bdrm 3 C
1E7003C8	North OSB Bdrm3	OSB	North	Bdrm 3
1E70036E	North stud Bath	Stud	North	Bathroom
1E70014D	North stud Bdrm3	Stud	North	Bdrm 3
1E700297	North stud Bdrm3 C	Stud	North	Bdrm 3 C
1E700069	South OSB MBath	OSB	South	M Bathrm
1E7003CE	South OSB MBdrm	OSB	South	M Bdrm
1E700043	South stud MBath	Stud	South	M Bathrm
1E700391	South stud MBdrm	Stud	South	M Bdrm
1E70030D	West OSB MBdrm	OSB	West	M Bdrm
1E700273	West stud MBdrm	Stud	West	M Bdrm

[a]OSB, oriented strandboard.

Wiedenhoeft 2009). As a design principle, wood and wood-based materials in buildings should be maintained at MC levels below the FSP, 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 OmniSense S-1 pin-type (resistance) sensors used in the test house were calibrated based on ASTM D444 (ASTM 2008). The accuracy of the OmniSense MC readings was determined by comparing recorded sensor measurements to gravimetric measurements of OSB samples of all readily available wood species mixes, using ASTM D4442 (ASTM

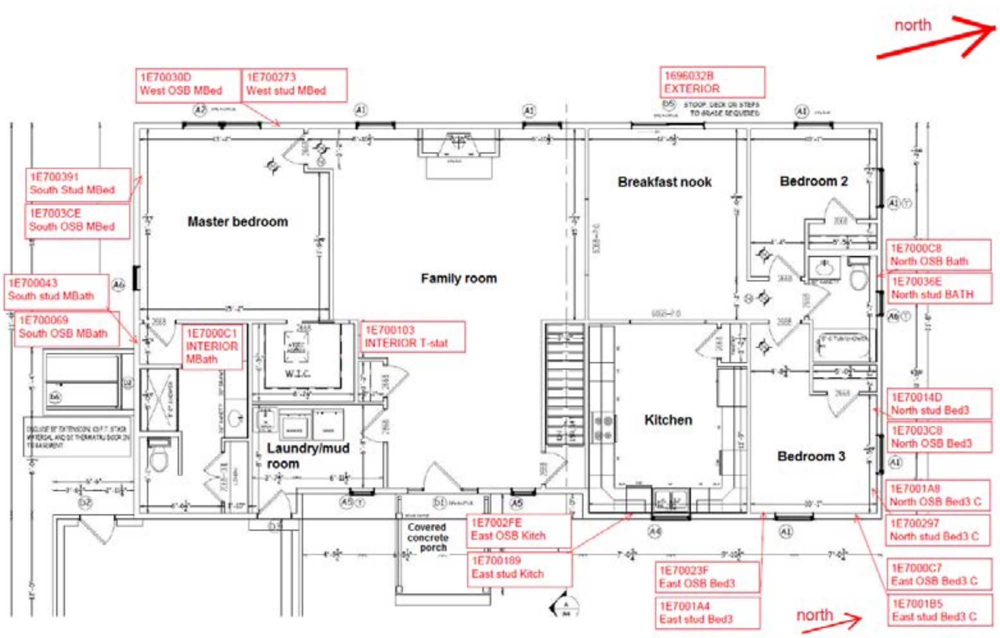


Figure 12—Location of wireless sensors in the test house plan.

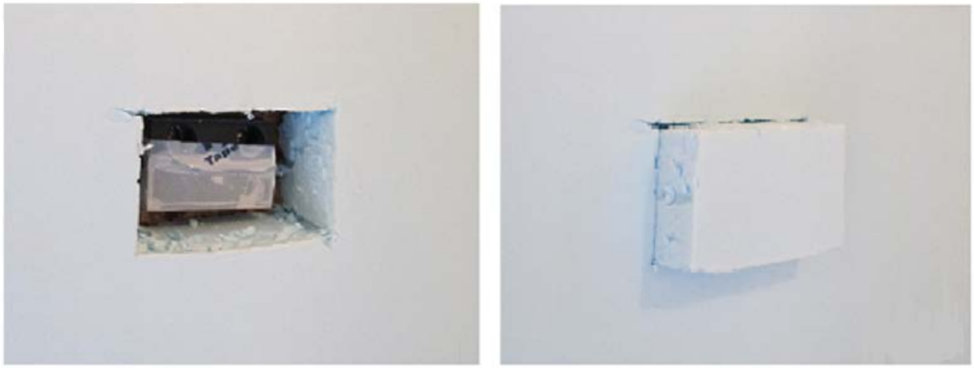


Figure 13—Typical installation of oriented strandboard sensors in the extended plate and beam wall.

2007). Multiple samples in a variety of combinations of the following conditions were tested: (1) temperature was held constant at 77 °F, (2) relative humidity ranged from 40% to 90%, (3) MC ranged from 7% to 25%. The conditioned specimens were considered stable when the difference in mass during a 24-h period was less than 0.04 g. All specimens were weighed on a balance with a precision of 0.01 g.

The sensors recorded temperature simultaneously with relative humidity. The sensor measured the resistance across the sensor legs (the tips of the screws) to determine moisture content and automatically corrected 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 14.

All wood MC values for OSB in this study have been corrected according to the following equation:

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

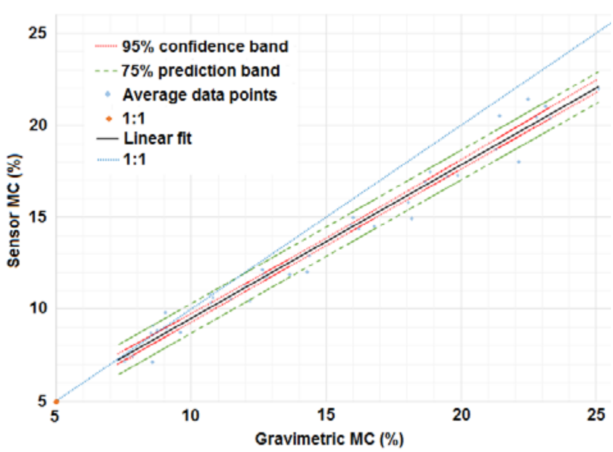


Figure 14—Curve fit chart for moisture content (MC) sensor calibration for all oriented strandboard data points (average meter correction equation).

The MC of the lumber and WSP in the demonstration house was documented with 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 (Mallay and others 2016, HIRL 2015). The baselines from those projects were used for comparison with the OSB moisture data gathered in this study, in addition to the heat and moisture transiency simulation using Wärme Und Feuchte Instationär (WUFI) software (Fraunhofer Institute for Building Physics, Holzkirchen, Germany).

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. However, this field test of the EP&B wall system prompted some changes to the recommended configuration (Appendix D).

Framing

Initially, the double top plates were to be two different sizes, to minimize the thermal bridge caused by framing. With a first top plate of 2 by 4 and a second top plate of 2 by 6, the calculated thermal bridge was 3.7% of opaque wall area in a typical wall section. With all three plates as 2 by 6 (bottom and two top) as shown in Appendix D, the thermal bridge was 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 decrease in thermal performance compared with exterior CI of just under R-1. The advantages associated with this modification are the following:

- Simplification of lumber ordering and sorting. Whether the framing occurs on site or at a manufacturing facility, all 2 by 4s can be precut stud lengths and all 2 by 6s can be framing lumber lengths. Mistaking studs for general framing lumber can be time-consuming and costly.

- 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 2 by 6 lengths), which the framers on site can use to tie the panels together. The 2 by 6 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, because in that case, the VTP would not be included. An example of the VTP is shown in Figure 15.
- In a field-framed situation, the top plate connection is simplified. In an EP&B wall with a 2 by 4 first top plate, only the 2 by 6 second top plate has a physical connection with the sheathing. By making both top plates 2 by 6, 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.

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 that the 4-in. nails were a major hurdle in the wall assembly process, based on the cost and lack of availability of the nails and the nailing gun. A subsequent, separately funded study tested and confirmed an acceptable alternative schedule of 3-1/2-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) (Appendix D). The advantages associated with this modification are the following:

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

Cutting List

Label	Member	Description	Qty	Length	Width
A	Bottom Plate	2x6 SPF No.2	(1)	7-11-15	0-00
B	Top Plate	2x4 SPF No.2	(1)	1-05-03	0-00
C	Top Plate	2x6 SPF No.2	(1)	7-11-15	0-00
D	Top Plate	2x4 SPF No.2	(1)	2-10-12	0-00
E	VTP	2x6 SPF No.2	(1)	2-08-08	0-00

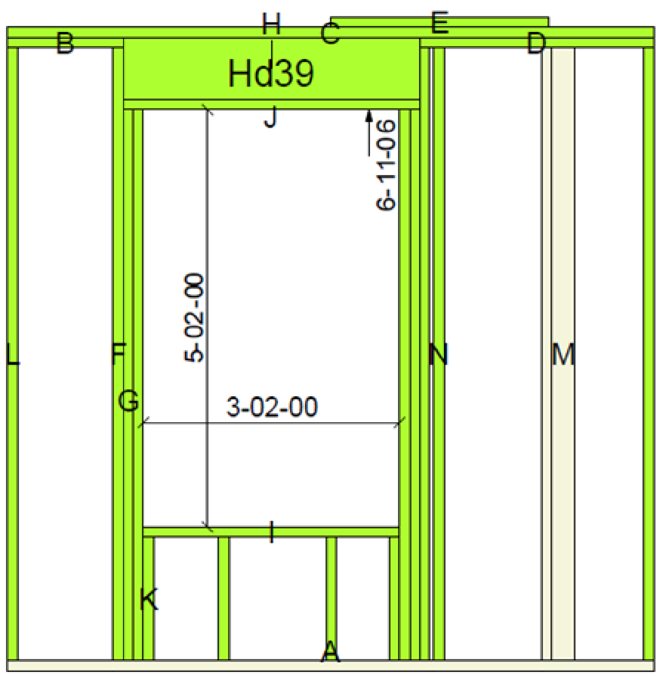


Figure 15—The very top plate (E) added to tie panels together on site (used with permission from Stark Truss Company, Inc., Whitesboro, New York).

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 decreased with four changes:

- Standard wall heights, which would allow the use of precut stud lengths (this was not an EP&B design issue).
- 2 by 6 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.
- FPIS available from the manufacturer in the necessary dimensions to decrease the number of cuts.
- 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. This is true for any wall panel system.

Field-framed wall sections can be much longer than those built in a panel factory, decreasing 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, which is 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 used, such as

- WRB tape at the OSB joint between wall panels (for example, Siga Wigluv (SIGA, Ruswil, Switzerland) 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 (for example, Knauf EcoSeal (Knauf Insulation LLC, Shelbyville, Indiana) or other) along the interior framing joints prior to installing the cavity insulation, and
- 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 the companion report on energy simulation results analysis (HIRL 2016a). 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 CZ 6: 2 by 4 16-in. o.c. standard framing with R-13 cavity + R-10 continuous exterior insulation (Table 7). The EP&B wall requires additional materials (WRB and 2 by 6 plates), which cost more than the materials for a CI wall, but the decreased complexity of window and siding installation caused by the nailing substrate being provided by the exterior layer of OSB sheathing more than offsets those costs.

Using the most basic comparison, a 2 by 4 and 2 by 6 EP&B wall with R-13 cavity insulation meets IECC (ICC 2011) minimum prescriptive R-values for all climate zones in the State of New York and costs no more than a code-minimum wall with full exterior CI. Depending on the complexity of the comparison wall, the EP&B wall can be considerably less expensive.

Table 7—Cost comparison of wall types

Wall type[a]		R-value nominal	R-value calculated	Total cost[b]	Cost per square foot	Cost per nominal R-value per square foot	Cost per calculated R-value per square foot
Standard EP&B	EP&B 2 by 4/2 by 6 R-13 w/ 2-in. XPS	23	21.8	$3,936	$19.68	$0.86	$0.90
Test EP&B	EP&B 2 by 4/2 by 6 R-15 w/ 2-in. XPS	25	22.8	$3,988	$19.94	$0.80	$0.87
Maximum EP&B	EP&B 2 by 6/2 by 7.5[c] R-21 w/ 2-in. XPS	31	30.3	$4,096	$20.53	$0.66	$0.68
CZ 6 code	2 by 4 studs 16 in. o.c. R-13 w/ 2-in. XPS	23	22.6	$4,098	$20.49	$0.89	$0.91

[a]EP&B, extended plate and beam; CZ, climate zone; XPS, extruded polystyrene.
[b]Total cost for 200-ft^2 wall section, rim, 3050 double window, interior–exterior finishes (HIRL 2016a, appendix F).
[c]2 by 7.5 actual measurement in inches.

Table 8—2012 building U-factor times assembly area (UA) compliance for climate zone 6

	Insulation levels	
Elements	2012 IECC[a]	As designed
Shell UA check		
Ceiling	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 and lower)	272.8	226.5

[a]IECC, International Energy Conservation Code.

Energy

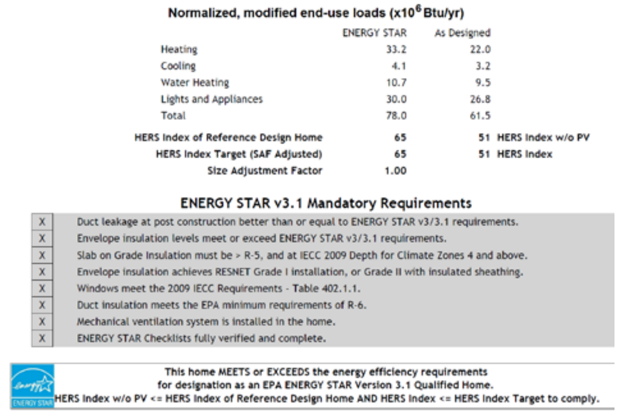
The companion report on analysis of energy simulation results (HIRL 2016a) describes details of the test home's construction and methodology for simulating energy use with REM/Rate software (NORESCO, LLC, Boulder, Colorado) and includes comprehensive discussion of results and conclusions. Major topics and final conclusions are summarized in this section.

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

The REM/Rate analysis indicated that for CZ 6A, the envelope of the home as designed exceeded prescriptive 2012 IECC Building UA (U-factor times assembly area) Compliance Section 402 requirements by 17.0% (Table 8). The home's energy performance exceeded the reference home 2012 IECC Energy Cost Compliance Section 405 requirements by 9.7% (Table 9). The home energy rating system (HERS) index target for Energy Star v3.0 was 60; the calculated HERS index for the house as designed was 54, qualifying it for certification (Fig. 16).

Table 9—2012 International Energy Conservation Code (IECC) energy cost compliance for climate zone 6

	Annual energy cost (U.S. dollars/yr)	
Energy use category	2012 IECC	As designed
Heating	1,329	1,135
Cooling	157	160
Water heating	476	476
Subtotal: Used to determine compliance	1,963	1,772
Lights and appliances	1,066	1,043
Photovoltaics	0	0
Service charge	195	195
Total	3,223	3,010



Normalized, modified end-use loads ($x10^6$ Btu/yr)

	ENERGY STAR	As Designed	
Heating	33.2	22.0	
Cooling	4.1	3.2	
Water Heating	10.7	9.5	
Lights and Appliances	30.0	26.8	
Total	78.0	61.5	
HERS Index of Reference Design Home	65	51	HERS Index w/o PV
HERS Index Target (SAF Adjusted)	65	51	HERS Index
Size Adjustment Factor	1.00		

ENERGY STAR v3.1 Mandatory Requirements

X	Duct leakage at post construction better than or equal to ENERGY STAR v3/3.1 requirements.
X	Envelope insulation levels meet or exceed ENERGY STAR v3/3.1 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.

This home MEETS or EXCEEDS the energy efficiency requirements
for designation as an EPA ENERGY STAR Version 3.1 Qualified Home.
HERS Index w/o PV <= HERS Index of Reference Design Home AND HERS Index <= HERS Index Target to comply.

Figure 16—Project Energy Star 3.0 report and home energy rating system (HERS) rating.

Compared with a 2012 IECC code home, the test home would be expected to save approximately $200 annually in utility bills (Table 10), almost entirely because of better efficiency during the heating season. The test home saved 14.6% in heating energy compared with the 2012 reference home (Table 11). This was because of several better-than-code envelope choices, including windows, foundation walls, and above-grade walls (EP&B).

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.

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 was so small, no cooling equipment was

Table 10. Test house annual energy cost savings compared with 2012 International Energy Conservation Code (IECC) reference house

	Annual energy costs (U.S. dollars/yr)			
Energy use category	2012 IECC	Test home	Savings	Percentage saved
Heating	1,329	1,135	194	14.6
Cooling	157	160	–3	–1.9
Water heating	476	476	0	0.0
Lights and 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 (U.S. dollars/month)	269	251	18	6.6

Table 11—Test house annual energy consumption savings compared with 2012 International Energy Conservation Code (IECC) reference house

	Annual energy consumption ($\times 10^6$ Btu/yr)			
Energy use category	2012 IECC	Test home	Savings	Percentage 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 and appliances	27.1	26.6	0.5	2.0
Total	94.7	86.7	8	8.5

installed and the value listed for annual energy costs for the category of cooling (–$3 per year in savings, in this case) was not a useful metric.

The standard EP&B configuration used in the NYSERDA test house (2 by 4 and 2 by 6 with R-15+10 insulation) had a lower total installed cost ($0.55 per square foot of wall for either field-framed or panelized construction) compared with a CZ 6 code-minimum wall with exterior CI. EP&B contributed, with improved windows and basement walls, to a projected whole-house energy cost savings of 6.6%, $214 annually. The advanced-framed EP&B wall configuration (2 by 6 and 2 by 7.5 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 with the code-minimum configuration.

Durability

Data acquisition began November 5, 2015, soon after occupancy. Interior and exterior ambient temperatures and relative humidity were within typical, expected ranges (Fig. 17) for winter and spring.

Moisture contents in the studs and OSB were analyzed with reference to two different baselines:

- The FSP of each: a maximum of 30% MC for studs and 26% MC for OSB.
- The MC found in studs and OSB in previous EP&B studies, particularly the two years of data from the study done in CZ 4 in controlled test buildings on Home Innovation's campus (HIRL 2015) (That study measured maximums of 11% MC for studs and 14% MC for OSB).

The EP&B studs in the NYSERDA test house performed well. In all orientations, average stud MC from November through May never exceeded 13%. Studs in south-facing walls never exceeded 11% MC. Wood MC for EP&B studs in all directions is shown in Figure 18.

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 (Fig. 19). These unusually high readings indicate a deviation from previous studies.

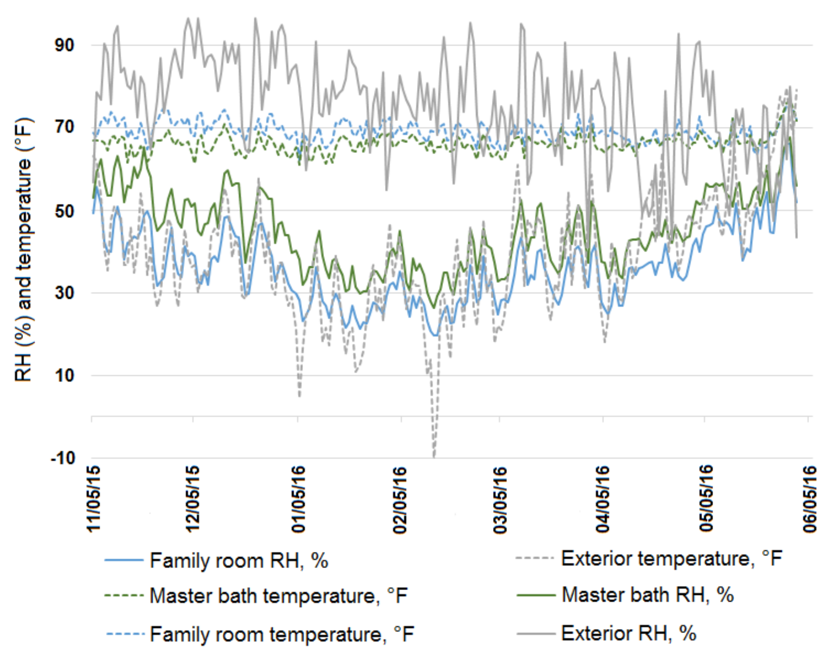


Figure 17—Test house ambient conditions (interior and exterior) (RH, relative humidity).

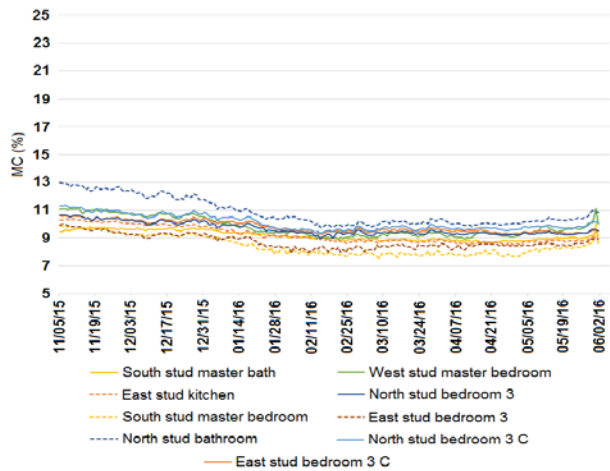


Figure 18—Daily average stud wood moisture content (MC) in the test house, all orientations.

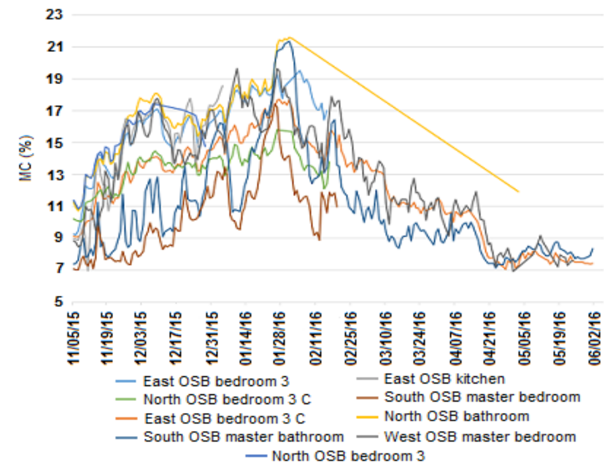


Figure 19—Daily average oriented strandboard (OSB) wood moisture content (MC) in the test house, all orientations.

Two sensors, South OSB Bath and North OSB Bath, exceeded 21% MC; the OSB FSP is 26%. The sensor in the north bathroom wall became inactive during that period; therefore, it is unknown if the OSB reached FSP 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 MC. 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 that continued to report MC into the spring indicated that the OSB began to dry relatively quickly; the south master bathroom, an east bedroom, and a west bedroom were all reading at or below 11% MC after the second week of April (Fig. 19).

Between December 28, 2015, and February 19, 2016, six of the nine OSB sensors became inactive, and a seventh sensor stopped transmitting data in July (Table 12). Possible explanations are discussed later in this section.

Because so few OSB sensors continued 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 WUFI software developed by the Fraunhofer Institute for Building Physics. 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 (Fig. 20) with similar conditions (Table 13) 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 (Fig. 21). For the WUFI model, the MC never rose above 12%, which is inconsistent with the data from the sensors monitoring the OSB at the NYSERDA house (Fig. 21). The WUFI simulation results illustrated in Figure 20 for conditions matching the NYSERDA test walls show good moisture performance. The OSB sensors in the NYSERDA test house recorded generally acceptable (although higher) MC levels until the middle of January.

Table 12—Inactive project OSB sensors[a]

ID	Name	Last activity	Direction	Location
1E70023F	East OSB Bdrm3	02-14-16 11:05:52	East	Bdrm 3
1E7002FE	East OSB Kitch	01-03-16 12:24:46	East	Kitchen
1E7000C8	North OSB Bath	01-31-16 18:54:28	North	Bathroom
1E7001A8	North OSB Bdrm3 C	02-16-16 07:11:12	North	Bdrm 3 C
1E7003C8	North OSB Bdrm3	12-28-15 01:15:08	North	Bdrm 3
1E7003CE	South OSB MBdrm	02-19-16 07:00:08	South	MBdrm
1E70030D	West OSB MBdrm	07-13-16 08:56:52	West	MBdrm

[a]OSB, oriented strandboard.

Figure 20—WUFI simulation of the moisture performance of the extended plate and beam north wall oriented strandboard (WUFI, The Fraunhofer Institute for Building Physics: Wärme Und Feuchte Instationär; MC, moisture content).

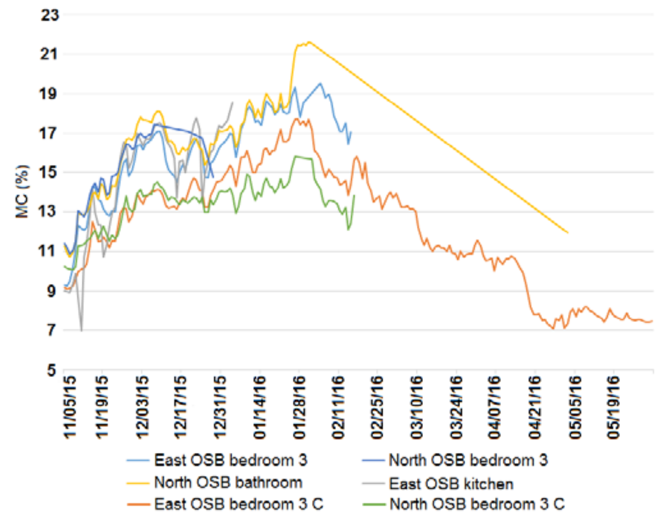


Figure 21—Moisture performance of the extended plate and beam north wall oriented strandboard (OSB) in the test house (north and east orientations) (MC, moisture content).

Table 13 compares the configuration of the NYSERDA test house EP&B walls to the WUFI simulation inputs that generated the graph in Figure 20.

Home Innovation Research Labs has concluded that the NYSERDA test house data obtained from the sensors in the OSB of the EP&B walls were not entirely reliable. The following circumstances were 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 MC 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 in which 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 to 185 °F and 0% to 100% RH. Nevertheless, the bulk of the sensors that became inactive appear 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 (Fig. 22).

The NYSERDA data for the stud moisture performance appears to have followed the trends of previous test walls and the WUFI moisture simulation. All are well within safe

Table 13—Comparison of previous, simulated, and current extended plate and beam (EP&B) test wall configurations[a]

Component	NYSERDA test house	WUFI simulation
Climate zone (CZ)	CZ 6	CZ 6
Interior air conditions	As recorded, per Figure 17	Sine curve for relative humidity and temperature to match Figure 17
Exterior air conditions	As recorded, per Figure 17	TMY3 Syracuse, New York
EP&B framing	2 by 4/2 by 6	2 by 4/2 by 6
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	1/2-in. OSB	1/2-in. OSB
Air-sealing	Caulked at framing connections	N/A
Water-resistive barrier	Nonperforated, ~12 perm	Nonperforated, ~12 perm
Start of operation	Early November 2014	Early November 2014

[a]NYSERDA, New York State Energy Research and Development Authority; WUFI, Fraunhofer Institute for Building Physics: Wärme Und Feuchte Instationär; XPS, extruded polystyrene; OSB, oriented strandboard.

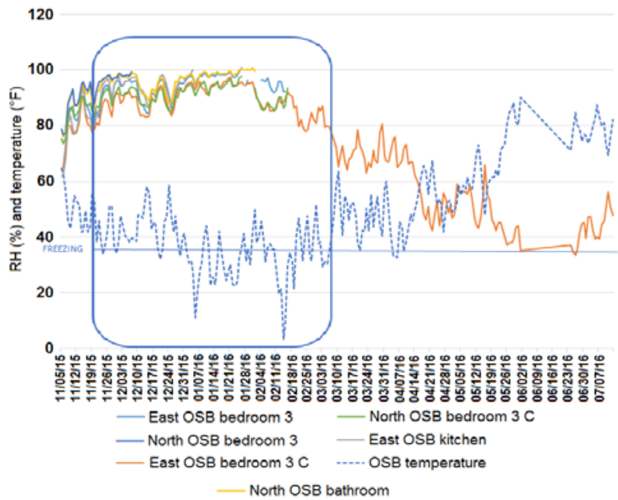


Figure 22—Relative humidity (RH) and temperature recorded by the sensors installed on the oriented strandboard (OSB) in the test house. The time period within the blue frame indicates the possible formation of ice.

MC ranges. The installation of the stud sensors did not deviate from previous tests (Fig. 23).

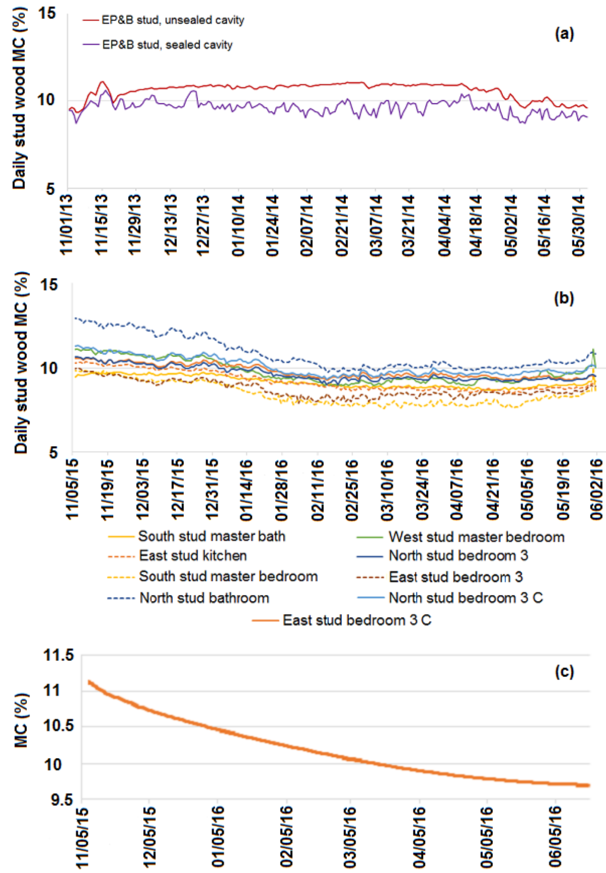


Figure 23—Extended plate and beam (EP&B) wall stud moisture content (MC) for (a) a previous study (north facing), (b) the test house (all orientations), and (c) WUFI moisture simulation. All show good correlation (WUFI, The Fraunhofer Institute for Building Physics: Wärme Und Feuchte Instationär).

Discussion and Conclusions

Moisture Performance

Previous study of the EP&B wall, including both simulation and field tests, indicated good moisture performance for all components. A WUFI simulation with inputs matching the NYSERDA test house predicted 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 because of the 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 that was not air-sealed, probably 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 the previous field test in CZ 4 and 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 that continued to transmit data appeared 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 were monitoring OSB in walls with three different orientations: west, east, and south. The highest measured MC readings, between 19% and 21%, occurred for a limited time of less than a week during the coldest periods. The two walls with OSB MC readings that spiked above 21% were in bathrooms. The sensor in the south bathroom wall remained active, settling in at around 7% MC by spring. The sensor in the north bathroom wall was inactive.

The available data show 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 slightly more than 21% MC for a minimum of 1 week and a maximum of 3 months, at which time a single data point recorded a recovery to 12% 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 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 CI, 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, 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 publication on construction (HIRL 2016b) provides builders who use 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 decrease construction complexities and spur adoption in the market, helping more builders to 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 that 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 should be specified to be the same dimension, which

  -decreases complexity (takeoffs, ordering, staging),

  -decreases opportunity for error,

  -improves the structural connection, and

  -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, and

  -fit in typically available framing nail guns in the market.

- Nailing pattern should follow a more typical pattern of perimeter or 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 a first line of defense air-tightness by avoiding coincident gaps.

- Best practices air-sealing techniques should be used, such as

  -air-sealing FPIS panel edges at the stud with caulk, elastomeric spray sealant, or spray foam and

  -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 probably work for field-framed projects as well.

The framing crew voiced concerns about nailing accuracy at studs. Factory quality assurance 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 renail 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 use with standard 2 by 4 or 2 by 6 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.

Thermal performance and moisture durability of an EP&B wall can be improved by

- careful air-sealing,
- use of an interior vapor retarder in CZ 5 and up and anywhere that interior vapor drives are relatively high, and
- close attention to construction drying.

The companion publication, "A builder's guide: Extended plate and beam wall system" (HIRL 2016b), includes instructions and final recommendations for EP&B construction. Appendix A of that publication contains computer-aided design drawings illustrating the modification to extend both top plates.

Cost and Marketability

A field-framed EP&B wall costs the same as or less than a code-minimum wall with exterior CI when the entire system is considered, including windows and siding. Panelizers will price the wall panels according to actual material costs, which naturally includes the additional lumber of 2 by 6 plates instead of 2 by 4 ones, but the builder can expect to realize savings as the house is detailed and closed in, because of the decreased complexity associated with window installation and siding installation over exterior wood sheathing compared with installing over 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, which will simplify 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% to 60% additional time for the first two or 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 with savings associated with decreased complexity for siding and window installation on site, netting a total savings of about $0.55 per square foot compared with a CZ 6 code wall with 2-in. exterior CI. For a small additional production fee, panelizers would be able to differentiate themselves in the market by offering a high-performing, code-compliant wall that 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 CI 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 can be 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 use waste materials and avoid construction delays and damage caused by weather.

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

Acknowledgments

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Appendix A—Definitions of Abbreviations

CI	Continuous insulation: generally a rigid or semirigid 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 and 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. Typical light-framed construction may be made up of as much as 28% lumber by area as viewed in elevation. Advanced framing techniques can decrease 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 that exceed energy code minimum requirements
IECC	International Energy Conservation Code
IRC	International Residential Code
MC	Moisture content: generally reported on a percentage basis by weight
o.c.	On center: the full measurement from the center of one dimensional stud to the center of the next (for example, 16-in. o.c. installation using studs with a 1-1/2-in. width would leave a 14-1/2-in. stud bay between studs)
OSB	Oriented strandboard: 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 ($h \cdot °F \cdot ft^2/Btu$)
U-value	Quantitative measure of thermal conductance: $Btu/(h \cdot °F \cdot ft^2)$ (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
WUFI	Wärme Und Feuchte Instationär (transient heat and moisture)
XPS	Extruded polystyrene: a type of rigid foam sheathing suitable for use in the EP&B wall system

Appendix B—Photo Documentation of Extended Plate and Beam Wall Panel Production in the Factory

Figure B1. Studs nailed to bottom plate, leaving 2-in. gap for foam.

Figure B2. Using hand saw to cut foam for windows.

Figure B3. Wall panel with window opening.

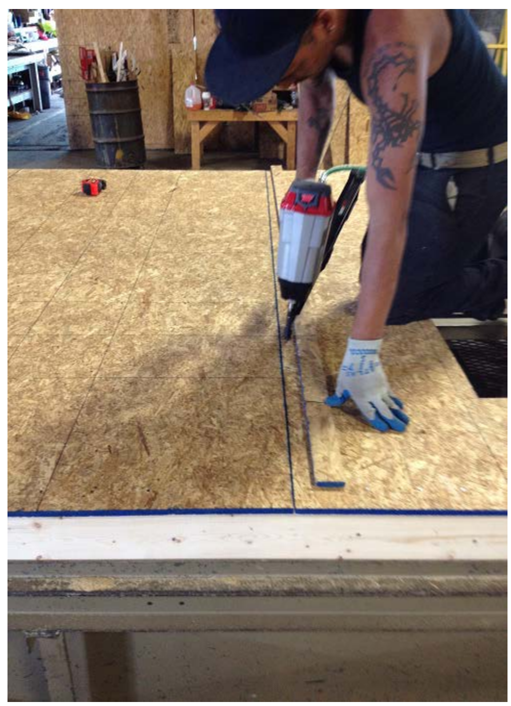


Figure B4. Using a guide to attach oriented strandboard to 2 by 4 studs with 4-in. nails.

Figure B5. Cutting extruded polystyrene on a table saw.

Figure B7. Completed EP&B wall panel bundles at plant, ready to be loaded.

Figure B6. Grouping finished wall panels for bundling and shipping.

Figure B8. Loading EP&B wall panels onto flatbed trailer.

Figure B9. EP&B panels strapped onto trailer for transport to the project site.

Appendix C—Photo Documentation of Extended Plate and Beam Wall System Erected on Site

Figure C1. EP&B wall panels unloaded on site.

Figure C2. EP&B wall panels tipped up and braced.

Figure C3. Engineered rim.

Figure C4. Oriented strandboard filler over rim (gap was considered too small for foam plastic insulating sheathing filler).

Figure C5. EP&B wall panels braced in place.

Figure C6. Window openings have 2 by 4 framing; door openings have 2 by 6 framing.

Figure C7. Typical EP&B window opening.

Figure C8. Connection between EP&B wall panels.

Figure C10. Outside corner connection.

Figure C9. Interior partition wall connection.

Figure C11. Inside corner connection.

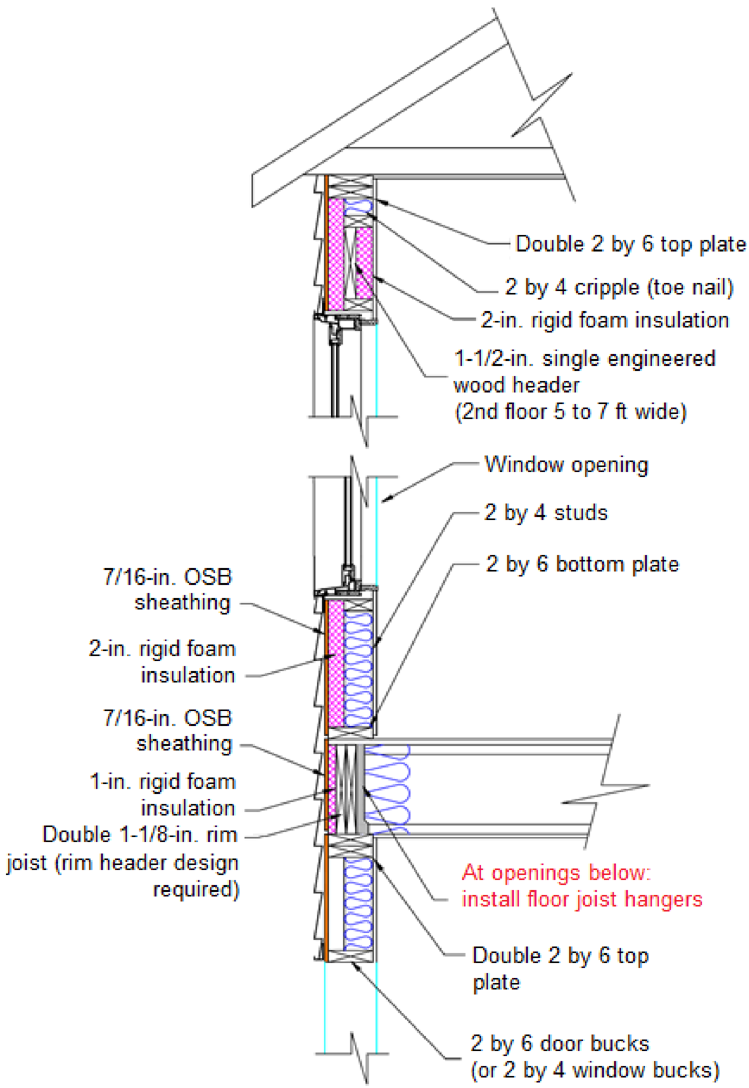
Appendix D—Recommended Modifications

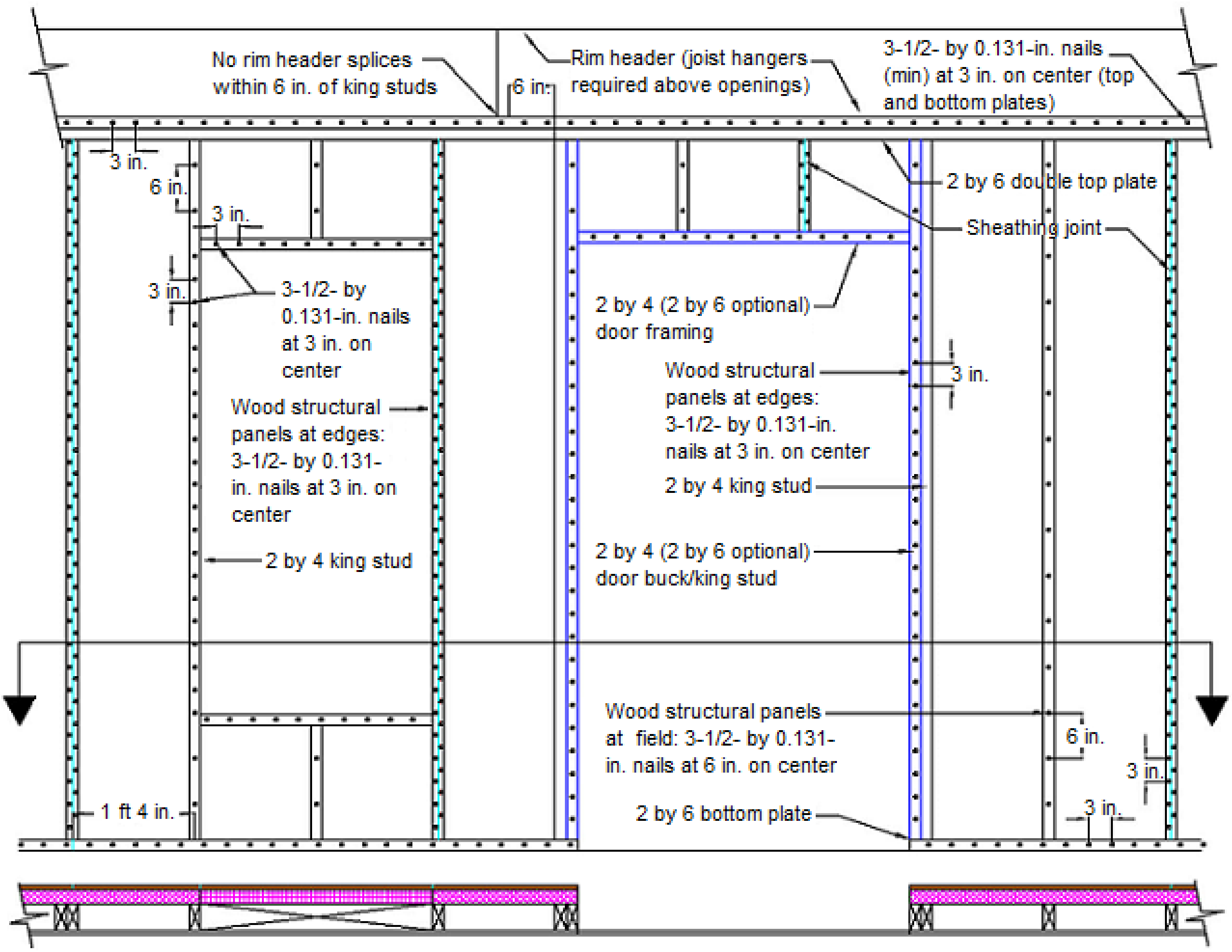
Nailing pattern:

- 3-1/2-in. nails at 6 in. on center in field
- 3-1/2-in. nails at 3 in. on center in edges

Plates:

- Bottom and both top plates extended




No rim header splices within 6 in. of king studs
6 in.
Rim header (joist hangers required above openings)
3-1/2- by 0.131-in. nails (min) at 3 in. on center (top and bottom plates)
3 in.
6 in.
3 in.
3 in.
3-1/2- by 0.131-in. nails at 3 in. on center
Wood structural panels at edges: 3-1/2- by 0.131-in. nails at 3 in. on center
2 by 4 king stud
1 ft 4 in.
2 by 6 double top plate
Sheathing joint
2 by 4 (2 by 6 optional) door framing
Wood structural panels at edges: 3-1/2- by 0.131-in. nails at 3 in. on center
3 in.
2 by 4 king stud
2 by 4 (2 by 6 optional) door buck/king stud
Wood structural panels at field: 3-1/2- by 0.131-in. nails at 6 in. on center
6 in.
3 in.
3 in.
2 by 6 bottom plate